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Editor

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Introduction Containerized Ports: The Entrepreneurial Kindle Wood under Global Supply Chain Management

Hercules E. Haralambides
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Port Management has been a most rewarding project, to put under one roof some of the best and most cited papers on ports, published in *Maritime Economics and Logistics* (MEL) since the journal's inception in 1999. Certainly these articles are by no means all, and certainly the selection has not been easy. One thing is certain though. All chapters in this book, updated when necessary to reflect subsequent developments in the port sector since their original publication, have broken new ground in the way we look at ports, their governance, and their performance. In this sense, it is my hope that this volume will be a precious addition to any maritime bookshelf or graduate classroom.

Two themes, as well as two parts, of the *Reader* will be distinguished by the discerning reader: the first and largest is a *macro* one, dealing with port governance and the new, entrepreneurial, role of ports, being the crucial 'make-or-break' nodes of global supply chains. The last five chapters – which comprise a *micro* part – deal with port performance, efficiency, and their measurement: an issue that has become of utmost importance in the competitive environment ports are now operating in.

Without intention to undervalue the significance of bulk, general cargo, or passenger ports and terminals, the emphasis of the *Reader* is on containerized transport. Containerization has often, and quite rightly, been described as a revolution in transport. But it goes beyond this. Being the locomotive in front of logistics and global supply chain management, containerization has revolutionized the very way we live our lives and go about our business. For instance, the bypassing of the waterfront in the stuffing and stripping of the 'through container', thus having it ready in port to be handled by automated equipment, has increased immensely the predictability and reliability of cargo movements, enabling manufacturers and traders to reduce high inventory costs through the adoption of flexible Just-in-Time and Make-to-Order production technologies. Inter alia, such technologies have helped manufacturers to cope with the vagaries and unpredictability of the business cycle and plan business development in a less risky operational environment.

The impact of containerization on ports has been equally profound: Containerization has transformed ports from the asphyxiating public bureaucracies of the past to the modern enterprises of the present. Automation and mechanization of container terminals has bypassed expensive port labor, it has relieved pressure on port space, and it has minimized ship time in port. These developments have increased ship and port productivity immensely and have allowed ships to become even bigger thus achieving economies of scale and low prices. Nowadays, containers are increasingly carried by specialized 'cellular' containerships some of which are able to carry more than 18,000 twenty-foot equivalent units (TEUs), while designs of even larger vessels are already on the drawing boards of naval architects. As I often teach my students, it is the port efficiency itself that has encouraged the growth in containership sizes and not the other way around; and of course, both port efficiency and technological advance have been the result of port competition, abolition of port monopolies, and the liberalization of port services.

Around the world, the port industry has invested massively so as to cope with competition and the technological demands of containerization. Modern container terminals – and suitable cargo-handling equipment – have been built; operational practices have been streamlined; the element of uncertainty in cargo flows has been largely removed; forward planning has been facilitated; port labor has been regularized and customs procedures simplified. These developments have taken place under the firm understanding of governments and local authorities that ports, now, constitute the most important link (node) in the overall door-to-door transport chain and thus inefficiencies (bottlenecks) in the port sector can easily whither all benefits derived from economies of scale in liner shipping. This understanding has often led ports, particularly those of northern Europe, to adopt a new, more proactive and entrepreneurial business model: that of extending their *gate* inwards, through hinterland investments, as well as by coordinating, and often managing, the various actors in the supply chain. Port administrations see clearly these days that the former port competition has now been transformed into supply chain competition.

However, both port competition *and* global logistics have not been without their downside; something that is often neglected in our enthusiasm with efficiency. The unabated development of land infrastructure, together with transhipment and the footloose nature of the container and its carrier, have intensified competition among ports. Today it makes little difference if a bicycle manufactured in Wuhan, China, will reach Paris through Le Havre, Antwerp, Rotterdam or Hamburg, while the same bicycle can reach Milwaukee, USA, in 147 different ways.

Such competition and the eagerness of ports to attract transshipment traffic (often at the cost of their neighbor) has often led to the development of excessive port infrastructure, paid, often reluctantly, by the taxpayer who does not always enjoy himself the benefits of such investments. In other words, the benefits of container terminal investments are not always localized but often defused all the way from the foreign exporter to the, also foreign, consignee. This fact is often making governments reluctant to finance port terminal infrastructure. Luckily, the private sector has been found ready to fill the gap through successful public–private partnerships, encouraged by higher port efficiency and the global trend of the often painful albeit necessary port reforms.

Logistics and distribution on the other hand are making heavy use of land infrastructure, both inter- and intra-city, and the external costs of such use – i.e. pollution, congestion, accidents, and global warming – are often not internalized in the price of the transport service. This is particularly evident in long distance land transport as a result of transshipment, port concentration, and the emergence of hub ports.

As should be fairly obvious from the above, port efficiency is driven by competition; by the 'footloose' nature of the container; and by the private sector involvement in the financing and management of container terminals, many of which dedicated terminals. At the same time, the spectacular increase in containership sizes, together with the carriers' need for fast turnaround times, are posing a real headache to many ports: Although increasingly bigger ships are calling at our ports, turnaround times need to remain the same if not shorter. No matter how large the ship, today it has to be turned around in no more than 48 hours. I remember quite vividly when Emma Maersk visited Rotterdam for the first time: Maersk complained that this port could only guarantee a cargo-handling rate of 150 TEUs per hour, while in Singapore they were able to achieve 200. Moreover, the consequently less frequent utilization of berths by bigger ships, as well as the fact that these berths were originally designed to host more than one ship at the same time, lowers overall berth utilization and this poses a problem in terms of port planning and financing. Finally, the relative easiness by which carriers can modify their itineraries, and select different ports of call, has led ports to benchmark their performance against each other and use these metrics as a marketing tool in order to attract new traffic.

Port productivity and its measurement have thus become hot topics in the academic agenda and Operations Researchers have found a new optimization field to keep them off the streets. The MEL journal has pioneered and encouraged this research direction, first in 2003, when it coined the term *Maritime Logistics*, and then in 2005, when the former *International Journal of Maritime Economics* (IJME) became *Maritime Economics and Logistics* (MEL).

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I would like to thank all authors for having enthusiastically responded to our call, and Rachel Sangster and her staff at Palgrave Macmillan who have so diligently put up with my often frustrating demands, as well as my limited time which, still, I am unable to optimize equally efficiently as that of the container terminals I have been talking about above.

1

Containerization, Box Logistics and Global Supply Chains: The Integration of Ports and Liner Shipping Networks

Jean-Paul Rodrigue and Theo E. Notteboom

In 2016, container shipping will celebrate its 60th anniversary as an innovation that had a tremendous impact on the geography of production and distribution. Production became globalized by a better usage of comparative advantages while distribution systems where able to interact more efficiently. This paper analyses the mounting pressures on box logistics in light of global supply chains.

It will be demonstrated that the basic principle of containerization remained the same notwithstanding scale increases in vessels and terminals and a clear productivity increase in container handling. Although the container was an innovation initially applied for maritime transportation, the emergence of global supply chains has placed intense pressures to implement containerization over inland freight distribution systems. Box – containerized – logistics is increasingly challenged to deal with the ever increasing time, reliability and costs requirements of global supply chains. Imbalances in trade flows and accessibility and capacity constraints are among some of the developments that are making it increasingly difficult to reap the full benefits of containerization.

Revised from *Maritime Economics & Logistics*, 10, 152–174, 7 March 2008, 10.1057/palgrave.mel.9100196, 'Containerisation, Box Logistics and Global Supply Chains: The Integration of Ports and Liner Shipping Networks', by Theo Notteboom and Jean-Paul Rodrigue. With kind permission from Palgrave Macmillan Ltd.

Introduction

Looking back at more than half a century of containerization

In 2016, container shipping will celebrate its 60th anniversary as an innovation that had a tremendous impact on production and distribution. It is only with containerization that production became truly globalized by a better usage of comparative advantages while distribution systems where able to interact more efficiently, reconciling spatially diverse supply and demand relationships. Yet, even after more than half a century, the role of containers in global trade, production and distribution is just starting to be acknowledged (Levinson, 2006). According to UNCTAD (2013), between 1970 and 1990 trade facilitation measures accounted for 45% of the growth in global trade while membership to global trade organization such as GATT/WTO accounted for another 285%. The container accounted for an additional 790%, exceeding all the other trade growth factors put together.

Container volumes around the world have seen tremendous growth in the last fifty years, with an accelerated growth since the mid 1990s. The total number of full containers shipped on worldwide trade routes (excluding transhipment) amounted to 155.0 million TEU for the year 2012, compared to just 28.7 million TEU in 1990. Volumes on the east-west trades (i.e. Transpacific, Transatlantic and Asia/Europe) and north-south trades are expected to increase at an average rate of around 6% per year. Intra-regional trades, however, are expected to show significantly higher growth of around 7.5% mainly as a result of booming intra-Asian trades, but also because of the setting of hub ports acting as points of transhipment for regional markets. The total throughput handled by the world's container ports (not to be confounded with the trade route volumes mentioned above) increased from about 236 million TEU in 2000 to 601 million TEU in 2012 (including empties and transhipment), representing an average annual growth rate of 8.1%. Transhipment traffic has been the driving force behind growth in container handling in the last decade.

In most developed regions around the world, the container has a high share in the maritime related import and export flows of general cargo. Table 1.1 presents the containerization degree in a number of North European ports, expressed as the share of containerized cargo in total general cargo handled in the port (so dry and liquid bulk excluded since these commodities have shown limited potential so far, outside niche markets, to be containerized). The data points to a logistical curve of diffusion which is common for many technological innovations. Not

Table 1.1 Degree of containerization in a selection of North European mainland ports (sorted according to degree in 2012)

	1980	1985	1990	1995	2000	2005	2010	2013
Antwerp	21.5%	29.0%	38.0%	50.9%	64.8%	77.6%	87.3%	87.5%
Zeebrugge	30.6%	22.5%	23.3%	30.0%	41.5%	55.0%	66.2%	58.9%
Rotterdam	57.4%	65.8%	69.9%	73.9%	77.7%	83.1%	82.6%	83.9%
Bremen/Bremerhaven	35.6%	47.1%	58.7%	73.4%	81.9%	82.8%	86.7%	88.5%
Hamburg	32.0%	42.6%	68.6%	81.7%	93.1%	96.4%	96.8%	98.0%
Le Havre	58.9%	67.7%	71.2%	66.8%	80.4%	90.3%	94.3%	94.4%
Dunkirk	14.6%	14.7%	10.5%	11.5%	27.9%	15.0%	13.2%	17.0%
Ghent	2.1%	2.0%	2.8%	3.3%	3.2%	6.0%	10.5%	10.3%
Amsterdam	21.0%	21.6%	30.2%	40.5%	25.9%	31.7%	27.9%	22.5%

Source: calculations based on data respective port authorities.

all ports have embraced or were in a position to embrace containerization. Early adoption appears to imply no guarantee of further containerization. These findings are in line with the spatial models of Hayuth (1981), Barke (1986) and Notteboom and Rodrigue (2005) on the development of container port systems. Hence, these models suggest that not all ports, which invested early in container infrastructure, become major container centres. The resulting port concentration can cause degradation of minor ports in the network. Taking into account the 'degree of containerizability' (not all general cargo can be put in containers), it is expected that the worldwide degree of containerization could reach a maximum of 75%.

Long-term patterns of international trade are influenced by product innovation and subsequent diffusion also in transport and logistics. Life cycle theory suggest all innovations are evolving following a pattern of a pioneering (or introduction) phase, a growth phase, a maturity phase, a saturation phase and finally a phase of decline triggered by obsolescence. This could ultimately lead to the disappearance of the initial innovation from the market. The duration of each stage of the cycle varies with the type of innovation, the management supporting it as well as its level of market penetration. Nakicenovic (1987) demonstrated life cycle theory can also be applied to transport modes and vehicle propulsion systems. Maritime transport by seagoing vessels and barges has always played an important role throughout history. We can refer to the many Chinese, Spanish/Portuguese, English and Dutch explorations aimed at setting up new trade routes (Fernandez-Armesto, 2006). In the second half of the 19th century rail became the dominant mode of land transportation, but it was overtaken by road transport in the second half of the 20th century. In terms of propulsion, we evolved from sail and manpower to steam and since the 20th century diesel, gas and electric engines. However, improvements in maritime propulsion technology over the last half century implied marginal speed improvements, but significant cost and reliability ones.

Given the inevitable fact that all technologies have a life cycle, the question arises what will happen to the container system as we know it in the decades to come, in particular when considering the requirements imposed on the system by global supply chains. Among the most significant questions that such an expectation puts forward are: What is the ultimate market potential of containerization in terms of volume and market penetration (usage)? What shapes and structures in respective maritime and inland containerized freight distribution this potential may imply? When a phase of maturity is likely to be reached? What could seriously undermine future containerization developments in terms of economic and technical issues? Although absolute answers to these questions cannot be provided, some elements shedding light in possible future development will be discussed.

Towards a phase of maturity

The container market is fast reaching a maturity phase characterized by a wide diffusion of the technology around the world and technical improvements which are more and more becoming marginal. Ships are getting larger and more efficient, but in essence the container technology driving the business altogether is basically the same as some 40 to 50 years ago. Shipping lines are deploying ever larger container vessels on the main trading routes driven by the promise of cost savings through achieve economies of scale (at sea), as evidenced by Cullinane et al (1999), Lim (1998) and Notteboom (2004). The technical concept of a container vessel has not altered dramatically during the evolution from first generation vessels to the latest “Triple-E” container carriers of more than 18,000 TEU capacity. Economies of scale are likely to be pushed as far as it is technically and economically feasible.

Container terminals have witnessed a series of innovations aimed at improving quay and yard productivity. Container gantry cranes now have longer outreaches (up to 23 containers wide), more lifting capacity (ZPMC developed cranes with up to 120 tons lifting capacity) and the spreaders have become more sophisticated (double lift, twin lift and tests by ZPMC for triple lifts). But again, the basic design of a gantry crane and spreader remained unchanged since the first developments by Sea-Land and

Matsons in the early 1960s. The development of straddle carriers, RMG (rubber-tyred gantry cranes), RTG (rail-mounted gantry cranes) and other yard equipment really took off in the early 1970s. The use of AGVs (automated guided vehicles) is of more recent date, i.e. a first application at Delta Terminal Rotterdam in the early 1990s. But also here the basic principle remained unchanged: loading/discharging a container vessel (vertical movements) and stacking the containers one by one on the terminal (vertical/horizontal movements). Modern terminal equipment is becoming widespread and more standardized with the emergence of global terminal operators (HPH, PSA, APM Terminals and DP World to name but a few) and with leading equipment manufacturers (ZPMC, Kalmar and others) having customers all over the world. This has made it increasingly difficult for terminal operators to achieve a competitive advantage solely through the terminal equipment used. Productivity gains have more than ever become a matter of terminal management skills (software and know how) and of course hinterland size instead of hardware.

Technology gains in equipment for moving containers inland are also becoming marginal. Push convoys have been around for quite some time now and although inland barges on the Rhine now reach capacities of close to 500 TEU, their design is quite standard (Notteboom and Konings, 2004). Rail shuttle technology dates back to the early days of containerization and even the double stack trains in North America were conceived as early as the 1980s (Thuong, 1989).

To summarize, the world is still embracing a decades old concept – the container – to deal with the challenges of contemporary global supply chains. And although globalization and the associated profound changes in worldwide manufacturing and distribution processes to a large degree have been made possible by containerization, the same global supply chains are now exerting strong pressures on the container concept, leaving the players in container markets with quite some challenges.

To further support growth of containerization and to avoid a phase of saturation or even decline, major innovations are needed in the way containerized logistics systems are managed. Smarter management of the container system and its related networks is a prerequisite for a sustainable deployment of the container concept in global supply chains in the longer term.

This paper thus analyses the mounting pressures on box logistics in light of global supply chains. The first section looks at the changing role of containers in global supply chains. The second part of this paper analysis to what extent existing liner service networks are adapted to cope with supply chain challenges in the medium and longer term.

Ports and terminals are the central focus in section three, while section four discusses the mounting pressures on inland distribution.

The role of containers in global supply chains

Logistics and the velocity of freight

Container shipping has changed the scale and scope of global freight distribution. By enabling a greater velocity in freight distribution, it has opened up new global markets for export and import as a greater quantity of space could be traded with a similar, if not lower, amount of time and often at a lower cost. This velocity is much more a function of time than of speed as containerization mostly improved the function of transhipment (Rodrigue, 1999). Thus, it is not that freight is moving faster along the respective modes servicing supply chains, but that the efficiency of transport terminals has dramatically increased the velocity of transhipments and, consequently, of supply chains. The concept of transhipment is here taken in a large sense to include activities taking place when the freight is not in circulation, namely warehousing which has adapted to provide a higher velocity to freight in the form of distribution centres. While prior to the introduction of the container, a standard break-bulk cargo ship could take weeks to be loaded or unloaded, a similar quantity of containerized freight can be transhipped in a matter of hours (Cudahy, 2006). It can be argued that the velocity of freight from a modal perspective has been achieved for more than half a century, but that containerization, through the transhipment function, truly permitted a multiplying effect for this velocity. Once a specific velocity threshold is reached, a time-based management of production becomes a possibility as logistics moves from a push (supply-based) to a pull (demand-based) structure, reaping significant distributional benefits.

Containerization has provided the mechanism to expand to international markets while improving the reliability, flexibility and costs of freight distribution. The convergence of these factors permitted the setting of global supply chains, many based on the principle of "just-in-time" which is an integration of the velocity of freight with production and distribution strategies.

Containerized global production networks

Global Production Networks (GPN) represent a functionally integrated network of production, trade and service activities which includes all the stages in a commodity chain, from the transformation of raw materials, through intermediate manufacturing stages such as assembly, to the delivery of goods to the markets (Henderson et al. 2002; Coe et al. 2004). Within this framework, global production networks have made many manufacturers contemplate global logistics strategies rather than simply relying on conventional shipping or forwarding activities. Most actors in the transport chain have responded by providing new value-added services in an integrated package, through freight integration along the supply chain. Thus, it has become widely acknowledged that the functional integration of commodity chains goes beyond the function of manufacturing, but also includes governance and transportation (Gereffi and Korzeniewicz, 1994, Gereffi, 2001, Chopra and Meindl, 2001, Appelbaum, 2004, Rodrigue, 2006).

The competitiveness of global production networks is to a large part determined by the performance of the logistics networks as they link production, distribution and consumption (Hesse and Rodrigue, 2004). These logistics networks are highly dynamic as a result of mass customization in response to product and market segmentation, lean manufacturing practices and associated shifts in costs as production and distribution assets are repositioned within global supply chains. The container is at the same time a transport, storage and management unit. When embedded within GPN, the container becomes a production unit since it carries all the inputs of manufacturing as identifiable and manageable batches. Production and distribution thus become a matter of insuring that containers – mobile inputs – reach the proper locations within a specified time range. Containerization also levelled the competitive playing field for global manufacturing. Manufacturers which previously had limited access to the global market because of remote locations and lack of transport infrastructures realized that the ubiquity of the container as a global transport product is linked with a whole new set of opportunities. Through containerization, all competitors have potentially the same level of access to an efficient and global freight distribution system through port facilities. Paradoxically, manufacturing clusters nearby major container terminals along the Chinese coast may have better accessibility to global markets than activities located in conventional central locations such as the American Midwest and the Western European Rhine / Ruhr deltas. Still, containerization remains under-acknowledged in its role and function in supporting global production networks (Hesse and Rodrigue, 2006).

In the following sections, we discuss the challenges to the world container system using a systems approach which will look consecutively to liner services, ports and terminals and inland distribution.

Are the existing liner service networks adequate?

Liner service networks in transition

With a growing complexity in global supply chains and networks, managing liner services has become a complex endeavour. Shipping lines design the networks they find convenient to offer, but at the same time they are bound to provide the services their customers want in terms of frequency, direct accessibility and transit times. This tension between routing and demand is important. The network planners may direct flows along paths that are optimal for the system, with the lowest cost for the entire network being achieved by indirect routing via hubs, some of the offshore, and the amalgamation of flows. However, the more efficient the network from the carrier's point of view, the less convenient that network could be for shippers' needs. Shippers could resent the indirect routes, opening the possibilities for other shipping lines to fill gaps in the market.

When observing recent developments in liner shipping, the productivity has been improved by using faster and larger ships and the devising of new operational patterns and co-operation between shipping lines. Some have suggested that the future of liner service lies in the equatorial round-the-world, following the beltway of the world (Ashar, 2002, De Monie, 1997). This service pattern focuses on a hub-and-spoke system of ports that allows shipping lines to provide a global grid of East-West, North-South and regional services. The large ships on the East-West routes will call mainly at transhipment hubs where containers will be shifted to multi-layered feeder subsystems serving North-South, diagonal and regional routes. Some boxes in such a system would undergo as many as four transhipments before reaching the final port of discharge. There are however a number of conditions that need to be satisfied before this scenario is feasible. The scenario assumes a cumulative growth of container traffic of 5 to 6% per year in the next 15 to 20 years, sufficient concentration on the supply side of maritime container transport (mergers and acquisitions) and avoidance of measures which prohibit or impede the deployment of plus 10 000 TEU ships. New types of container terminal are needed at a minimal deviation distance from the main axial East-West route. As such, some of the current 'regional' hubs can develop in the next 10 to 15 years into 'global hubs'.

The establishment of a high degree of connectivity between the North-South and the East-West services is also a prerequisite for the realization of this scenario. This connectivity will contribute to an increase in the density of the goods flow on the main trade route and will consequently lead to higher service frequencies. Only a handful of lines have built relay networks that effectively involve the full integration of trade routes. Maersk Line is a prime example. The post-Panamax ships deployed on its pendulum services not only provide slots on the Far East and Europe/North America, but also act as a conveyor belt between a series of controlled hubs – notably Algeciras, Salalah and Tanjung Pelepas. Virtually all the carrier's cargo to/from West Africa moves through Algeciras, from which weekly loops radiate. Most of these loops are 'double loop' or mini-pendulums. The main difference between Maersk Line relaying and that of many other carriers is the close integration of all parts. Different services dovetail to provide smooth connections, and operations at the main hubs are effectively under its control. The only other liner operator to have made serious steps in this direction is MSC, which has several firmly-established relay services, and launched several mini-pendulums (e.g. on the west Australia/Singapore/Thailand route). Mini-pendulums not only give extra direct services, but offer a safety valve in case of delays. For the strategic alliances and groupings (e.g. G6, CKYHE and the initially planned but later abandoned P3 alliance, etc.), such a strategy is unlikely given the different priorities of the members. Few dedicated relay services have been started under joint banners, and integrated operations in the Maersk Line mode are unlikely.

The concept of an equatorial round-the-world system might have its merits, but we argue it will be an addition to, not a replacement of, existing systems. Shipping lines have a wide range of patterns at their disposal, all of proven merit in particular circumstances. In the future, shipping lines will continue to mix triangle services, pendulum services, butterfly services, conveyor belt services and other forms of varying complexity with line-bundling services (loops with a limited number direct port calls) and simple end-to-end services, and adapted for both main-haul and relay services to create a network best fitting a carrier's requirements. This growing complexity in liner service networks is in line with the findings of Robinson (1998). In referring to the Asian hub/feeder restructuring, he argues that a system of hub ports as main articulation points between mainline and feeder nets is being replaced by a hierarchical set of networks reflecting differing cost/efficiency levels in the market. High-order service networks will have fewer ports of call and bigger vessels than lower order networks. Increasing volumes as such can lead to an increasing segmentation in liner service networks and a hierarchy in hubs. Hub-and-spoke systems are just a part of the overall scene.

There is no 'one size fits all' approach to the future of liner service networks. The port hierarchy is determined by the decisions of individual container shipping lines (operating as independent carriers or in groupings) thereby guided by strategic, commercial and operational considerations. The decisions of these lines regarding the hierarchy of the ports of call are rarely identical. Hence, a port may function as a regional hub for one liner operator and as a feeder port for another. The network function of a container terminal might also change. Ports serving long-haul mainline services could be degraded to feeder ports. Alternatively, a shipping line might decide to turn a regional port into a major interlining hub.

Schedule integrity issues

A major threat to the future of complex liner service networks lies in increased schedule unreliability. Low schedule integrities can have many causes, ranging from weather conditions, delays in the access to ports (pilotage, towage, locks, tides) to port terminal congestion or even security considerations. Notteboom (2006) demonstrated port terminal congestion is currently the main cause of schedule unreliability by far. A low berth and or crane availability leads to disruptions in the liner service schedules of shipping lines. Given the nature of many liner services (more than one port of call, weekly service, hub-and-spoke configurations, etc..) which are closely integrated, delays in one port cascade throughout the whole liner service and therefore also affect other ports of call (even those ports which initially had no delays). A low schedule integrity is a serious challenge for terminal managers as their planning tools (yard planning and ship planning software such as NAVIS) can only work optimally when the ship arrivals can be forecasted rather accurately (based on allocated slots). In case of serious congestion, terminal planning tools have their limitations and even a system of time slots does not work in practice.

Figure 1.2 provides an overview of the average schedule integrities on trade routes for the year 2010. For example, on the Asia – Europe trade only 49.1% of the vessels made it according to their schedule. At the global level, 45.8% of port calls are on time, 19.8% are one day late, and 25.2% are two days or more late. 10.2% of port calls arrive a day before or earlier. Maersk Line recorded an average worldwide schedule integrity of 70%. MSC is amongst the poorest performers with only 41%. MSC keeps time buffers relatively low and tries to solve resulting problems via ad hoc changes to the order of port calls, the ad hoc transhipments of containers at relay ports in the Mediterranean and the seemingly random skipping of one or more ports of call during a round voyage.

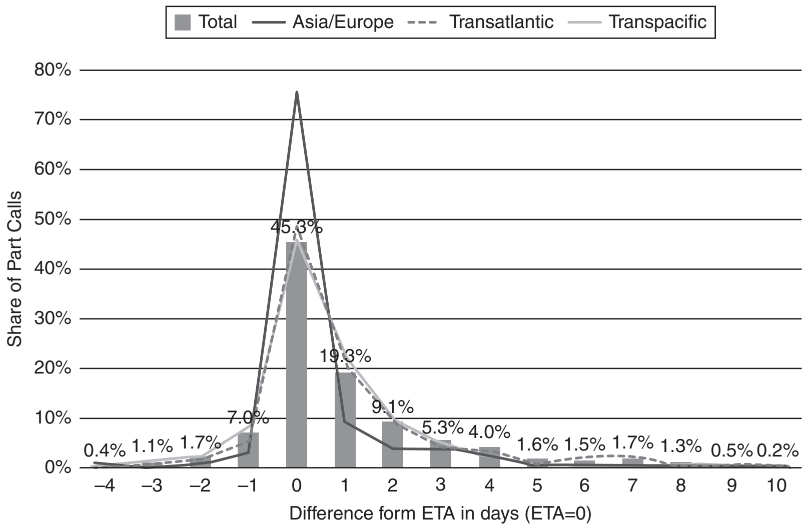

Figure 1.1 Schedule reliability in container shipping, 2010
Source: Drewry, 2010.

Alternatively, Maersk Line is more strict in respecting the scheduled times and the order of ports of call. Time buffers are sufficiently high to cope with unexpected disruptions.

It is expected that the issue of schedule unreliability will become even more important in the future, as liner service networks are getting more complex, slow steaming is becoming the rule and new terminal capacities in some parts of the world do not come on stream in time. Under such circumstances, guaranteeing a high schedule reliability and a high transit time reliability to global supply chains will have an ever higher price (e.g. more ships need to be deployed on a loop) and this could have an impact on freight rates and on supply chain efficiency. Vessel delays compound to delays in inland freight distribution. It also indicates that a lot of improvements in the time performance through logistics and better inland strategies are yet to be seen.

Managers in the logistics industry are already spending a growing share of their time handling freight transport missteps and crises, partly due to a low schedule reliability. Reliability and capacity issues have emerged as critical factors next to pure cost considerations. Accepting a continuous high level of schedule unreliability as the new normal might in the longer term have adverse effects on the whole logistics system and eventually also on global production and consumption networks.

Towards new intercontinental shipping routes

Parallel to the strategies of establishing equatorial round-the-world container services, a set of circum-hemispheric routes around the northern hemisphere are also a possibility, particularly since it is along this hemisphere that the bulk of the world's economic activity is taking place. This strategy would integrate a sequence of maritime and land (rail) transportation corridors in a seamless fashion. A continuous and bi-directional transport chain across a hemisphere is thus established. However, such a corridor does not yet exist and is likely to be decades away, but the North American landbridge segment has been operating for more than 20 years. The Northern East-West Corridor (NEW) linking the Atlantic with the Pacific through the trans Siberian has been in the design phase for many years. The beginning of the 21st century has however brought renewed interests for the NEW corridor, especially with the booming Asian trade and the increasing pressure to ship containerized freight in a time sensitive manner over long distances.

A complementarity could thus be established between the equatorial corridor, which will be mostly a maritime segment, and the north hemispheric corridor involving land and maritime segments. While the north hemispheric corridor would have less capacity, particularly along its trans-Siberian leg, it would provide a faster long distance service than the equatorial corridor, servicing supply chains that are more time dependent. Shippers would thus pay a premium to use this faster route, which would be reflected in the commodities in circulation. The expansion of the Panama Canal (scheduled for 2015) to larger dimensions is also likely to trigger an additional impetus to transcontinental shipping, making the equatorial corridor even more time (faster transit time) and cost (economies of scale) efficient. On the long run, and subject to controversial issues about global climate change, an arctic circum-hemispheric maritime corridor could also be established, thus setting three latitudinal corridors of circulation. Consequently, many opportunities in terms of production and distribution are likely to arise with the setting and operationalization of long distance trade corridors.

Can ports and terminals cope?

Growing container trade, larger vessels, new liner service configurations and new long distance trade corridors challenge container terminals. The current performance requirements for global hub an gateway terminals on main-line vessels typically take the shape of: (a) a sustainable ship output of 5,000 moves per 24 hours, (b) a sustainable ship-to-shore gantry crane output of 40 moves per gross hour, (c) a ratio working time to time at berth of 90%, (d) an average number of gantries operating per main-line vessel of six and (e) an annual throughput per berth of 1.5 million TEU. A 18,000 TEU vessel with only three ports of call in Europe implies an average number of moves of about 12,000 TEU (loading and discharging) in each port of call at 100% vessel utilization level and about 10,000 TEU at 85% vessel utilization. Such volumes pose huge demands on container crane density (number of cranes per vessel), on yard equipment and on the required stacking area. The associated peaks make the hinterland transport issue more complicated.

Rising environmental and social concerns related to terminal development backed up by complex environmental legislations which do not always guarantee legal certainty to port/terminal developers, result in time-consuming and complex planning processes (Notteboom and Winkelmans 2003, Dooms and Verbeke, 2006 and Van Hooydonk 2006). As such a breeding ground is formed for an ever slower adaptability/

Table 1.2 Delays in the planning process – some cases in Northwest Europe

	Development of initial plans	**Proposed date for start operations (first phase)**	**Actual or earliest date for start terminal operations**
Le Havre 'Port 2000' – France	1994	2003	2006
Antwerp – Deurganck Dock – Belgium	1995	2001	2005
Rotterdam – Euromax Terminal – the Netherlands	2000	2004	2008
Rotterdam – Maasvlakte II – the Netherlands	1991	2002	2013
Deepening Westerscheldt* – the Netherlands/Belgium	1998	2003	2010
Wilhelmshaven/ JadeWeserPort – Germany	n.a.	2006	2012
Cuxhaven – Germany	n.a.	2006	Never
Dibden Bay – UK	n.a.	2000	Never
London Gateway – UK	n.a.	2006	2014
Bathside Bay – UK	n.a.	2004	2008
Felixstowe South – UK	n.a.	2006	2008
Hull Quay 2000/2005	n.a.	2000	2007

* Nautical access to the port of Antwerp

responsiveness of the physical infrastructures to changes in port demand and associated cargo flows. Table 1.3 points to considerable delays in the planned opening of terminals and the actual opening of the container handling facilities. This issue becomes particularly acute when a paradigm shift towards supply chains takes place. Seaports are on the verge of becoming scarce goods. Port congestion along the US West Coast and in many European ports, such as in the summer of 2004, demonstrated how scarcity of port facilities and intermodal throughput capacity can impact a broader economic system. Scarcity in markets can lead to more efficient use of resources, which is on the long run positive. But a sustained high level of scarcity can in the longer term negatively affects the out-of pocket and time costs related to the transport of goods in global supply chains.

Scarcity of terminal capacity can however also open prospects for new cargo routing patterns using new gateway concepts. On the one hand, terminal developments outside dominant container port regions can contribute to a more even distribution of containerization in port systems around the world (option C in figure 1.2). For example, congestion in LA/Long Beach gave incentive to start considering the development of container facilities in Prince Rupert, Canada and Ensenada, Mexico. On the other hand, new terminal initiatives in the vicinity of established container gateways can trigger the formation of multi-port gateway regions that offer flexible cargo and vessel routing solutions to shipping lines, logistics players and shippers (option D in figure 1.2). For example, JadeWeserPort in Wilhelmshaven (Germany) adds to the value propositions of existing load centres in Hamburg and Bremerhaven. The expected rising importance of multi-port gateway regions as a model serving global supply chains is further supported by the observation that shipping lines are not putting all their eggs in the same basket, so a multi-port gateway can offer an opportunity for a port operator to enter a regional market by using a new terminal / port outside the "stronghold" of a competitor (e.g. Singapore / Tanjung Pelepas). The above factors could in the longer term lead to new port hierarchies and a multiplication of the number of ports engaged in containerization.

Are the mounting pressures on inland distribution manageable?

Pressures on inland distribution

The current development and expansion of intermodal transportation relies on the synchronization of different systems of circulation as well as of different geographical scales. But when the synchronization level increases,

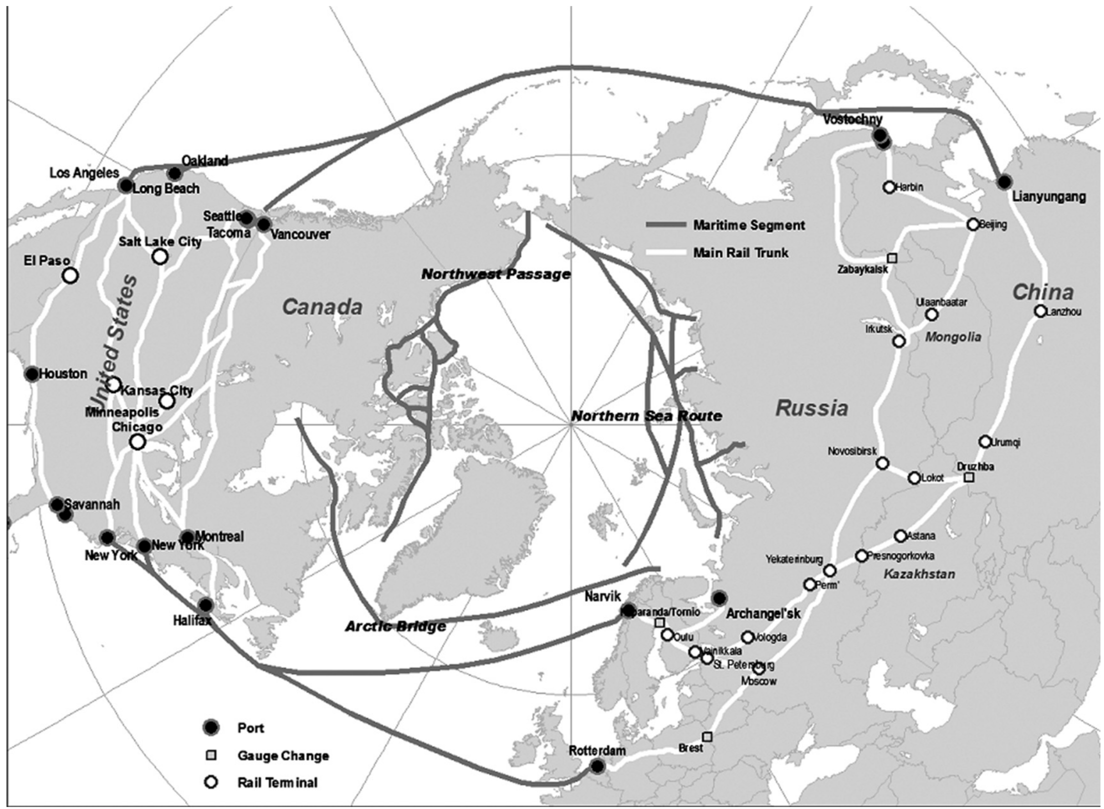

Figure 1.2 The Northern Circum-Hemispheric Routes

the maritime / land interface as a whole becomes more vulnerable to disruptions. For instance, if a segment in the container chain does not work efficiently in a highly synchronized environment, then the whole chain will be affected, triggering unforeseen consequences in time dependent global production networks. This leads to extra costs to find alternative routes, which from a maritime standpoint does not present too many difficulties as this simply involves new port calls along existing pendulum routes. However, for port terminals and particularly for inland distribution systems, new routings and new volumes are much more difficult to accommodate. There are thus been mounting pressures on inland freight distribution to cope with the growth of maritime containerized shipping.

The future is likely to bring attempts to cope with three particular geographical scales. At the continental level, the setting of high capacity long distance corridors will continue to offer a viable option for long distance container movements. Regionally, the process of integration between maritime and inland transport systems will lead to a number of penetration and modal shift strategies where each mode is used in its most cost and time effective way. The conventional representation of a hinterland, often linking the clients of the port with a distance decay perspective, is being replaced with one where spatial discontinuity and clustering prevails, but which is more functionally integrated. Locally, on-dock rail facilities where containers are exiting/entering a port terminal on rail instead of on truck, with the destination of these rail shipments often going much further inland. These configurations can ease the pressure on deepsea container terminals by moving the sorting function inland, thus increasing the efficiency of existing terminal facilities and the overall throughput. In all cases, the future of containerization will largely depend on the land side, particularly on efficient intermodal and transmodal operations.

Imbalances and repositioning

With the emergence of global trade imbalances, ports and inland transportation are facing acute pressures to cope with disequilibrium in container flows. The repositioning of empty containers is becoming a key logistical challenge, particularly in North America where imbalances are taking dramatic proportions; containerized exports have simply not kept pace with imports. For the United States, this implied an imbalance that totalled 7.3 million TEU with Asia and Europe in 2011. The outcome are rate imbalances across the Pacific as it costs more per TEU for westbound flows than for eastbound flows, making freight planning a complex task for container shipping companies. In recent years containerized freight flows between Asia and Europe have become three times as voluminous as containerized flows between Europe and the United States. Thus, production and trade imbalances in the global economy are clearly reflected in physical flows and transport rates. The impacts on the geography of maritime transportation are major, requiring a re-assessment of their strategies in terms of port calls and hinterland transportation.

As such, the repositioning of empty containers is one of the most complex problems concerning global freight distribution. The major causes of this problem include, as previously stated, trade imbalances, but also repositioning costs, container manufacturing and leasing costs and usage preferences (Notteboom and Rodrigue, 2007). Trade imbalances are a macro-economic factor to which maritime transportation is forced to address by repositioning empties at the transatlantic and transpacific scales. This ties up existing distribution capacities, particularly for long distances. Repositioning costs include a combination of inland and international transport costs. If they are low enough, a trade imbalance could endure without much of an impact as containers get

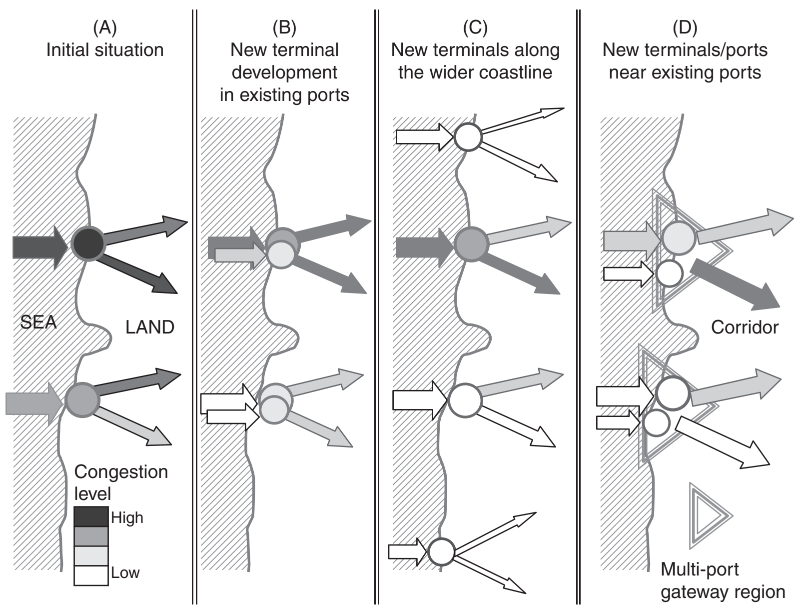

Figure 1.3 Terminal development options to ease congestion/capacity problems in a port system

repositioned. A large number of shipping lines use containers as a way of branding the company name. This observation combined with the reluctance of shipping lines to share market information on container positions and quantities, makes it very difficult to establish container pools or to widely introduce the grey box concept. Many strategies are attempted to cope with repositioning issues. For instance, a large amount of transloading from maritime (40 footers) to domestic (53 footers) containers takes place in the vicinity of the ports of Los Angeles and Long Beach. It confers the added advantage of transferring the contents of three maritime containers into two domestic containers, thus reducing inland transport costs and justifying additional transloading costs.

Port regionalization

Changing port-hinterland relations have a clear impact on port development patterns. The performance of seaports is strongly entwined with the development and performance of associated inland networks that give access to cargo bases in the hinterland. Load centres are only as competitive as the inland and relay links that connect to it. To reflect changes in port-hinterland dynamics, Notteboom and Rodrigue (2005) introduced a regionalization phase in port and port system development.

Regionalization expands the hinterland reach of the port through a number of strategies linking it more closely to inland freight distribution centres. The phase of regionalization brings the perspective of port development to a higher geographical scale, i.e. beyond the port perimeter. The port regionalization phase is characterized by a strong functional interdependency and even joint development of a specific load centre and (selected) multimodal logistics platforms in its hinterland, ultimately leading to the formation of a regional load centre network or logistics pole (figure 1.3). The port system consequently adapts to the imperatives of distribution systems as supply chain management strategies finally permeate to transport operations and transport infrastructure.

An important driver for the creation of regional load centre networks and logistics poles relates to the requirements imposed by global supply chains. No single locality can service efficiently the distribution requirements of a complex web of activities. Port regionalization permits the development of a distribution network that corresponds more closely to fragmented production and consumption systems.

The transition towards the port regionalization phase is a gradual and market-driven process that mirrors the increased focus of market players on logistics integration. In the regionalization phase it is increasingly being acknowledged that land transport forms an important target for reducing logistics costs. The responses to these challenges go beyond the traditional perspectives centered on the port itself. Regionalization as such provides a strategic answer to the imperatives of the inland distribution segment of the supply chain in terms of improving its efficiency, enhancing logistics integration and reducing distribution costs.

Another factor having a major impact on port development dynamics are local constraints. Ports, especially large gateways, are facing a wide array of local constraints that impair their growth and efficiency. The lack of available land for expansion is among one of the most acute problems, an issue exacerbated by the deepwater requirements for handling larger ships. Increased port traffic may also lead to diseconomies as local road and rail systems are heavily burdened. Environmental constraints and local opposition to port development are also of significance. Port regionalization thus enables to partially circumscribe local constraints by externalizing them.

Many ports around the world are reaching a stage of regionalization in which market forces gradually shape regional load centre networks with varying degrees of formal linkages between the nodes of the observed networks.

One of the problems port authorities are facing relates to the infrastructural part of the port regionalization phase. Port authorities try to enhance the intermodal capacity of the port with a heavy reliance on the performance of infrastructures and transport services. However, the manoeuvrability offered to port authorities seems to be restricted. First of all, the hinterland infrastructure level is dominated by public authorities who have to take into account social and political aspects and financial limitations in the decision making process. Secondly, the logistical hinterland is dominated by market players, which under normal circumstances do not have to give account to the port authority. The powers of port authorities in developing hinterland infrastructure are thus limited. In most cases, the role of the port authority is restricted to initiator and facilitator of the necessary infrastructures that should guarantee a maximum of land accessibility in relation to the logistics pole.

Maritime Gateways

The emergence of globally oriented container transportation systems reinforces gateways as major locations of convergence and transhipment. While intermodal transportation integrates different modes, gateways integrate different systems of circulation. Port regionalization is thus a strategy used to improve the geographical connectivity of gateways through a more flexible intermodal function. The maritime / land interface used to occur in a very specific part of the gateway; the port and its neighbouring warehousing and manufacturing clusters. Port regionalization has not changed the function of gateways, simply the geographical space over which this function is taking place and its efficiency.

This perspective has however significant geographical variations in port regionalization (figure 1.4). In North America, long distance trade corridors are servicing large markets; port regionalization aims at reducing existing congestion and access the hinterland with new and more efficient alternatives, mainly through inland load centres accessible through rail. The inland system is highly clustered but with significant distances between those clusters once beyond coastal areas. In Pacific Asia and particularly in China, most of the manufacturing activities and logistics zones are directly adjacent to the gateways due to low hinterland accessibility: port regionalization simply involves the opening of new terminals that are diverting local truck flows. It is not a matter of accessing the hinterland, but insuring that local/regional manufacturing clusters have the port capacity to support their export oriented function. In the latter case the port hinterland is simply a matter of manufacturers bringing truckloads to a nearby distribution centre

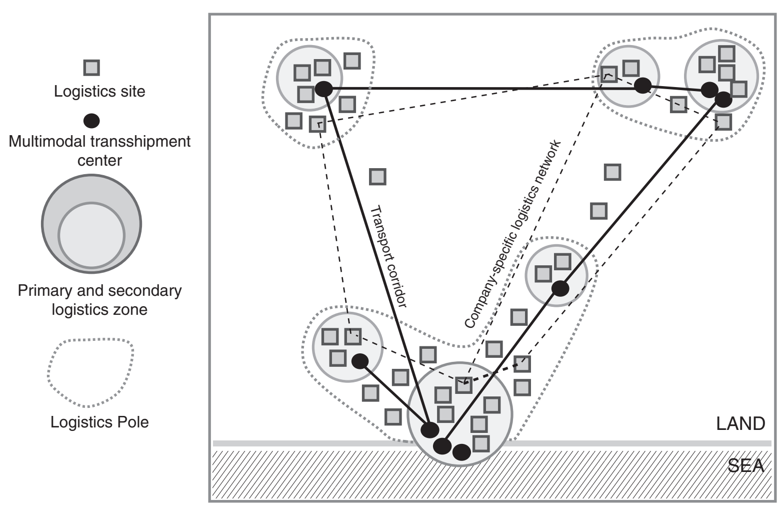

Figure 1.4 Port regionalization and the development of logistics poles

which will be assembled in container batches that will then be sent to an adjacent port for export to global markets. In Europe, a mixture of both models can be found with some multi-port gateway regions, such as the Helgoland Bay ports in Northern Germany and the Rhine-Scheldt Delta in the low countries, combining vast European logistics zones in the vicinity of the ports with corridor-based access to distant hinterland regions (e.g. to Northern Italy). However, the distances involved are shorter due to the regional geography and transportation networks that historically have developed in a relative independent manner.

Conclusions

The container system is slowly reaching maturity in a market environment where freight transportation has become the most volatile and costly component of many firms' supply chain and logistics operations. The financial crisis of 2008–09 took many shipping lines and terminal operators (and the industry in general) by surprise and growth expectations have been revised, downward for the most cases. Managers have to deal with delays in the transport system, with rising oil prices, complex security issues, and with labour and equipment shortages and trade imbalances. Each of these problems adds risk to the supply chain, and the problems are likely to get worse before they improve. Managers in the logistics industry, including the port and maritime industry, are spending more and more of their time handling freight transport missteps and crises. As such, reliability and capacity issues have emerged as critical factors next to pure cost considerations.

These developments undermine the very fundamentals of the container system and urge market players and governments around the world to look for innovations in the way container flows and the associated logistics infrastructure are managed. Smarter management of the container system is a prerequisite for a sustainable deployment of the container concept in global supply chains in the longer term.

In this paper we have pinpointed to some critical factors in view of a sustained containerization. With respect to liner shipping networks, it is expected that a multiplication of service network types (instead of a narrowing down to an equatorial multi-layer hub-and-spoke network) is likely to provide the best value attributes in dealing with global supply chains. The co-existence of different network types on the same trade route ensures flexibility in routing options and as such is likely to decrease network synchronization and vulnerability problems in an era of increased schedule unreliability.

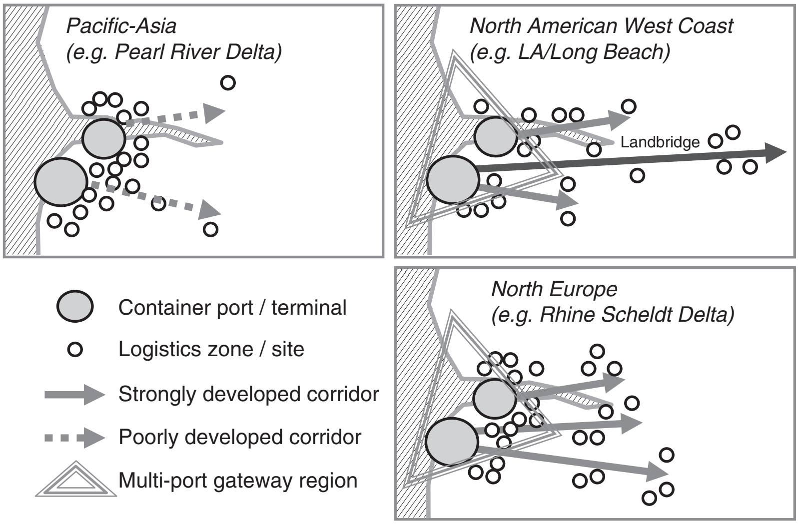

Figure 1.5 Gateways and the logistical hinterland

The availability of sufficient terminal capacity remains a concern. It was demonstrated that rising environmental and social concerns related to terminal development have resulted in major delays in bringing new capacity on the market. Scarcity of terminal capacity can open prospects for new cargo routing patterns using new gateway concepts. We argue that the further development of multi-port gateway regions will become an ever more important element in offering both flexibility and service to global supply chains. This conclusion is in line with the findings of Gilman (1980) who rightly stated that the idea of one superport to serve a region is fictional. Gilman's motivation was based on operational aspects related to shipping networks. This paper added to this by including another dimension, i.e. the requirements of global supply chains. The expected rising importance of multi-port gateway regions as a model serving global supply chains will result in new port hierarchies and a multiplication of the number of ports engaged in containerization.

This paper also identified mounting pressures on inland freight distribution to cope with the growth of maritime containerized shipping. The problem of the repositioning of empty containers will continue to be a key logistical challenge. The future is likely to bring attempts to cope with three particular geographical scales. At the continental level, the setting of high capacity long distance corridors will continue to offer a viable option for long distance container movements. Regionally, the process of integration between maritime and inland transport systems will lead to a number of penetration and modal shift strategies (to rail and/or barges) where each mode is used in its most cost and time effective way. Locally, the concept of linking on-dock rail or barge facilities to a nearby inland terminal where containers can be sorted by destination is expected to become more important. Port regionalization was identified as a key concept in driving the relationships between ports and inland freight distribution centres. Although significant geographical variations might develop throughout the world, the phase of regionalization in all cases will bring the perspective of port development beyond the port perimeter.

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2
A New Approach to Port Choice Modelling

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With the progressive integration of ports in supply chains, it has become clear that shippers no longer choose a port per se, *but rather a supply chain – a package or bundle of logistics services; a pathway to markets – in which a port is just an element* albeit *an important one of the system. Yet, surprisingly, a number of studies continue to focus on how a shipper chooses a port in isolation of the chain systems in which it is embedded. Clearly, shipper's influence on port choice decisions is diminishing, particularly now that a single shipping line, a third-party service provider or a supply chain integrator may control the freight from the origin to the final destination using various transport arrangements and multiple alternative pathways designed to minimise the total logistics cost and maximise value for both the customer and the supplier. The main purpose of this paper is to suggest a new and more effective analytical framework within which the modelling of port choice can be conducted and shipper choice decisions well understood. The proposed framework is fundamentally an operationalisation of the earlier paradigm of ports as elements in value-driven chain systems proposed by Robinson in 2002.*
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Introduction

Ports have always been part of the maritime transport chain but their full integration in supply chains is a recent phenomenon. Earlier chains were highly fragmented, uncoordinated and inefficient. Ports were important but weak links in the chain. Individual firms in the chain including ports were internally rather than market-driven; their focus was on maximising their own profit by being managed as stand-alone entities. Shippers were more concerned with minimising transport cost to remain competitive. For most shippers, therefore, the actual selection of a port, shipping line, and land transport service providers was a major logistics consideration because these elements of the transport chain were perceived as significantly eroding value created and thought to be delivered to end customers. Competition was driven by cost; the quality of the service provided was a secondary consideration.

In such circumstances, the question of how a shipper chooses a port as such was an important issue not only for shippers but also for port managers, shipping lines, and policy makers. It is then not surprising that research was called in to shed light on the issue. In response, a number of studies on port choice were undertaken and published in economics and management journals using a number of methodologies depending on the tastes and knowledge of the researchers involved (Murphy *et al*, 1992; Slack, 1985; Bagchi, 1989). Most of the studies provided useful insights on the determinants of port choice in different contexts with significant implication for policy and practice. Nevertheless, none of the studies has examined port choice in a situation where a port is considered as an element of a supply chain (Magala, 2004). Robinson (2002) can be credited with being the first researcher to propose and articulate the view of a port as an element in value-driven chains and to call for a paradigm change. The significance of this shift in thinking was recognised as a major breakthrough by Panayides in 2006 in a special edition of the *Maritime Economics and Logistics* and noted later by other authors in a number of subsequent academic papers. Yet, its operationalisation has not been seen, reflecting in part the difficulties researchers are having in abandoning their old models and thinking and endorsing radically new and more effective frameworks.

Kuhn (1970) argues that when research dwells on the same issue for a long time it is an indication of its importance, but often it is a sign of a lack of progress on the subject matter. He further argues that when the reality changes and old frameworks are inadequate, it is a sign that a *new paradigm* or *a paradigm shift* is required (Robinson, 2002).

In the highly competitive and rapidly globalising economy of today, the integration of supply chains is taking place and ports are increasingly competing not as individual firms but rather as firms within supply chains. Better integrated supply chains, rather than individual firms or highly fragmented chains now compete with other supply chains (Lam, 2006; Robinson, 2002, 2003, 2006). Integration has been driven mostly by third-party service providers not simply seeking to extract costs and efficiency advantages but in so doing to deliver competitive advantage to the end customer with the view to extracting value and competitive advantage for themselves.

Clearly ports can no longer expect to attract cargo simply because they are natural gateways to rich hinterlands. Major port clients are now likely to choose ports not simply on their efficiency and location advantages but rather on the quality and reliability of the entire supply chain. The successful functioning of ports is indistinguishable from the successful functioning of the entire supply chain. For shippers, port choice becomes more a function of the overall network performance and ports are chosen on the basis of faster, better and more cost-effective access to the markets in which shippers compete for profit. Shippers see as the greatest value of competing as part of an integrated supply chain the opportunity to reduce vulnerability to competition by providing the port with complementary resources and capabilities needed to compete more effectively in the marketplace. In essence, supply chain integration may allow some firms to compete effectively in the marketplace without first owning all the critical resources needed to do so.

Under the new circumstances, it is apparent that shippers are being offered for the most part logistics packages of varying composition and prices, which include among other ports' services. Third-party services providers have assumed the role of integrators who package and market logistics services and solutions to shippers. This means that shippers can now focus on their core businesses and intervene only when a selection/choice of a supply chain solution that suits their tests and objectives is required. Therefore, the choice of a supply chain solution rather than the choice of a port *per se* becomes the focal point of shipper decision-making.

Interestingly, however, research continues to focus on how shippers choose a port in isolation from the system in which it is entrenched (Nir *et al*, 2003; Bruno and Guy, 2006; Ding *et al*, 2005). The same frameworks and approaches that were used when a port was part of highly fragmented transport chains continue to be used. While there may be instances where such studies continue to be relevant (eg in some developing economies where the transport chain is still highly fragmented), the new reality and context suggest that new approaches and frameworks are needed if studies on port choice are to provide decision makers with useful insights.

In the face of changing economics of port competition and global logistics, the aim of this study is to suggest a new alternative approach to port choice modelling. The study uses insights from systems theory and the literature on bundling to suggest that port choice should be modelled within the paradigm of a port as an element in a value-driven supply chain.

This paper is conceptual in nature. Its aim is to establish a framework within which a new approach to port choice modelling can be implemented. The paper has been structured into eight sections. The next section reviews the literature on port choice. The subsequent section defines a port as an element in the supply chain as the paradigm shift. It is within this framework that the new approach to port choice modelling is proposed. Systems and bundling theories are discussed in the later section as the supporting theories for the new approach to port choice modelling. Then, the proposed approach to port choice modelling is discussed. The approach is based on discrete choice modelling and information integration theory by Anderson (1981). The sixth section briefly suggests some key variables that should be considered in port choice modelling. In the penultimate section a brief discussion of who actually chooses a port is presented. The final section draws general conclusions.

Literature review

There exists an extensive array of published studies which attempt to explain the methods and criteria shippers and shipping lines use to choose a port (Nir *et al*, 2003; Tiwari *et al*, 2003; Bruno and Guy 2006; Ding *et al*, 2005; D'Este and Meyrick, 1992a, b; Lirn *et al*, 2004; Murphy *et al*, 1992; Slack, 1985; Brooks, 1984, 1985; Bagchi, 1989). In addition, similar studies describe intersecting and weighted factors used when shippers select their preferred shipping line and land transport mode. Indeed, these studies use a number of approaches such as fact-based evidence and captured interview data to support specific conclusive formulations and models of port choice. But, how useful are these studies when a port is no longer competing as a stand-alone entity but rather as an element in supply chains? The review that follows is a call for a deeper thinking on the issue of port choice and the relevance of the current modelling approaches in today's business dynamics.

Without doubt port and carrier choices are interrelated along with other relevant factors in the supply chain event. This event re-occurs from time to time when attributes of certain elements alter and often affects other deliverables and outcomes in the supply chain order. The point being made can be illustrated with a 2006 study whereby a major port in Australia commissioned research to assess the criteria by which the owners and executive of shipping lines determine port selection. On the face of it this request appears to be a simple study of researching elements of a ports' service abilities and physical characteristics including geographical positioning. As the study unfolded, however, it became clear there were multi-dimensional supply chain considerations that caused a rethink of the approach to unlock the port selection criteria and port choice modelling.

In this realisation it emerged that the choice of a port made by the shipping line was interrelated to the choice made by the shipper(s); and more importantly both choices were only one part of the supply chain selection process. Surprisingly, however, in review of some earlier papers there appears to be degrees of missing data or missed opportunity to include a bundle of events in assessing the forces driving port choice.

For instance, a study by Nir *et al* (2003) dealing with shippers' port choice in ROC Taiwan found that proximity to port in distance, cost equation over that distance and travel time determined shippers' decision to use a particular Taiwanese port. While it may hold true that the drayage distance from factory to container receivals yard influences shipper's port choice in Taiwan, it can be argued that also a series of connected and bundled supply chain events such as forwarders preference of consolidation terminal, ocean carriers empty container yard, truckers backhaul terms and rates, influence and preference of overseas buyer, etc, play a significant role in the decision-making.

Indeed, a study by Guy and Urli (2006) dealing with port selection by shipping lines in North America gives credence to supply chain approach to port choice by recognising in its conclusions that there is a need to put into perspective the importance of supply chain factors in the port choice. Unfortunately, there is no attempt to model port choice based on the supply chain perspective. The study stops short of suggesting that port infrastructure, cost, services and geographical location are criteria that guide shipping line decisions in the context of North America port competition.

D'Este and Meyrick (1992a, b) examined carrier selection in a Ro/Ro ferry trade in the Bass Strait market (between mainland Australia and Tasmania) and established that shippers treat ports as just another factor in the overall carrier selection process. The study suggests that shippers are not particularly committed to a particular port that a shipping company they select currently uses. Instead, shippers weigh the relative advantages of the competing carriers and make a decision based on a combination of shipping and port factors. This finding is very important for the purposes of this paper. It suggests that when shippers choose a shipping line or a port they base their final choice and decision on the overall assessment of the supply chain system. It follows then that modelling port choice based on one component of the supply chain or without taking into account the system in which a port is embedded may not provide sufficient insights to understanding shippers' port choice decisions and what makes one port more competitive than others in a highly competitive environment.

The study by Tiwari *et al* (2003) looking at shippers' port and carrier selection behaviour in China is an interesting one and represents a significant departure from other studies. The study is one of the few if not the only published study that attempts to model port and shipping choices simultaneously. This approach is interesting and refreshing as it touches on the theory of interrelationships between a package of services and their deliverables. Indeed, this approach discusses service combination variables and shows that just reviewing one single element of the supply chain is not enough to gain a true identity of the package of services that drive the final choice outcome. The study identifies distance of the shipper from port, distance from origin and to destination, port congestion and shipping line's fleet size as key criteria for port choice. But, it also omits other supply chain components such as railroad operators, road operators, customs agents, logistics service providers, freight forwarders and others in the analysis. An emphasis remaining upon distance of shipper's factory to port and carrier's fleet size and flag state does not address the fundamentals driving the outcome as created by the bundled supply chain event. When one considers that East-West liner services in operation today are the product of consortium agreements then the relevance of flag state and number of ships by a single owner bears little relevance.

In summary, there exists evidence that we understand the relationship between ports and carriers in the service deliverable sense but another method is required in making the connection between port choice and supply chain selection. The shipper is pivotal in the process of service demand and choice because both shipping and port services are derived demand; they are derived from shipper's propensity to trade. On this platform we can then use case studies to examine the bundle of freight services arrived at by the shipper and unravel each event to understand the drivers and relationships between each factor. This then will add relevance to any study on both carrier and port choice.

Effective review of the supply chain events can offer insight into port selection which without such method would remain a guessing game. A good example of this can be understood through the examination of imported construction steel into Australian ports in New South Wales. In this case the importer/merchant has control over shipping and routes goods with carriers that call at a regional port we shall call 'port NC' where they have a major warehouse facility. However carrier space is limited so they must route major volume into another port we shall call 'port SY' which is 200 km south of their warehouse. In this example there exists several forces that cannot be explained until the full supply chain event is examined and in this case it is far more cost effective for the steel merchant to import through port 'SY', deliver by road to warehouse at port 'NC' than to warehouse locally at port of entry at port 'SY'. This would never be understood by either port management or ocean carriers unless they reviewed the complete supply chain events.

In another instance of a dedicated shuttle vessel for mine re-supply products (chemicals, grinding media, tyres, etc), it remained uncertain why it had settled on a small port located at a tourist town a thousand nm[1] further than a seemingly ideal commercial port with better waterfront infrastructure. This until the knowledge that fear of tropical cyclones at the much closer port would shut down or limit supply coupled with mine site procurement and logistics expatriate officers favouring the tourist town as their home base allowed complete unbundled cognizance of the influencing conditions.

Another such example of port location coming under scrutiny is with the manufacture of aluminium billet and ingot by smelting plants within very close proximity to regional ports but choosing to select ports many miles away. This, when examined closer being due to the offset of supply chain forces whereby the net equation allows backhaul land transport of empty containers, marshalling and packing into containers and front haul delivery as a more economic outcome than to load for export at their seemingly conveniently located local port.

These examples perhaps refute the application that port proximity rules the day for all circumstances. More importantly, these examples seem to lend support to the argument that shippers may no longer choose a port as such but rather a port-oriented supply chain in which the port is embedded as a critical element. Robinson (2002) has comprehensively argued that in a competitive environment a number of supply chains will be focused on the port and shippers will choose between chains on the basis of competitive advantage and value they can gain. In this context ports will compete not simply on the basis of operational efficiency, price, location, but on the basis that they are embedded in quality supply chains that offer shippers greater value than the alternatives. For this matter, chains rather than individuals firms including ports compete one against others. In this sense ports are elements in supply chains, and are chosen based on their ability to provide superior and low cost pathways to markets.

Port as an element in the supply chain: the conceptual framework

The primary concern of a shipper is to move freight from market A to market B or more specifically from a point of production to a point of consumption or further processing in the most cost-effective way. In consigning cargo to an endmarket the shipper chooses a logistics pathway that the freight follows. The notion of logistics pathways connotes a sequential set of logistics operations, warehousing, depot operations, port operations, trucking, freight forwarding, which deal with the end-to-end movement of freight.

Figure 2.1 is a simple high-level representation of logistics pathways. From the figure it can be recognised that a shipper has a number of choices to make to reach the end market in which they compete with other shippers for value. The shipper has to choose routes, modes, carriers and ports. These choices are hardly made independently or as an end *per se*; they are interdependent and often internalised in the overall choice of the supply chain pathway. In this conceptualisation a port is just an element – an important one – of the supply chain system.

The availability and suitability of a particular pathway is governed by a number of spatial, temporal and logistical factors including the availability of a shipping line, land transport, accessibility, connectivity and alignment with shipper needs and strategy. It follows then that when choosing a pathway a shipper will consider not only the possible combinations of ports of origin and destination, but also the availability of shipping lines, routes, land transport and a host of other logistics factors. Since all these elements are part of the pathway, it can be argued with some degree of confidence that the choice of a port is a by-product of a choice of a logistics pathway in which the total logistics cost is a major supply chain consideration.

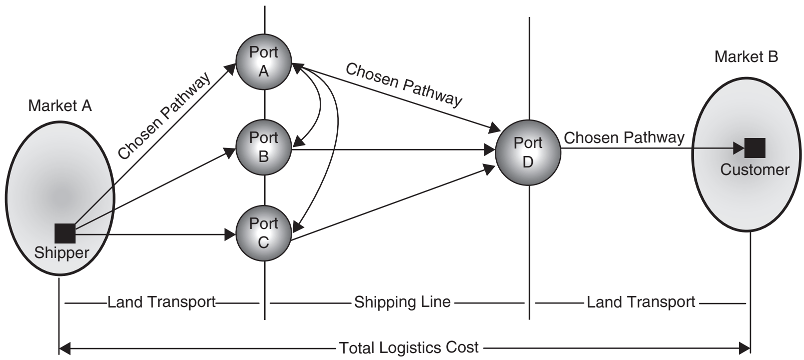

Figure 2.1 Logistics pathway in a port-oriented supply chain

Logistics pathways are being offered to shippers at a price by the third-party service providers who intervene in firm-to-firm transaction to effect the freight movement and by so doing capture value for themselves (Robinson, 2002). The 3PLs offer packages that include not only transport, cargo handling, and storage of goods, but also full responsibility including risk over the cargo from origin to destination on the basis of a single supply chain contract and bill that reflects the total logistics cost and not the cost of separate functions carried out by individual firms in the chain. They do so because, in the eyes of the customer, no longer is it satisfactory to supply one part of the solution; a total logistics solution has become a threshold requirement to compete. Surprisingly, however, a number of studies on port choice seem to suggest that the port and port-related activities are removed from the essence of the supply chain events. This view is held up by some in the relativity of port choice modelling regimes where the port is regarded as a crossroads in the supply chain rather than being hardwired into the integration of events.

We argue here that the more we study various examples of port choice models the more reticent we become in the notion that the port element is a stand-alone proposition as far as its selection criteria are concerned. Indeed, our most recent understandings present the case time and again that the port selection criteria and choice models are directly connected with the complete supply chain event.

An example in support of this argument is the case of Darwin port in Australia in the very North of the continent and the export of Uranium (yellow cake) to North America and Europe. Darwin was selected as part of the supply chain despite not having direct shipping services supporting this option. The exporters of this commodity had for some time been frustrated by the lack of service continuity to support their through logistics as a result of consortium liner operators refusing to handle this IMDG hazardous *class seven product*.[2] Thus a combination of road, rail, pre-receivals and port access together with two or even three transhipment points were combined in the supply chain event to conclude a successful logistic routing. Darwin alone as a port consideration is meaningless without taking into account the dynamics of the complete supply chain event supporting the choices.

This real-world example is useful to emphasise this fundamental change in port choice. It demonstrates that the choice of a port bears little relevance if it is not placed in the context of supply chain selection. Shippers choose ports not simply on their efficiency and location but more importantly on the extent they exist as elements in supply chains that provide low cost transport pathways to markets. Ports not only must themselves be efficient, they must exist within efficient chains where the total cost of the elements is lower than the cost of competing chains for a comparable level of service. Quality and reliability of the entire supply chain is a major consideration. For shippers, port choice becomes more a function of overall network performance and ports are chosen on the basis of how well they are integrated in the supply chains. This notion forms the key foundation for an effective modelling and understanding of shipper port choice.

Key theories

There are two well-developed theories which offer exceptional insights on how to approach the modelling of port choice from a perspective of a port as an element of a chain system. The first is based on systems theory and the second on the economic and marketing theory of bundling. The theories share a number of similarities but the way they explain how things work is different though not necessarily contradictory.

Systems theory

The systems theory emerged as a reaction to the analytical or classical natural science approach which is based on the assumption that the parts make up the whole and as long as the parts are described well enough the individual merely has to put them together to get the whole picture (Capra, 1997; Churchman, 1981). The behaviour of the whole is assumed to be understood entirely from the properties of the parts.

The systems theory on the contrary states that the various parts of the system are linked together and can only be understood by a holistic approach. Put in the context of port choice, this means that the choice of a port can be fully understood if we examine the overall choice of a supply chain.

Under a systems approach, instead of breaking the supply chain or pathway into its component parts, that is, port, shipping lines, land transport, the parts are integrated into larger, unifying supply chain or pathways framework. This way, from the holistic supply chain view, it is claimed that one can therefore more fully understand and model shipper port choice – albeit one still needs to put the intricate parts together in the first place. In the maritime business this is being done currently by 3PLs and chain integrators.

When dealing with a system such as the supply chain, understanding the guiding principles of the systems theory approach can lead to a superior understanding of how things work in the way they do and why sometimes there is a failure in the system. For example, more recently in Newcastle, Australia (Lloyd's List DCN, 2007) there was a big issue with longer queues at the port. Queues never seen before of more than 70 bulk coal vessels were at the centre of heated debates with fingers pointing to the world's biggest coal port as the problem. The port of Newcastle handles more than 80 million tonnes of coal annually. But, was the port alone the real problem? When a proper supply chain analysis was conducted it quickly emerged that the problem was created in part by the coal marketing companies that had promised to supply coal volumes that the logistics chain infrastructure was unable to handle. This persistent pattern is not unique to Newcastle; Dalrymple Bay coal terminal is another example (Robinson, 2007). Essentially, it demonstrates that chains are often characterised by power regimes and the quest for value appropriation which generally prevent cooperation between players and the attainment of high levels of efficiencies in the chain.

The examples are a caution against judging parts of a system without taking into account a holistic view of the system. Systems theory maintains that the efficiency of the whole system is not equal to the sum of the efficiencies of its parts. In fact, for a well-functioning system, the efficiency of the system is greater than the sum of efficiencies of the parts because of the leverage and synergies gained through complementarity. In this context, aggregating choices of individual elements yield suboptimal insights on the determinants of the choice of the whole supply chain.

Bundling

The way shippers go about constructing and evaluating a set of shipment options is of considerable interest in particular when consumer behaviour theories based upon single-item choice fail to predict behaviour adequately in a situation involving multiple choices.

In such circumstances bundling appears to offer an adequate framework within which multiple category choice can be well understood. Bundling is concerned with the joint offering of two or more non-substitutable items together at a single, combined price (Yadav, 1994). In the case of a shipping industry, for example, a shipper selects a number of logistics services all of which are necessary to enable them to move the goods from one end of the market to the other. The key feature of bundling is the treatment of the choices as interrelated because each item in the final set of services contributes to the achievement of a common behavioural goal.

Under bundling it is predicted that the consumer will choose the bundle with maximum 'utility', that is a bundle that will maximise customer satisfaction for a given service requirement.

Thus, bundling is an integrating approach for offering shippers a greater choice of cost control, flexibility, competition, reliability, risk management, and a one-stop service that is more cost-effective than the alternative options. It offers shippers with the opportunity to select combinations of logistics packages that offer the level of efficiencies and costs that is more aligned with customer's expectations. The usefulness of bundling for this study is that it provides a framework within which we can explore how a supply chain is formed, priced and evaluated by the shipper to arrive at final choice decision.

According to Russell *et al* (1997), bundles are formed through a selection process in which items with different features are combined to compose the set. These items in the set are not substitutes and must complement each other to fit the purpose. The relative importance of each item may be different but the items must be interrelated.

The economic rationale for bundling (Guiltinan, 1987) is based on the reality that the cost structure of most service businesses is characterised by high ratio of fixed to variable costs and by a high degree of shared costs; and the services offered by most service businesses are generally interdependent in terms of demand. The effectiveness of price bundling then appears to be a function of the degree to which it stimulates demand in a way that achieves cost economies.

Consider, for example, a case in which we have two services on offer. If we assume the reservation prices[3] of four shippers for logistics service PS (port service) and SS (shipping service) in Table 2.1 (let P_{PS}, P_{SS},

Table 2.1 Economic rationale for bundling

Shipper	**Reservation prices ($)**			**Consumer surplus**	
	$\boldsymbol{RP_{PS}}$	$\boldsymbol{RP_{SS}}$	$\boldsymbol{RP_{PS+SS}}$	$\boldsymbol{RP_{PS}-P_{pp}}$	$\boldsymbol{RP_{PS}-P_{SS}}$
1	800	100	900	100	–
2[1]	300	600	900	–	200
3	800	700	1500	100	300
4	500	200	700	–	–
	If P_P = $700, P_S = $400, then			If P_{P+S} is set at $900, then	
	Shipper 1 buys only PS			Shipper 1 buys bundle	
	Shipper 2 buys only SS			Shipper 2 buys bundle	
	Shipper 3 buys both PS and SS			Shipper 3 buys bundle	
	Shipper 4 buys neither PS nor SS			Shipper 4 does not buy	

Under independent demand, $RP_{PS+SS} = RP_{PS}+RP_{SS}$. Thus, shipper 2 will buy the bundle even though P_{PS} exceeds RP_{PS} by $400. The gap $RP_{PS}–P_{PS}$ has been closed;the bundled price RP_{PS+SS} provides a discount of $200 in comparison with the sum of P_P+P_S because shipper 2 has a consumer surplus of $200 from the purchase of P_{SS} ($RP_{SS}–P_{SS}$ = $200). In effect, the consumer surplus from P_{SS} has been transferred to P_{PS}.

and P_{PS+SS} represent the prices of PS and SS, and PS and SS bundled together in a mixed-joint), then if bundling is not available, only shipper 3 will buy both services because at P_{PS} = $700 and P_{SS} = $400 only customer 3 has a reservation price greater than or equal to both of these prices. However, if shippers' reservation prices for the bundle are equal to the sum of the individual reservation prices, then at P_{PS+SS} = $900 shippers 1 and 2 will also purchase the bundle. As shown in Table 2.1, shipper 2 has a $200 consumer surplus (benefit) on SS. When shipper 2 is confronted with the chance to buy both PS and SS at the bundled price, this surplus plus the discount P_{PS+SS}–(P_{PP}–P_{SS}) provides the *motivation to choose to buy the bundle or a supply chain solution*. That is, the judgement of a bundle's total costs is viewed by shippers as less than the sum of the individual service costs.

The issue of bundle evaluation is central to the approach we propose. Yadav (1994) developed and tested a model of how buyers evaluate product bundles. The model was adapted from Lopes' (1982) proposed strategy which suggested that in the presence of substantial amount of information buyers anchored their evaluation on the item perceived as most important and then made adjustments on the basis of their evaluations of the remaining bundle items. Yadav's (1994) results suggest that buyers tend to examine bundle items in a decreasing order of perceived importance and make adjustments to form their overall preference of the bundle. This bundle evaluation process is depicted in Figure 2.2 and

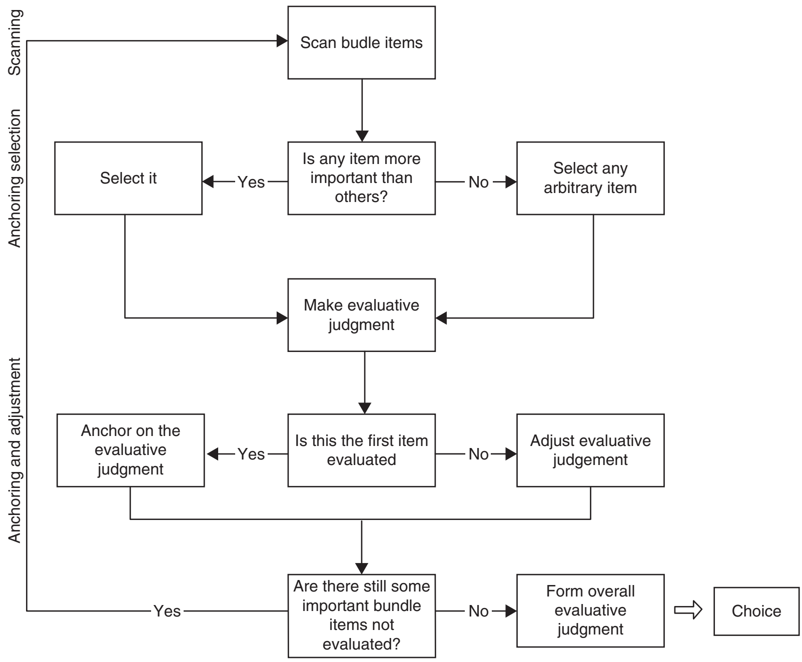

Figure 2.2 Bundle evaluation process
Source: Adapted with modifications from Yadav (1994), How buyers evaluate product bundles: A model of anchoring and adjustment, *Journal of Consumer Research* **21**: 342–353.

can be viewed as an extension of Anderson's (1981) *information integration theory*.[4] It also offers a richer perspective for understanding how shippers may evaluate and choose a port within the paradigm of a port as an element of a supply chain system.

The proposed new approach

Because many choice problems deal with the selection of several items either sequentially or simultaneously, modelling the selection of a port outside the system does not provide a clear understanding of how a choice of a set of items such as supply chain is made. Even a single item choice task can be viewed as a selection of a multiple item set by appropriately redefining the scope of the decision. *Because of this ambiguity, a richer analytical framework is needed to draw attention to the distinguishing features of choice of a set of items.*

In this section we attempt to provide such a framework by incorporating insights of systems theory and bundling into a discrete choice modelling framework premised on the behavioural and economic theory of utility maximisation to study the choice of port as an element of a supply chain system.

Systems theory and bundling are useful in helping us to understand why it is more appropriate to model a port as an element of a supply chain. The main thrust of the theories is that modelling a system provides a better understanding of the choice of individual elements that compose the system. Trying to study a system by focusing on its individual parts has weaknesses in that it omits the key interdependences and influences that ultimately affect our perception and overall evaluation of the system. It also prevents us from understanding why a system rather than its elements is the primary concern in the choice. Shippers choose a system to profit from synergies that a well-functioning system provides. The contention that the total cost of the system is less than the sum of the costs of its elements certainly is an attractive proposition. Both bundling and systems approach promote the idea that efficiency of a system is greater than the sum of efficiencies of its elements, and the cost of a system is less than the sum of the costs of its parts.

The modelling framework

The modelling approach suggested in this paper is based on discrete choice modelling and on the treatment of choice of port as an element of a supply chain. The approach views the decision to choose a port-oriented supply chain as a multi-step, complex process which is guided by a variety of economic and non-economic issues, and by quasi-rational assessment of economic and benefits that are also filtered through behavioural processes of perception and interpretation. It follows then that not all choices are an outcome of an explicit decision-making process; the decision-maker can for instance assume some form of conventional behaviour or follow intuition (Allison *et al*, 2000; Khatri and Ng, 2000). The purely rational model of choice behaviour which views choice as a product of a sequential decision-making process including the definition of the choice problem, the generation of alternatives, the evaluation of attributes of the alternatives, the actual choice, and finally the implementation (Ben-Akiva and Lerman, 1985, p. 32), can be modified to take into account the lack of information about the set of factors that the analyst would otherwise consider to be in the universal set. This entails bounded rationality on the part of the decision-maker who is affected by his or her own past experience and learned responses.

Two different modelling approaches dominate the study of choices individuals make in a decision context (Hensher and Johnson, 1981; Ben-Akiva and Lerman, 1991). The first uses discrete choice models based upon revealed choice data. Revealed choice data provides information about past choice decisions individuals made on the subject of interest. The second approach uses choice models derived from stated choice experiment data and it is very useful for situations where the subject of interest is the behaviour in the presence of new situations. A key assumption is that decision-makers behave rationally (although admittedly bounded) and will always choose those alternatives that yield maximum utility or satisfaction.

Stated choice models are based on information integration theory in psychology (Anderson, 1981), random utility theory in economics, and econometric specifications of discrete choice models (Hensher and Johnson, 1981). The presumption is that shippers arrive at a choice by cognitively integrating the utilities attached to the attributes that characterise the choice object (eg, supply chain), according to a simple algebraic rule and by implementing a utility-maximising rule to convert their preferences into a choice.

In order to estimate the assumed utility function and to test the underlying choice model, shippers in a sample are typically presented with choice sets that may vary in size and composition and are asked to select from each choice set the alternative they like best. The choice possibilities or alternatives may be examples from the real word (eg, supply chains), but more typically they represent profiles of hypothetical supply chains. Choices are aggregated across individual shippers for each choice set and analysed by means of a formal choice model, usually a multinomial logit model (MNL) (Kuhfeld, 2003; Louviere *et al*, 2000; Hensher and Johnson, 1981). Once a specific model is assumed, the aggregated choice frequencies may be decomposed to determine the contribution of each factor/attribute.

To model complex decision problems with a large number of intervening factors, Louviere (1984) developed a hierarchical information integration approach illustrated in Figure 2.3, which is an extension of information integration theory (Anderson, 1981). Basically, the approach (1) categorises attributes into several non-overlapping sets based on theory, logic or empirical evidence, such that the sets represent particular factors including port, shipping line, land transport or the like; (2) designs and administers separate experiments to define each factor in terms of the attributes that categorise it; and (3) develops an overall or bridging design based on the factors that allow one to concatenate the results of the separate designs and overall design into one fully specified utility model. Essentially, the attributes, X, in Figure 2.3, can be combined into constructs or factors to represent the choice process. This process is repeated in Figure 2.4 with a more specific example of choice of a port as an element embedded in a supply chain.

Figure 2.4 identifies two possibilities to model choice using the systems approach thinking. At one level, it is possible to model supply chain choice in the presence of a number of competing supply chain alternatives. At another, it is possible to use the same model specification to understand the determinants of port choice, shipping line, land transport, and other elements that compose the supply chain.

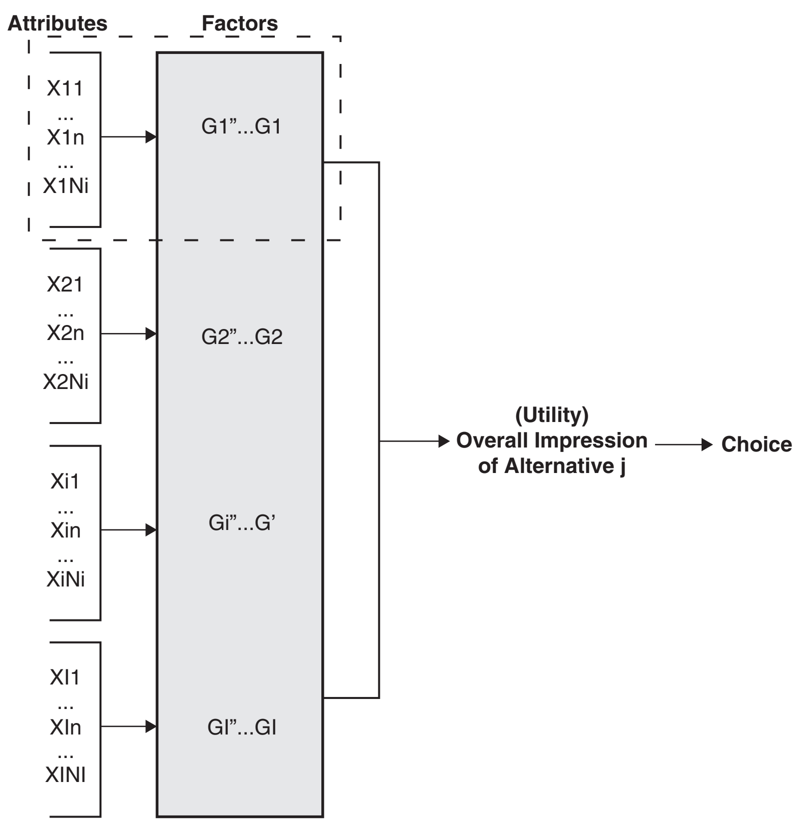

Figure 2.3 Overview of the hierarchical information integration approach

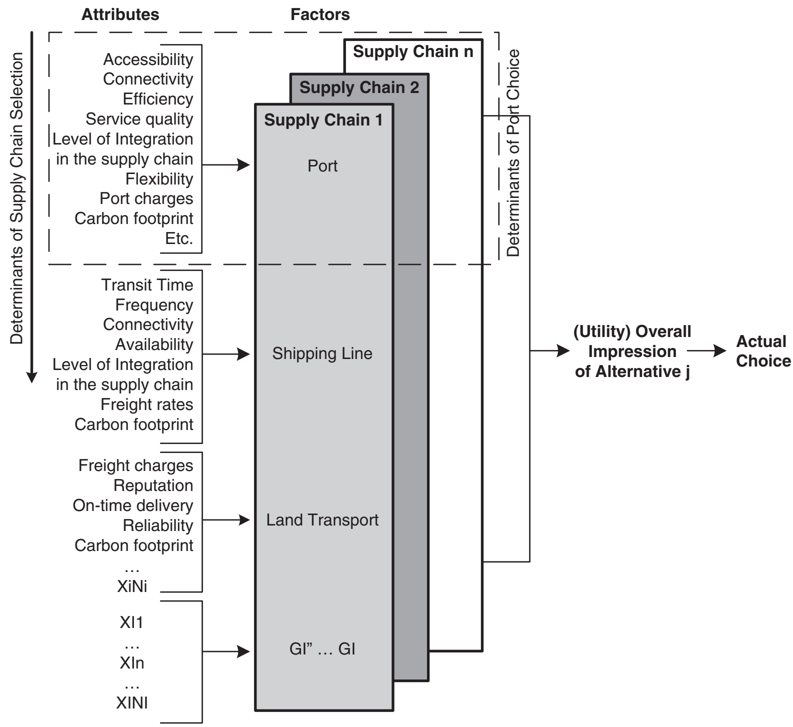

Figure 2.4 Port choice process

Deriving the choice model

In this study, the hierarchical information integration approach developed by Louviere (1984) is used to model port choice within a supply chain perspective.

Formally, the random utility theory (RUT) model can be expressed as:

$$V_{ij} = \beta' x_{ij} + \varepsilon_{ij} \tag{1}$$

where V_{ij} is the systematic utility of alternative i in choice set j; x_{ij} is an index of the observed influences (attributes) on utility (usually linear additive in the attributes); β is a vector of unobserved marginal utilities (parameters); β' is the transpose of β; ε_{ij} is an index of the unobserved influences or random errors.

The presence of the random component implies that utilities or preferences are inherently stochastic. It also suggests that the researcher can predict only the probability that an individual *j* will choose option *i*, not the exact option that will be chosen. That is, we can specify the probability that individual *j* chooses option *i* from a set of competing options as follows:

$$P\left(i \mid C_q\right) = P\left[\left(\beta' x_{ij} + \varepsilon_{ij}\right) > Max\left(\beta' x_{kj} + \varepsilon_{kj}\right)\right] \qquad (2)$$

The equation above states that the probability that individual *j* chooses option *i* from the choice set C_q is equal to the probability that the systematic and random components of option *i* for individual *j* are larger than the systematic and random components of all other options that compete with option *i*.

Families of probabilistic discrete choice models can be derived from the previous equation by specifying particular probability distributions for ε_j (Louviere *et al*, 2000); but the assumption that the random components are independent and identically distributed (IID) Gambel (McFadden, 1974) leads to a well-known *Multinomial Logit* (MNL) model, which has become the workhorse of practical applications. Unfortunately, however, if the random components are not IID, the Gambel distribution lacks a closed-form expression for the probabilities. In addition, the MNL may suffer from the consequences of independence from irrelevant alternatives (IIA). The IIA property states that for any individual, the ratio of the probabilities of choosing two alternatives is independent of the availability or attributes of any other alternatives (Hensher and Johnson, 1981).

Unrealistic consequences of IIA can render the model irrelevant; nevertheless they can be avoided by including a manageable number of relevant variables in the observed set of influences of the utility function. Another way to alleviate these consequences is to base predictions on a model other than the MNL; that does not have IIA property such as the nested logit model, the heteroskedastic MNL and the multinomial probit (see Louviere *et al*, 2000). In this study, it is suggested that the violations of IIA can be minimised through a robust model specification that includes relevant design attributes and their levels.

Specifying the choice estimation model: the MNL

In mathematical terms the MNL is formulated as follows:

$$P_{ij} = \frac{e^{\mu V_{ij}}}{\sum_{k=1,L} e^{\mu V_{kj}}} \qquad (3)$$

where P_{ij} is the probability of selecting alternative i from the jth choice set containing K possible choices; V_{ij} the systematic utility of alternative i in choice set j; μ is a scale parameter.

Representing a choice alternative as a bundle of its attributes, and by assuming an additive utility function, V_{ij} can be calculated in the following manner:

$$V_{ij} = \sum_{l=1,L} \beta_l x_{ijl} \tag{4}$$

where x_{ijl} is the level of attribute l of alternative i in choice set j; β_l the relative utility weight (part-worth utility) associated with attribute l; L the total number of attributes.

In the MNL the challenge is to estimate the β_l parameters or the relative utility weights. There are a number of approaches to finding β_l parameters although in practice the maximum likelihood estimation procedure is used.

In specifying the choice model a distinction must be made between generic attribute weights and alternative-specific attribute weights. A generic attribute involves constraining the parameter estimates associated with an attribute in each utility expression to be equal where the equality can be a theoretical condition and/or an empirical result. Where the possibility exists of shippers evaluating the choice attributes differently for different alternative supply chains, the model should include the alternative-specific effects. Kuhfeld (2003) suggests that there is no need to use a more complex model containing the alternative-specific effects if a much simpler generic model can be derived and provide similar information. This is consistent with the parsimonious principle, which states that the aim of modelling is to produce and make use of the simplest model – a model that includes the fewest number of explanatory variables and permits an adequate interpretation of the dependent variable.

Key variables

For the purpose of choice modelling, a supply chain and a port can be described as a combination of factors and attributes at different levels. The key factors or variables relevant to the modelling are those known to influence shipper behaviour and subsequent choices of a port and supply chain. Some variables are qualitative such as the quality of a service or reputation of a port; others such as freight rates, transit time, etc are quantitative.

The literature provides a rich set of factors that bear significance in port choice modelling (Tiwari *et al*, 2003; Bruno and Guy, 2006; D'Este and Meyrick,1992a, b; Slack, 1985; Brooks, 1984, 1985). However, with the notable exception of Tiwari *et al* (2003) and D'Este and Meyrick (1992a, b) most factors were derived without taking into account other elements of the supply chain nor a holistic view of a supply chain. This limits the usefulness of such models in explaining the determinants of port choice particularly in a new competitive environment in which a port is chosen as an element of a system or supply chain.

Therefore, we suggest that other factors such as accessibility to markets, connectivity, level of integration in the supply chain, overall port efficiency, efficiency of supply chain interfaces and links, supply chain total cost, level of supply chain coordination, type of service (intermodal, port-to-port, door-to-door, door-to-port, etc), carbon neutrality/carbon footprint should be incorporated in the port choice modelling. In this paper we do not, however, discuss these factors but we indicate that their relationship with port choice has been established in a number of studies (Magala, 2004; Slack, 1985; Wang and Cullinane, 2006) and if included in the model design they are likely to provide us with quality information on the port choice process and its determinants in the context of supply chains competition.

A final note

The question of who actually chooses a port is a legitimate one. A year ago Cullinine[5] was asking the same question at the International Association of Maritime Economists Conference in Melbourne, Australia. Others have also asked the same question on other occasions (D'Este and Meyrick, 1992a, b; Wang and Cullinane, 2006; Fleming and Baird, 1999). The importance of this question cannot be overstated; it has important implications for policy formulation and investment decisions. Notwithstanding, a universal answer is yet to be provided, partly because the answer is complex and research has not paid sufficient attention to the issue.

In as much as ocean carriers review who are the controlling parties in the decision of liner choice this fundamental also arises and stands true in port selection. Ocean carriers, for example, in commencement of marketing their services will distil the transactional elements of the terms of international sale/ purchase of goods and the involvement of third parties such as freight forwarders, customs agents, consolidators, multi modal service suppliers covering the vertical integration of freight services. The ocean carriers conduct this prior research in order to resolve the query as to who to target with their canvassing sales activity. Certainly this has proven to be the simplest and most time-efficient method of strategic commercial activity. However, in many cases the ocean carriers get it wrong and have to re-establish the investigation as to who controls the cargo routing because the ‘terms of sale’ do not always dictate the party controlling the choice of the carrier due to other varied influencing factors. Similarly, the port choice argument we have presented provides a multidimension perspective on how the port choice is arrived at and who are the controlling or influencing parties.

Indeed, the main contributors in the circle of events surrounding the supply chain would be the supplier, service providers including shipping lines and purchaser. In simple terms, the port selection would be woven into a similar set of criteria as ocean carriers take towards their sales focus. But it is more complex than that as we can see from the examples listed and again when reviewing current cases of main port and minor port selection. This is because the influencing parties and stakeholders in the supply chain event combine to weight the same elements differently dependent upon the unique events in each case.

As the third-party service providers (3PLs) intervene in bringing a consignment to the final customer, a seller is rarely the manufacturer/producer of goods and the buyer is rarely the final customer. 3PLs or integrators create efficiency and value improvements by integrating a supply chain through importing or exporting a large variety of items on behalf of shippers and buyers. Such services allow shippers to outsource logistics functions and concentrate on their core activities.

As Hayuth (1987) noted, intermodalism offers choice of routes, ports of call and modes of transport reducing the shipper’s influence with routes/logistics pathways and modes increasingly determined by an intermodal operator, freight forwarders or large shippers. Therefore in a port-oriented supply chain and in the context of this study which suggests that a port is an element of the supply chain it is not unreasonable nor out of the context to argue that all the major players in the chain, the shippers, shipping lines, freight forwarders and/or chain integrators make port choice decisions but in different ways and for different purposes. Most probably they attach different relative importance to the port. Nevertheless, the choices they make are related. Shipping lines, for example choose a port as part of their network configuration with the view of supplying competitive services to shippers and other shipping line customers. Shippers too, choose a port but more generally as part of the overall choice of their preferred bundle of logistics solutions being offered mostly by 3PLs. The third-party service providers also choose a port but as part of their effort to offer packages of competitive logistics service which they then offer to the shippers, shipping lines and to a lesser extent consignees.

If it is accepted that shippers, shipping lines and third-party service providers are all suppliers who provide value to the end customer and capture value for themselves through the provision competitive supply chain solutions, perhaps the relevant research questions should ask how shippers, shipping lines and third-party service providers choose a port as part of the overall supply chain selection process. A subsequent issue is; what is the relative importance that each major player in the chain attaches to the port and the criteria they value most to arrive at a final selection of a supply chain in which the port is embedded? A related issue of interest which is worth investigating is the power relativities that the key players have in the choice of a port as a pathway or supply chain element.

There is some anecdotal evidence that points to shipping lines having the 'last word' in port selection decision but there is lack of empirical evidence to establish the relationship. Indeed, the examples that follow may increase the ambiguities or suggest otherwise. In Australia, for example, a construction firm we will call 'Alpha' based in Darwin purchases steel products, for example, Shanghai through a trader based in Melbourne on FIS[6] terms. There exists a direct shipping service from Shanghai to Darwin at a comparable freight cost to other ports in Australia. However the freight is not delivered on the direct shipping service and instead is routed to Fremantle and trans-shipped on a coastal carrier, discharged and delivered FIS to company 'Alpha' in Darwin (travelling over 3,500 nm more than the direct route). Why is this the case?

In unbundling the supply chain events including the terms of sale we find that the trader uses a domestic freight company that supplies warehouse and storage at a cost connected with volume throughput. Therefore the trader must satisfy the minimum volume in order to achieve the favourable warehouse and storage rates. He in turn offsets this against the higher level of ocean freight charge when delivering FIS to his customer in Darwin.

So we are left with the query 'who is the controlling party'? In this instance the controlling party is not identified as 'who' but instead as a combination of influences and decisions including third parties that seemingly from a casual assessment would not carry much weight.

This same combination and bundle of events carries forward to any case of port selection that we may like to address and as is the case of the global freight consolidator offering linked services to importers and exporters which in turn negate the supposed influence the terms of commercial (sale/purchase) transaction may have as each importer has assigned the carrier selection to the Global forwarder under the terms of their consolidation agreement. In turn, the Global consolidator selects the carrier using his combined blue water freight volumes to achieve the lowest possible unit (TEU/FEU) freight rate and best terms. The port selection in this case is as an indirect result of the freight contract transaction between the Global consolidator using economies of scale and the Ocean carriers willingness to offer long-term contract conditions to lock in the cargo volume.

We can see this indirect result whereby various ocean carriers serving the East-West trade route from Far East to West Coast USA call at different ports but major shippers and consolidators switch carriers without much interest in the port of call. This can be seen in the example of the world's busiest container ports in the Greater Pearl River Delta, including the Kwai Chung Container Terminals in Hong Kong, the Yantian Port in Shenzhen, the Huangpu Port and Nansha Port of Guangzhou. Port charges in these locations are recognised as being some of the most competitive in the world, but hold little relevance to port selection without taking into consideration the bundled events surrounding the complete supply chain.

Another development supporting the reason why we need to re-evaluate the past theories of port choice modelling is the emergence of Inland Container Terminals and Depots (ICT/D). These facilities are becoming more common-place around the globe due to the diminishing availability of cost effective port land for handling the ever-increasing container volumes. The ownership of these inland terminals is split between the seaport operators and as such are proprietary service centres and others are owned and operated by third-party commercial property developers (similar in development terms to shopping malls). These third-party inland terminals are offered as 'common user' facilities being open to all service providers and incorporate freight villages whereby consolidators, forwarders, road and rail freight operators can all take leased space and operate as an integrated intermodal group.

Either type of ICT/ICD ownership adds a new dimension to the influence in port choice and just one common user inland terminal (inland port) can connect rail, road and freight consolidation networks to many competing seaports. This gives cause to consider the future dynamics and relationships between inland Ports and Seaports and who may hold greater influence in the overall supply chain event.

A simple conclusion of this discussion is that all major players in the supply chain make port selection decisions but with different focus and relative importance attributed to the port. Moreover, they take a holistic view and choose a port as an element of a supply chain.

Conclusions

In this paper it was argued that the current approaches to port choice modelling are at best ineffective at worse outdated and therefore a new approach that models port choice within the framework of a port as an element of a supply chain was needed and was more likely to provide us with a better understanding of the determinants of port choice.

There is no question that a shipper does choose a port but, in the current business environment in which ports compete as part of supply chain, the approach shippers use is based on selecting a port as an item in a logistics package, often assembled and offered to the shippers by the 3PLs or supply chain integrators which are now becoming the key intervening elements in firm-to-firm transaction to effect the freight movement from one end to another.

Within this view, it is suggested that discrete choice modelling provides the right modelling framework to handle both the system and the port choice. Particular specification of a model will be context dependent but the universal paradigm is that a port is chosen not in isolation but rather as an element of a supply chain system.

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Notes

1. Nautical miles.
2. IMDG code class 7 – radioactive material.
3. Reservation price is the maximum price a shipper is willing to pay for a service.
4. Information integration theory contends that in complex decision problems, individuals are likely to group or categorise decision attributes into separate high-order decision factors and then integrate information about attributes to form impressions of alternatives with respect to those factors. The separate factor impressions are then integrated to evaluate alternatives holistically.

5. Cullinane was a guest speaker at the IAME 2006 Town and Gown Session in Melbourne. He presented the topic titled *The Asian/China Dynamo: Implications for Ports & Shipping*.
6. Free into store. The seller is responsible for all costs and risks until the goods are delivered to the buyer's warehouse.

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3

Coordination in Hinterland Transport Chains: A Major Challenge for the Seaport Community

Martijn R. Van Der Horst and Peter W. de Langen

Many different private companies – shipping lines, terminal operating companies, forwarders, hinterland transport providers, and inland terminal operators – are involved in hinterland transport. In addition, different public actors such as the port authority, customs and excise, and infrastructure managers are involved. Creating effective hinterland transport chains requires the coordination of all these actors; it does not come about spontaneously. Its development may be hindered by free-riding problems, a lack of contractual relationships, information asymmetry, and a lack of incentives for cooperation. This paper presents analyses of the coordination problems in hinterland chains of seaports and arrangements to resolve these problems. The most relevant coordination problems in hinterland chains are discussed. Based on insights from institutional economics, four main categories of arrangements to improve coordination are identified: the introduction of incentives, the creation of an interfirm alliance, changing the scope of the organization, and collective action. An analysis is presented of a substantial number of coordination arrangements in hinterland transport to and from the port of Rotterdam, thereby indicating how coordination could be improved.

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Introduction

In many seaports, container transport has become the most important cargo flow. Some of the transport flows originate from or are destined for captive hinterlands in the proximity of these ports. However, most ports not only attract *captive* cargoes, but also compete fiercely for *contestable* container cargoes. These flows can easily be switched between different ports (Notteboom & Winkelmans, 2004). Since container ports have become links in a global logistics chain (Robinson, 2002), port competition has moved from competition between ports to competition between transport chains. As a result, ports are eager to enhance the quality of their hinterland transport services (Notteboom & Winkelmans, 2004). Many studies on competition between container ports state that infrastructural access to the hinterland and the availability of efficient port-related transport services are important determinants (among others de Langen, 2007, Wiegmans et al., 2008, and Tongzon, 2009).

De Langen (2004) argues that coordination between a large group of actors in the hinterland chain is required. The quality of a port's hinterland access depends on the behaviour of many actors, including terminal operators, freight forwarders, container operators, and the port authority. The assessment of coordination in inland container transport requires a theoretical approach to enhance understanding of the inter-organizational coordination.

Although coordination in maritime container transport has been studied extensively, mainly because of the ongoing debate about the effects of cooperation in conferences and alliances (e.g. Heaver et al, 2000), coordination in hinterland container transport has received little attention from a scientific perspective. Port hinterlands have been studied from a geographical perspective. This research has led to a number of important concepts and findings (see e.g. Notteboom and Rodrigue, 2005), but in general limited attention has been paid to coordination in hinterland transport chains. This has been studied from an operational and network perspective (e.g. Konings, 1996). Such studies are valuable, but they do not provide a basis for understanding the advantages and disadvantages of different coordination mechanisms. The limited attention paid to coordination in container hinterland transport is surprising. Hinterland-transport costs are generally higher than the maritime-transport costs. According Notteboom en Winkelmans (2001) the portion of inland costs in the total costs of container shipping would range from 40% to 80%. Stopford (2002) shows that inland transportation, including port costs, account for about 54%. Moreover, most bottlenecks in the door-to-door chain occur in the hinterland. Examples include congestion, inadequate rail infrastructure, and problems with the handling of barges at deep-sea terminals.

Panayides (2002) acknowledges the lack of attention paid to integration and coordination in hinterland transport systems. He presents an analytical framework firmly rooted in transaction costs economics. However, he has not used this framework for empirical analysis; neither have other scholars used the framework. De Langen and Chouly (2004) investigated coordination in hinterland transport. They introduced the concept of *Hinterland Access Regimes* (HARs). This was a first step towards analysing cooperation in hinterland chains, but the concept does not provide a basis for identifying where coordination is required or what mechanisms could be introduced to enhance coordination.

Although studies specifically addressing coordination in hinterland transport are scarce, the supply chain management literature recognizes that inter-organizational issues are crucial in supplychain efficiency. Notwithstanding the theoretical contributions made (e.g. Ballou et al, 2004), supply chain management literature still lacks a theoretical basis for the explanation and understanding of inter-organizational collaboration (Halldorson et. al, 2005). Supply chain management literature presents insights into the design and management of particular relationships between various actors or stages in the chain and provides a framework within which to address the issue of coordination in a wider context.

This study advances the present body of knowledge of coordination in hinterland transport in three ways. First, coordination problems in hinterland transport chains are identified on a solid empirical basis. Second, a framework within which to analyse coordination problems and evaluate mechanisms to enhance coordination is presented. This framework is based on insights from institutional economics and distinguishes four mechanisms to enhance coordination: the introduction of incentives, the creation of interfirm alliances, changing the scope of an organization, and collective action. Third, the paper analyses a huge number of coordination arrangements in inland container transport to and from the port of Rotterdam.

On the basis of this analysis, the conditions that influence the effectiveness of mechanisms to enhance coordination are identified.

Coordination problems in hinterland chains

For identify coordination problems in hinterland transport two kinds of sources have been used. First, relevant news items have been collected through scanning reports, studies, and industry magazines and journals. All relevant news items have been stored in a database. Second, expert interviews were conducted with managers in the hinterland transport chain, including terminal managers, managers from transport companies, and representatives of industry organizations. The conversations with these experts led to modifications of the list of coordination problems derived from the analysis of industry magazines. The result is a set of coordination problems in hinterland chains to and from Rotterdam. Before identifying specific coordination problems in the hinterland chain for waterway, railway and road transport, seven general arguments that explain why coordination problems arise are discussed:

- Different business models. As stated by de Langen (2010), firms in port-related transport chains have different interest. For example the core logic of a transport company is on efficient utilization of transport capacity (ships, locomotives, truck, etc.), in contrary to a non-asset based logistics service provider who is interested in optimizing good flows.
- The unequal distribution of the costs and benefits of coordination. If one actor in the chain has to invest (e.g. in ICT systems) while other actors obtain the benefits, coordination may not arise spontaneously. Gain-sharing mechanisms that redistribute benefits may fail owing to high transaction costs and the risk of free-rider behaviour.
- The lack of resources or willingness to invest on the part of at least one firm in the transport chain. Even though all actors may agree that investments (including management involvement) are required to improve coordination, some firms may not be able or willing to take part. This issue is especially relevant for coordination problems involving relatively small firms.
- Strategic considerations. These can also impede coordination. Firms may be reluctant to improve coordination if competitors would also benefit. This situation is likely to arise in a market characterized by fierce competition.
- The lack of a dominant firm. A firm with *supply chain power* will have a major impact on the structure of a transport chain (see e.g. Groothedde, 2005). A lack of *supply chain power* reduces coordination.
- Risk-averse behaviour and a short-term focus of firms in hinterland chains. Firms that expect the process of establishing better coordination through cooperation to be time-consuming and feel that results are uncertain may be reluctant to put any effort into this process. Contractual relations. A lack of contracts between firms in the hinterland chain hinders coordination. For example, there is no contractual relationship between the hinterland transport company and the container stevedore (see figure 3.1, 3.2 and 3.3). Such a

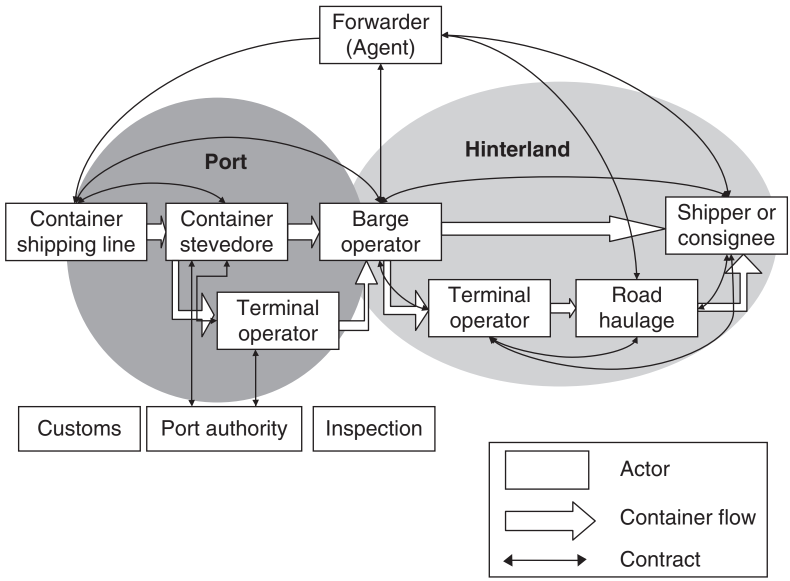

Figure 3.1 Inland shipping hinterland chain

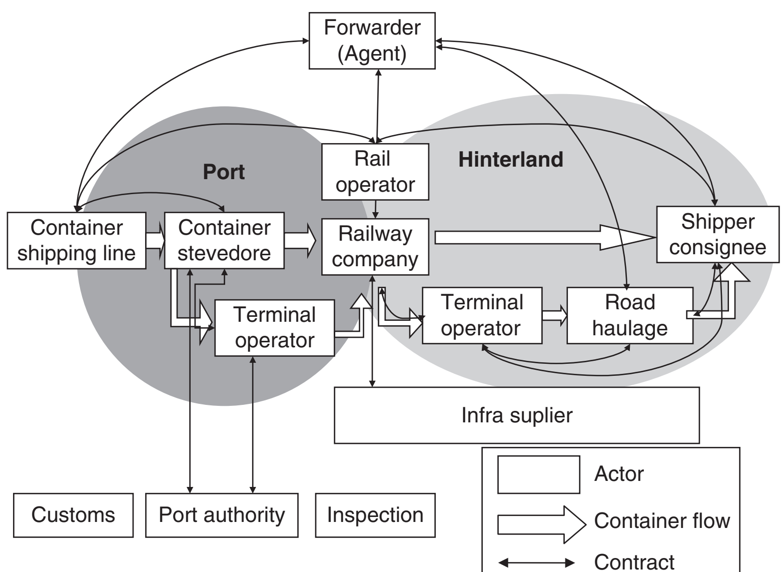

Figure 3.2 Railway hinterland chain

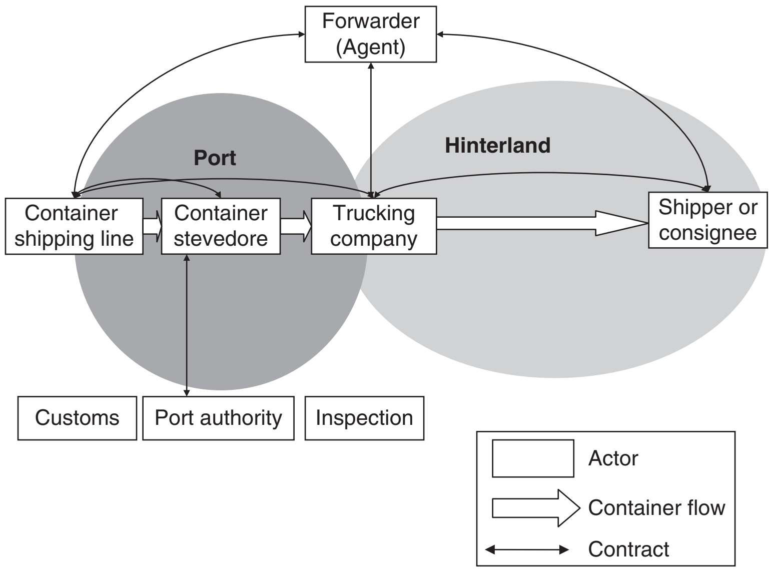

Figure 3.3 Truck hinterland chain

contract would give an incentive to both parties to better match the quay planning of the container stevedore and with the planning of the transport company.

These reasons explain in general why the efforts and investments firms make to improve cooperation and coordination are in some cases limited. Firms often concentrate on internal issues and put less effort into resolving the coordination problems of the chain as a whole. This attitude is more marked if actors expect cooperation to be difficult to achieve. Thus, previous experience in coordination also determines a firm's attitude (Nooteboom, 2004).

Figure 3.1 shows the actors in the hinterland chain and their contractual relationships. Apart from the private actors who provide transport and terminal services, several public actors are involved, such as Customs, a port authority, inspection services, and infrastructure providers. Figure 3.1 shows the many different activities in the hinterland chain that lead to the involvement of a large number of different firms and public organizations.

Table 3.1 shows the main coordination problems in the container barging. The first two are the most important. The long duration of

Table 3.1 Coordination problems in container barging

Coordination problem	Actors involved
Long stay of barges in the port through too many calls and too small call sizes	Barge operator, container terminal operating company, terminal operator in port, forwarder
Insufficient terminal and quay planning with respect to the sailing schedules of both deep-sea vessels and barges	Barge operator, container terminal operating company, terminal operator in port,
Limited exchange of cargo	Barge operator, forwarder

(un)loading cargo in the port, caused by the many calls and the small call sizes per terminal, is a first coordination problem. All barge operators call at a variety of terminals in the port and unload limited numbers of containers per terminal. Better coordination between barge operators could lead to fewer calls in the port. In the port of Rotterdam the average rotation time of a container barge varies from 21 hours (smaller vessels < 85 meter) to 36 hours (larger vessel > 111 meter) The average call size of the eleven container terminals in Rotterdam is 33 containers, but fluctuates largely between 15 and 52 containers (Nextlogic, 2012).

Second, the terminal and quay planning for barge handling is inadequate. Barges cannot be handled as planned frequently. In Rotterdam 59% of the barges are handled outside –2 or +2 hours from the planned starting time (Nextlogic, 2012).

Both coordination problems can be partially explained because barge operators have no contracts with the terminal operating companies (TOCs). TOCs give priority to seagoing vessels. Barges are scheduled after seagoing vessels have been dealt with and any delays affecting seagoing vessels are passed on to the barges. Barge operators try to make an efficient rotation schedule over the various terminals (Moonen et.al, 2005), but have hardly any influence on the terminal planning.

The third coordination problem is the limited exchange of cargo between barge operators. The exchange of cargo can allow barge operators to operate larger vessels, have higher service frequencies, and fewer port calls. This exchange of cargo does not develop spontaneously, because many barge companies firmly wish to remain independent.

The railway hinterland chain (figure 3.2) differs from inland shipping, because of the role of a rail-infrastructure supplier, who has contractual relationships with railway companies. The European rail cargo market has been liberalized, resulting in the separation of infrastructure provision from transport services provision. In the Netherlands, infrastructure

Table 3.2 Coordination problems in container rail transport

Coordination problem	Actors involved
Peak load on terminals; spread of terminal slots is not realized	Container terminal operating company, Rail terminal operator in port, rail terminal operator in hinterland, railway company, infrastructure manager
Unused rail tracks because of insufficient tuning	Railway company, infrastructure manager
Limited planning on rail terminal causes regularly delays	Container terminal operating company, Rail terminal operator in port and hinterland, railway company, infrastructure manager
Limited exchange of traction	Railway company
Limited exchange of rail cargo	Railway operator, forwarder

is provided by ProRail, an independent rail-infrastructure manager. ProRail allocates tracks to railway companies. The most important coordination problems in the Dutch railway market are presented in table 3.2.

The allocation of rail tracks gives rise to coordination problems between ProRail and the railway companies. ProRail allocates train paths on a yearly basis. This method is rigid and is not aligned with the market demand for flexibility in the allocation of railway tracks. More flexible allocation could prevent mismatches and help reduce the shortage of track capacity in the port, but more and better coordination would be required.

Coordination problems also arise on rail terminals in ports. Terminal operators draw up a daily terminal-handling plan with time slots for each train on the terminal. However, because of the lack of contractual relationships between the rail terminal operators and railway companies, the coordination required to achieve a terminal planning that maximizes chain efficiency falls short of requirements.

The exchange of traction (e.g. through a pool of locomotives) would increase efficiency, because the utilization of locomotives could increase substantially. Coordination is particularly required on the last kilometres of the rail track, because of the many small shunting activities that lead to idle time for locomotives. However, the strategic considerations of the railway companies can impede the exchange of traction. This hindrance is partly explained because the local offices of some railway companies do not have the autonomy to take such decisions. The fifth coordination problem is the limited exchange of cargo between railway operators and/or forwarders. This cooperation could generate economies of scale and higher equipment utilization rates, but it does not develop spontaneously.

The truck hinterland chain (figure 3.3) is the 'simplest' hinterland chain. The number of actors is large (there are more than 1000 container truck companies in the Netherlands[1]), but the coordination in the truck chains is relatively straightforward.

Table 3.3 shows the coordination problems in container trucking. The major coordination problem is the peak in the arrivals and departures of trucks at the gate of TOCs. Peak hours are from 6.00 to 9.00 a.m. and 5.00 to 8.00 p.m. These peaks are caused by the truck companies' planning and the warehouses' limited opening hours. The increasing numbers of mega-container vessels of different container lines can aggravate problems during the peak period (Midoro, 2005). In Rotterdam, the road capacity, especially on the main highway (A15), is limited. In the period 1995–2002, the traffic on the A15 grew by 20 percent. Research by Geerlings et al. (2009) shows that congestion is mainly caused by commuters, container transport by truck accounts for 5% of the total traffic on the highway A15. Congestion in rush hours can also be considered a coordination problem.

A third coordination problem is the limited exchange of information between a container TOC, a truck company, and a forwarder. A lack of information exchange leads to an inefficient delivery and pick-up process at the deep-sea terminal. A fourth coordination problem is the limited exchange of cargo and truck capacity between truck companies. The utilization of trucks could increase through exchange, but this does not develop spontaneously.

Table 3.3 Coordination problems in container trucking

Coordination problem	Actors involved
Peak load in arrival and departure of trucks at deep-sea terminal	Container terminal operating company, truck company
Peak load in road transport causes congestion on the road infrastructure in port region area	Truck company, infrastructure supplier
Truck driver's lack of information leads to inadequate pick-up process on terminal	Container terminal operating company, truck company, forwarder
Limited exchange of cargo and truck capacity	Truck company, forwarder

Table 3.4 presents the general coordination problems across these hinterland modes that are relevant on top of the coordination problems in barging, rail transport, and trucking.

The inadequate exchange of information between the container shipping line, the TOC, and the transport companies is a coordination problem. Often, there is a lack of information about the destination of the container, the consignee, and the customs status of the cargo. This lack is especially the case for export containers; almost all the cargo information for import containers is present on the ship's manifest. In contrast, transport companies often have inadequate information about export containers so the planning of the TOC and the shipping line is hampered.

A second general coordination problem is the lack of commitment of cargo-controlling firms to guarantee volumes for newly-developed hinterland services. Introducing a new hinterland service (e.g. a container

Table 3.4 General coordination problems in hinterland chains

Coordination problem	Actors involved
Insufficient information exchange of container data causes inadequate planning	Container shipping line, container terminal operating company, forwarder, truck company, barge operator, rail operator
Investments in hinterland terminals do not come about spontaneously	Forwarder, rail terminal operator hinterland, barge terminal operator in hinterland
Introducing new hinterland services requires a basic volume; however, 'cargo controlling' parties do not commit to new services of other transport providers	Forwarder, shipper, container shipping line
Insufficient planning on transporting and storing empty containers	Container terminal operating company, rail terminal operator in hinterland, barge terminal operator in hinterland, container shipping line
Limited customs declaration physical and administrative inspection causes delay	Forwarder, Customs, truck company, barge operator, rail operator
Limited planning for physical and administrative inspection between Custom and Inspection authorities causes delay	Customs, Inspection services
Insufficient information about Customs clearance of a container	Forwarder, Customs, shipper

rail shuttle) requires a *base volume*. However, shippers, forwarders, and container shipping lines are often unwilling to commit themselves to new services, either through opportunism or concern about benefits for competitors.

The planning of empty containers is a third coordination problem. Coordination between the TOC, hinterland terminals, and container shipping lines could reduce empty movements. Consultants estimate the share of empty containers in hinterland transport at 40 percent of all containers transported (Konings, 2005). These unproductive movements entail high costs.

Finally, coordination problems arise between hinterland transport companies and such organizations as Customs and inspection services, like the veterinarian or nutrition inspection. Insufficient information and poor coordination between the parties causes delay.

In conclusion, the coordination problems described above are relevant in the port of Rotterdam. Consequently, various initiatives have been taken to improve coordination. These initiatives are analysed in the next section.

A framework to analyse mechanisms of coordination in hinterland transport

This section presents a framework for the analysis of coordination problems and the evaluation of mechanisms to enhance coordination. Coordination problems arise when coordination beyond price is required on the one hand, to ensure an efficient transport chain, but is problematic on the other hand, due to opportunism and bounded rationality. Institutional economics provides a framework within which to address such questions as: Why do deep-sea container terminals take up shares in inland terminals? Why does a port authority take the initiative to start a port community (ICT) system? Why does a deep-sea container carrier own a railway company? Why do barge operators share cargo capacity in a joint pool?

In all these cases, coordination beyond price emerges. Such questions were first addressed by Coase (1937 and 1960). He argues that transaction costs with alternative forms of coordination (e.g. within a corporate hierarchy) can be more efficient than coordination through markets. Williamson (1975) expanded Coase´s work, introducing behavioural assumptions to transaction costs economics. Williamson's transaction costs concept is based on two behavioural assumptions: bounded rationality and opportunistic behaviour. While people aim to be rational, their capacity to be so is limited, owing to behavioural uncertainty concerning the intentions and competencies of transaction partners and environmental uncertainty and the conditions that may affect the outcomes of agreements. Secondly, there is a possibility of opportunism, with a self-interest-seeking assumption that makes allowance for guile (Willamson, 1996: 56). Because of bounded rationality and opportunistic behaviour, transaction costs (e.g. the costs of finding a partner, preparing and concluding a contract, monitoring the execution of the agreement) of contracts can be substantial, especially for complex agreements. In the most efficient governance structure, total production and transaction costs are, in the long run, less than in any other governance structure.

These insights are relevant for the analysis of coordination problems (in transport); coordination problems arise when coordination beyond price is required on the one hand, to ensure an efficient transport chain, but problematic, owing to opportunism and bounded rationality on the other hand. Two devices for coordination beyond price are vertical integration and partnerships. Collective action (e.g. of all the firms in an industry) is a third mechanism to enhance coordination (beyond price). Fourth, changing the incentive structure of contracts may help enhance coordination. Thus, four broadly-defined mechanisms to enhance coordination can be identified.

The first mechanism is the introduction of incentives or change of the incentives structure[2]. Incentives can be used to align the interests of individual firms within an efficient overall transport chain. In general,

Table 3.5 Four coordination mechanisms and possible coordination arrangements

Coordination mechanism	**Possible coordination arrangements**
Introduction of incentives	Bonus, penalty, tariff differentiation, warranty, auction of capacity, deposit arrangement, tariff linked with cost drivers
Creation of an interfirm alliance	Subcontracting, project-specific contract, standardized procedures, standards for quality and service, formalized procedures, offering a joint product, joint capacity pool
Changing scope	Risk-bearing commitment, vertical integration, introduction of an agent, introduction of a chain manager, introduction of an auctioneer, introduction of a new market
Creating collective action	Public governance by a government or port authority, public-private cooperation, branch association, ICT system for a sector of industry

incentives can be used to internalize the harmful or beneficial effects (externalities) of a firm's decision on other firms. Incentives can have different forms: bonus/penalty systems, differentiated pricing systems (e.g. a discount on tariffs for customers that guarantee the use of a certain amount of container slots on a rail shuttle or pricing structures for peak and off-peak hours), and non-financial rewards (like a fixed window for loading/unloading).

The second mechanism for enhancing coordination is the creation of an interfirm alliance between several actors in the hinterland chain. Incentives might induce firms to act in the interests of other actors in the chain, but could yield high transaction costs. Alliances are arrangements with more commitment between the companies involved. Alliances are a better instrument than incentives, especially in cases where coordination requires investments, but benefits are unclear and uncertain. Alliances include many forms of interfirm cooperation that go beyond market transactions and include vertical alliances between buyer and supplier (subcontracting) and horizontal alliances between competitors (e.g. a joint capacity pool between hinterland transport firms). Furthermore, the term alliance covers a whole range of cooperative agreements, such as licensing and joint ventures (Nooteboom, 1999). An important characteristic of an interfirm alliance is that the actors involved remain to some extent independent.

A further step in Williamson`s framework is changing the scope of the organization. This mechanism includes hierarchical coordination of the chain and vertical integration. The fourth and last mechanism for enhancing coordination is collective action. This mechanism is especially relevant when investments have collective rather than individual benefits. Collective action can be structured through a public organization, a public/private organization or an industry association.

These four mechanisms for enhancing coordination form the starting point for the analysis of coordination arrangements in inland container transport to and from the port of Rotterdam.

Analysing coordination in hinterland transport: an empirical application

This section gives an overview of the arrangements set up to enhance coordination in the hinterland transport chain. The analysis starts with the coordination problems identified in section 2. For each of these, the arrangements to enhance coordination are identified and classified as one of the four mechanisms of coordination discussed above. On the basis of a literature review, the scanning of industry magazines, and expert interviews, 91 coordination arrangements have been identified These include some arrangements that are no longer in place as well as those that are currently implemented[3]. The database specifies the transport mode, the actors involved, relevant coordination problem(s), the coordination mechanism (incentives, interfirm alliance, scope and collective action), type of actors involved (incl. involvement of the port authority), number of actors involved, initiator, power relation of initiator to other actors involved, horizontal/vertical cooperation, and the use of information and communication technology.

The incentive structure is changed in 8 coordination arrangements; 39 can be characterized as interfirm alliances. The changing scope of an organization was found 23 times and collective action 37times. The list of the coordination arrangements and related coordination problems is shown in appendix 1. Appendix 2 shows the links between the coordination problems and examples of coordination arrangements for container railway transport and container trucking. In this section, the arrangements of container barging are discussed in detail. Table 3.6 illustrates the links between coordination problems and some coordination arrangements for container barging.

Twelve coordination arrangements for exchanging cargo were developed: four through collective action and eight through interfirm alliances. These are established to exchange cargo in a joint cargo pool. This arrangement started in the 1980s on the Rhine with the Fahrgemeinschaften. This is an interfirm alliance between various barge operators with a joint sailing schedule combined with a profit pool. The main motive for cooperation is to generate economies of scale. In 2007, only two Fahrgemeinschaften were still active on the Rhine: Fahrgemeinschaft Oberrhein (PENTA Container Line) and URCA Upper Rhine Container Alliance. As Notteboom and Konings (2003) observe, the conditions for cooperation are gradually changing owing to higher market entry barriers, the stabilization of the number of operators, and growing transport volumes. Another cooperative structure is active in the feeder traffic between the port of Rotterdam and Antwerp, namely the Barge Planning Centre. The large number of terminals in both ports creates a need to bundle container flows. There have been several bilateral agreements of barge operators on sharing equipment, but since 2001 almost all operators (CEM, Eurobarge, WCT MTA, and Interfeeder) have joined the Barge Planning Centre. There are two important conditions for establishing interfirm alliances like the Fahrgemeinschaften and Bargeplanning Center. First, the cooperating firms need to have

Table 3.6 Coordination arrangements in container barging

Coordination problem			**Examples of coordination arrangements**
Limited exchange of cargo	**INC**	-	-
	IA	8	Fahrgemeinschaften, Barge Planning Center, Bargelink.com, Teleship
	SCO	-	-
	CA	4	Lumpesammler, AMS barge
Long stay of barges in the port because of many calls and small call sizes	**INC**	3	Fixed 'time window' at a terminal as a bonus
	IA	4	Lumpesammler, MIS COBIVA
	SCO	5	Extended Gate Model stevedore ECT, Barge operator Van Uden starts inland terminal Alphen aan den Rijn, Transferium Alblasserdam
	CA	8	Hinterlink protocol, AMS Barge (crane ship concept)
Insufficient terminal and quay planning with respect to sailing schedule of both deep-sea vessels and barges (will increase crane utilization)	**INC**	2	Pact 1999 between barge operators and container terminal operating company ECT about Quay settlement
	IA	5	Association of Inland Terminal Operators and stevedore ECT cooperate in barge planning platform, MIS CoBiVa
	SCO	4	Extended Gate Model stevedore ECT, investments of Maersk inland terminals
	CA	8	Internet application Barge infolink of Port infolink

complementary capabilities. Second, the transaction costs for establishing and maintaining the capacity pool must be low.

Because of the strong strategic differences, interfirm alliances are a more effective arrangement than complete vertical integration (changing scope). In addition to cooperation in capacity pools, some Dutch barge operators are linked to Internet membership sites where it is possible to exchange freight. Examples include Teleship, and Bargelink.

Three barge operators on the Rhine – CCS, Frankenbach, and Rhinecontainer – jointly operate a 'Lumpesammler'. This ship bundles small amounts of cargo from the three barge operators at several terminals along the Rhine. The Lumpesammler facilitates the exchange of cargo between barge operators and thereby increases a ship's efficiency. Similarly, the barge handling efficiency of TOCs is also increased, because the call sizes of barges are larger. Thus, the concept of cargo exchange in the hinterland resolves not only the (first) coordination problem of limited exchange of cargo, but also the (second) coordination problem concerning the long stay of barges in the port because of the many calls and small call sizes. The Rotterdam port authority has an interest in setting up the Lumpesammler, because a shorter stay in the port by barges increases the quality of the port product as a whole. These collective benefits justify the port authority's involvement. Twenty coordination arrangements address the second coordination problem: barges' long stay in the port. Four arrangements can be categorized as an interfirm alliance; in 5 arrangements, the scope of the organization was changed; 8 coordination arrangements create collective action; in 3 coordination arrangements incentives are introduced. A cooperative arrangement based on the introduction of incentives has been launched in 2005. This includes an agreement between the barge operators and TOCs about guaranteed handle times (time window). Barge operators can 'earn' a window if they meet a set of criteria. This opportunity influences their behaviour. The agreement between barge operators and TOCs about guaranteed time windows to handle barges is part of the Hinterlink protocol, a set of rules between barge operators, container shipping lines, and TOCs. The Hinterlink protocol also includes other agreements, like the Lumpesammler project mentioned above.

An example of collective action is the AMS-Barge project. This new transport concept consists of a container barge equipped with a crane. The concept was developed by the barge operator Mercurius and the port authority of Amsterdam. AMS Barge can provide daily pick-up and delivery container services for companies in the region or connect them to the other transport services and transportation modes.

In three coordination arrangements a container terminal operating company, a barge operator, and a container shipping line changed their scope. First, the Rotterdam container-terminal operating company ECT introduced the *Extended Gate Model* concept. In this, the ECT seeks to extend the gate of its deep-sea terminal to inland terminals by offering both container handling and hinterland transport services to their own hinterland terminals in Venlo, Willebroek and Duisburg. This endeavour leads to *terminal* *haulage*. In the Extended Gate Model, the ECT organizes terminal services and hinterland transport. The hierarchical coordination of the hinterland chain by ECT reduces the length of stay of barges in the port.

Second, the Dutch barge operator Van Uden has extended its scope by setting up an inland terminal in Haaften, Amsterdam, and Alphen aan den Rijn. In 2010, the terminal with an annual capacity of 200.000 TEU/year in Alphen aan den Rijn was opened. The terminal is close to the Heineken brewery, one of the largest shippers of the port of Rotterdam. With the commitment and guarantee of volumes from Heineken for exporting beer, Van Uden was able to establish a regular barge services from/to Rotterdam.

The vertical integration by container stevedores and barge operators in the port hinterland network of Rotterdam can be considered as a good solution. Bundling of containers inside one company or at deep-sea or inland terminals may result in smaller call sizes. Also port authorities can undertake other initiatives to improve the handling of container barges in the port. In the case of the new terminal in Alphen aan den Rijn, the Port of Rotterdam Authority authority enabled the initiative by purchase of the site and lease it to the operator Van Uden. The Port of Rotterdam Authority took also the initiative to invest in a 'container transferium' outside the port area. The goal is to consolidate container transfers between the deep-sea container terminals and the inland terminal with annual capacity of 200,000 TEU in the proximity of the port (Alblasserdam, about 25 kilometer from the port area). Primarily, the terminal serves as (de)consolidation point for containers by truck. The containers will be bundled at the terminal and transferred by barge to the deep-sea terminals (and vice versa), and as a result reduce road congestion on the highway A15. In addition, the transferium can act as decoupling point between container barge operations in the hinterland and in the port. Container barges from the hinterland may call at the transferium, where containers can be exchanged among barge operators in order to reduce the number of terminals and increase the call size.

The third and last coordination problem in container barging is insufficient terminal and quay planning. The coordination of the sailing schedule of deep-sea vessels and barges would increase terminal efficiency. Nineteen coordination arrangements address this problem, mostly through collective action. In 4 arrangements, the scope of the organization was changed. Incentives were found twice and interfirm alliances five times. Coordination arrangements that resolved the previous coordination problem can also be used to improve the terminal and quay planning with respect to the sailing schedule of deep-sea vessels and barges. The incentive structure in the Hinterlink-protocol could also be used to improve the inadequate terminal and quay planning. In addition to agreements between the barge operators and seaport terminal operators about guaranteed time windows, Hinterlink also includes agreements about improving information exchange. An earlier protocol was agreed in 1999 by the Dutch Inland Shipping Association the Central Bureau for Rhine and Inland Shipping (CBRB). Like Hinterlink, this covenant included operational agreements regarding barge handling at ECT terminals. In 2008 five inland barge operators joined forces to develop a Management Information System to support container barging in an interfirm alliance called MIS-CoBiva. The system works with real time information based on GPS. By linking this information (number of containers, location, etc) with the planning from container stevedores and inland terminals planning could take more accurately, and it offers to the possibility to anticipate on possible interruptions somewhere else in the hinterland transport chain. In addition, the organization Portinfolink (in 2009 renamed as PortBase) developed Barge Infolink, an Internet application to verify whether parties are observing the stipulations of the covenant mentioned above. Portinfolink is a public-private partnership between the Rotterdam port authority and the Ports and Industries' association Deltalinqs.

Conclusions

This paper argues for the need to analyse the coordination in hinterland container transport: first, because costs for hinterland transport are generally higher than the maritime transport costs; second, because most bottlenecks of the door-to-door container transport chain, such as congestion, insufficient infrastructure, and problems with handling of barges, trains and trucks at deep-sea terminals, occur in the hinterland network.

This study advances the present body of knowledge of coordination in hinterland transport by identifying the coordination problems in the hinterland chains and proposing a framework within which to analyse these coordination problems. In general, coordination problems in hinterland chains arise because of an imbalance between the costs and benefits of coordination, a lack of willingness to invest, the strategic considerations of the actors involved, and risk-averse behaviour. The relevant general and specific coordination problems in road, rail, and waterway transport have been identified. Coordination problems in road, rail, and waterway transport include the long stay of barges, trains, and trucks in the port region or at the terminal (often in combination with a peak load at the terminal), the limited exchange of cargo and transport capacity, unused and also overused rail and road infrastructure, limited quay and crane planning at the deep-sea terminal, and limited information exchange with Customs and inspection authorities.

After identifying the coordination problems, a framework based on insights from institutional economics for the analysis of coordination problems and evaluation of mechanisms to enhance coordination was presented. This framework features four key mechanisms to enhance coordination: the introduction of incentives, the creation of interfirm alliances, changing the scope, and the creation of collective action. For each coordination problem, arrangements to enhance coordination were identified and classified in one of the four mechanisms of coordination. It was demonstrated that, in the port of Rotterdam, new arrangements are continuously being developed; about 37 collective action arrangements were identified. The associations of transport companies, the port cluster association, and the port authority are active in bringing about collective action; there were 39 forms of interfirm alliance. These arrangements cover a whole range of forms of cooperation between independent firms, through transport capacity pools, freight exchange websites, train shuttles, and so forth. There were 23 *scope arrangements* in which container terminal operating companies, transport companies, terminal operators or container shipping lines changed their scope. Incentives were only introduced in 8 cases; penalty systems, differentiated pricing systems, and non-financial rewards (like a fixed window) are used to influence actors' behaviour.

In conclusion, an important issue in ports is hinterland access. Ports and their hinterland transport systems can only attract and manage additional container volumes if the hinterland transport network is organized efficiently and effectively. The framework for the analysis of coordination problems in a port's hinterland is not conclusive, but provides a solid basis for further research[4]. Additional research is needed to specify more precisely under what conditions a certain coordination mechanism is chosen. The framework proposed deserves further theoretical and empirical testing. Another promising line of research would be to carry out the same analysis in other hinterlands of European ports.

Appendix 1 List With Coordination Arrangements

Abbreviations mechanisms:

INC: introduction of incentives
IA: creation of an interfirm alliance
SCO: changing scope
CA: creating collective action

Coordination arrangement	Hinterland chain	Coordination mechanism
AMS-barge container service	barge	CA
Barge Planning Center	barge	IA
Hessennoordnatie (Antwerp) inland barge terminal in Rotterdam	barge	SCO
River Information Services	barge	CA
Container Transferium Alblasserdam	barge	SCO
Sikzneb	barge	IA
Pact 1999 Central Bureau for Rhine and Inland shipping Association and stevedore quay protocol with procedure rules	barge	INC
Fixed time window as a bonus at terminal of stevedore ECT	barge	INC
Combined Container Services establishment	barge	IA
Rhinecontainer establishment	barge	IA
Hinterlink protocol	barge	CA
Waterslag project	barge	CA
Fahrgemeinschaft Oberrhein, (PENTA Container Line)	barge	IA
Fahrgemeinschaft Niederrhein	barge	IA
Lumpesammler (joint barge to collect and exchange cargo)	barge	CA & IA
Teleship (freight exchange)	barge	IA
www.bargelink.com	barge	IA
www.bargeplanning.nl	barge	CA
B-W@ve	barge	CA
Fixed window bonus (part Hinterlink-protocol)	barge	INC & CA
Freight exchange barging via www.overmeer.com	barge	IA
URCA Upper Rhine Container Alliance	barge	IA
Barge operator Van Uden inland terminal Alphen aan den Rijn, Haaften and Amsterdam	barge	SCO

(*continued*)

Appendix 1 Continued

Coordination arrangement	Hinterland chain	Coordination mechanism
Cooperation 4 Dutch inland terminals	barge	CA
Association of Inland Terminal Operators and stevedore ECT cooperate in barge planning platform	barge	IA
AIT and Penta in joint Rhine service Amsterdam-Basel	barge	IA
AGRO ship	barge	CA
MIS: Cobiva management information system	barge	IA
LIVRA: Information system between Rotterdam and Antwerpen	barge	IA
CARIN Cargo information	barge	INC
Quality Rail Rotterdam	rail	CA
Rail Cargo Information Netherlands	rail	CA
Keyrail	rail	IA
Cooperation between rail terminals Eindhoven and Tilburg	rail	IA
BoxXpress	rail	IA & SCO
Platform rail capacity extension	rail	CA
Cooperation of several branch organizations in Rail Freight Transport	rail	CA
Rail4Chem Benelux BV	rail	SCO
Trailers-on-trains project	rail	CA
Kombiverkehr established Intercontainer Austria shuttle	rail	IA
Kombiverkehr - Optimodal Rotterdam	rail	IA
Rail4Chem drives NYK trains	rail	IA
ROLYS: shuttle to Lyon established by Non Rail Operating Common Carrier Trimodal	rail	IA
Rail Shutte Wenen Linz-Rotterdam	rail	CA & IA
Geest North Sea Line opens rail shuttle Rotterdam-Hamburg	rail	SCO
Raillink	rail	SCO
Raillink Europe	rail	IA
Cooperation railway company ACTP and rail and barge terminal Tilburg	rail	IA
Swiss logistics service project Bertschi opens rail terminal in Rotterdam	rail	SCO
European Railway Shuttle	rail	SCO
Agreement on exchange locomotives and train drivers between 5 Dutch railway companies	rail	IA
User's platform Rail Freight Transport	rail	CA

(*continued*)

Appendix 1 Continued

Coordination arrangement	Hinterland chain	Coordination mechanism
ACTS and Den Hartogh: shuttle Milan with flexible tariff structure	rail	IA
Chain Management Port Rail Track	rail	CA
Inland port network	rail	IA
Tariff system with bonus/penalties for efficient use of rail way and yards.	rail	INC
Public transshipment point outside port regions (de-coupling point)	truck	CA
Cargo Card	truck	INC
W@ve Road planning	truck	CA
www.vrachtuitwisseling.com (freight exchange webiste)	truck	CA & IA
Quality Road Rotterdam	truck	CA
Van Uden Nedcargo and RFM container transport alliance	truck	IA
Pact 1997 stevedore ECT en Ass. Dutch Sea Container Truckers	truck	INC
Alliance Hoekstra and Hoving Transport	truck	IA
One Way Truck: project empty container trips	truck	IA
Ceres-Rijn service established by 2 terminal operators	truck	IA
Road Planning and exclusive 'pre-arrival desk' at terminal	truck	INC
Compensation ECT to truck company in case of waiting times	truck	INC
Containerised plant transport	truck	CA
Truck Load match	truck	IA
Alliance Elst and Timmermans	truck	IA
Alliance Nathan en Melis Transport	truck	IA
Extended Gate Model ECT ('terminal haulage')	barge/rail	SCO
Investment of Maersk in terminals	barge/rail	SCO
Port Infolink (Port Community System)	truck/barge/rail	CA
Rotterdam Representatives in hinterland	truck/barge/rail	CA
Inland terminals of stevedore ECT in Venlo, Duisburg and Willebroek	truck/barge/rail	SCO
Inland Container Terminals Netherlands BV	truck/barge/rail	IA
Land bridge Rotterdam-Rostock	truck/barge/rail	IA
Platform Modal Split - PCR RIL	truck/barge/rail	CA

(*continued*)

Appendix 1 Continued

Coordination arrangement	Hinterland chain	Coordination mechanism
Combi terminal Pernis	truck/barge/rail	SCO
FENEX (forwarders) regular conference with Customs/Inspection	truck/barge/rail	CA
Mobile Custom Scan	truck/barge/rail	CA
Central direction 'verifying containers'	truck/barge/rail	SCO
Custom check at inland terminals (export containers)	truck/barge/rail	CA
Central Electronic Gate ('secure lanes')	truck/barge/rail	CA
Pre-arrival check in warehouses of forwaders	truck/barge/rail	SCO
Lading gate (1 office for scanning en nuclear control)	truck/barge/rail	CA
Authorized Economic Operator = Custom	Truck/barge/rail	SCO

Appendix 2 List With Coordination Arrangements

Coordination arrangements in container rail transport

Coordination problem			Examples of coordination arrangements
Peak load on terminals; spread of terminal slots is not realized	**INC**	1	Tariff system with bonus/penalties for efficient use of rail way and yards.
	IA	3	Cooperation between rail terminals Eindhoven and Tilburg.
	SCO	5	Maersk – inland terminals
	CA	4	Quality Rail Rotterdam
Unused rail tracks because of insufficient tuning	**INC**	1	Tariff system with bonus/penalties for efficient use of rail way and yards.
	IA	1	Keyrail
	SCO	–	–
	CA	4	Platform rail capacity extension
Limited planning on rail terminal causes regularly delays	**INC**	–	–
	IA	2	Cooperation between rail terminals Eindhoven and Tilburg
	SCO	5	Maersk - inland terminals
	CA	4	Pressure Group Rail Freight Transport, Quality Rail Rotterdam, Association of Inland Terminal Operators (VITO)
Limited exchange of traction	**INC**	–	–
	IA	7	Agreement on exchanging locomotives and train drivers between 5 Dutch railway companies

(*continued*)

Appendix 2 Continued

Coordination problem			Examples of coordination arrangements
	SCO	3	Rail4Chem Benelux
	CA	4	Quality Rail Rotterdam
Limited exchange of rail cargo)	**INC**	–	–
	IA	8	ROLYS: shuttle to Lyon established by Non Rail Operating Common Carrier Trimodal
	SCO	3	European Railway Shuttles, Raillink (CMA-CGM)
	CA	6	Cooperation of several branch organizations in Rail Freight Transport

Coordination arrangements in container trucking

Coordination problem			Examples of coordination arrangements
Peak load in arrival and departure of trucks at deep-sea terminal	**INC**	3	Pact 1997 stevedore ECT en Ass. Dutch Sea Container Truckers, Road Planning and exclusive 'pre-arrival desk' at terminal
	IA	–	
	SCO	1	Public transhipment point outside port regions (de-coupling point)
	CA	4	W@ve Roadplanning,
Peak load in road transport causes congestion on the road infrastructure in port region area	**INC**	3	Road Planning and exclusive 'pre-arrival desk' at terminal
	IA	–	
	SCO	1	Public transhipment point outside port regions (de-coupling point)
	CA	4	Quality Road
Truck driver's lack of information leads to insufficient pick up process on terminal	**INC**	3	Cargo card
	IA	–	
	SCO	–	
	CA	2	Road planning, Port Infolink
Limited exchange of cargo and truck capacity (would increase efficiency, but does not develop spontaneously)	**INC**	–	
	IA	4	One Way Truck
	SCO	–	
	CA	5	Dutch Sea Container Transporters Alliance involvement in freight exchange website www.vrachtuit wisseling.com

Notes

1. About 7% of the container truck companies have a truck fleet of more than 50 units (Konings, 2009). The average truck fleet is 5–7 TEU, which is very small in comparison with other transport companies in the hinterland chain.
2. The mechanism is related to the concept of property rights. A primary function of property rights is that of guiding incentives to achieve a greater internalization of externalities (Demsetz, 1967).
3. For the earlier paper -Van der Horst & de Langen (2008) a database with 76 coordination arrangement has been used. The database was updated and extended up to 91 coordination and used for research of Van der Horst & Van der Lugt (2011).
4. Since the publication of this article in 2008, it has been widely cited. (>100 citations in Google Scholar, May 2014). This is mainly because the issue of port hinterlands in general is increasingly analyzed in Port Economics Policy and Management (Pallis et al., 2010). We do not fully analyze the citations to this article and how other authors have extended the findings of this paper, but provide some general remarks. The main argument of this paper, that hinterland access can be fruitfully analyzed as a coordination problem has provided the basis of further research. Van den Berg et al., 2012, provided a detailed analysis of the role of Barcelona Port Authority in the process of developing new intermodal services – as one example of an 'intervention' of a port authority to overcome coordination problems.

   The article has also been instrumental in the re-conceptualisation of the role of the port authority as coordinator (see e.g. Verhoeven, 2010), and the development of inland terminal networks and dry ports (see e.g. Roso and Lumsden, 2010). Finally, the coordination problems in hinterland transport also have been addressed with quantitative approaches, see for instance Douma (2009) and Caris et al (2012).

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4

An Optimization Model for the Inland Repositioning of Empty Containers

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The inland repositioning of empty containers is a crucial problem for shipping companies providing door-to-door transport services to customers. This activity consists of the allocation of heterogeneous fleets of empty containers between inland depots and ports, so that they can be properly positioned in anticipation of future customer requests. This paper describes how shipping companies perform this complex activity and its connections with truck routing problems and the repositioning of empty containers on maritime networks. To address the inland repositioning of empty containers, we propose a time-extended optimization model, whose innovative elements are decision variables and constrains on the so-called flexible leased containers, which can be on-hired and off-hired according to a number of clauses, and substitution options between container types. The experimentation shows that the model is an effective instrument to support the current decision-making process on this issue, because realistic size instances can be solved within time limits imposed by planning operations.

Introduction

Although the main business of shipping companies is maritime transportation, in the competitive environment of freight transportation it

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is not sufficient for them just to have control of their containers on maritime networks. Since customers typically request door-to-door transportation, shipping companies are required to provide transportation services from initial shippers to final recipients. As a result, in order to become successfully involved in the domain of intermodal freight transportation, shipping companies are also required to achieve high levels of performance in the management of their assets also within the domain of inland networks.

Containers are probably the most important assets for maritime shipping companies. Their repositioning is an unavoidable activity, because locations where containers are requested and delivered are not usually the same and directional imbalances in freight flows result in the accumulation of containers in areas where there are few demands for them. Moreover, sometimes imported and exported commodities cannot be moved in the same container type.

Empty container management has received a growing attention in recent years (Braekers et al., 2011). At the operational planning level the literature is concentrated on two topics: the maritime repositioning of empty containers and the routing of trucks (or drayage). The first issue consists of the repositioning of empty containers in maritime networks using the capacity available on vessels (Moon et al., 2010; Song and Dong, 2011). This problem is particularly difficult when uncertain events are explicitly taken into account (Di Francesco et al., 2013). The second issue consists of determining the optimal truck routes, starting and ending at ports, so that customers are served, while satisfying several operating requirements, such as truck capacity constraints and time windows at customer locations. The latter belongs to the class of the Vehicle Routing Problems, where large instances cannot be solved to optimality due to their considerable difficulty (Namboothiri and Erera, 2008; Caris and Janssens, 2009; Xue et al., 2014).

Due to the complexity of both previous issues, the current state of technology does not make possible to develop a single planning model for empty container management at the operational planning level. Moreover, one additional problem needs to be investigated at this level: the inland repositioning of empty containers between inland depots and ports. Indeed, containers also transit through inland depots, because they typically provide lower storage fees than ports. Therefore, empty containers can also be moved from import customers to inland depots and from inland depots to export customers in response to their transportation requests.

Generally speaking, the number of containers returned by import customers and delivered to export customers is different. As a result, import-dominant depots tend to accumulate unnecessary empty containers, whereas export-dominant ones are in short supply. The inland repositioning of empty containers aims at planning how to guarantee enough empty containers in inland depots in order to serve customers, while minimizing a wide array of operating costs. Failure to provide empty containers in inland depots results in the risk of competitors providing containers as requested and, in this highly competitive market, some transportation opportunities may be lost.

The goal of this paper is to describe and model the inland repositioning of empty containers, accounting for the specific characteristics of the problem: the space and time attributes of customer requests, possible substitutions among container types, coordination among inland and maritime repositioning, the relationship with lessors and the management of the so-called flexible leased containers. Unlike company-owned containers, flexible containers can be kept or returned to lessors, taking into account a number of contractual clauses. Moreover, due to recent advances in mathematical programming methods, we aim to evaluate whether realistic size instances of the model can be addressed by a state-of-art solver.

The contributions of this paper are as follows: to shed light on the main repositioning options adopted by shipping companies for empty container repositioning in the context of inland networks, that is transportation, storage, substitutions among different container types and rental opportunities; to propose a new optimization model incorporating decisions on both company-owned and leased containers; to illustrate how the resulting decisions can be exploited to address the maritime repositioning issue; to show that this formulation can be solved exactly within the time constraints imposed by planning operations.

The remainder of the paper is organized as follows. First, we describe which operational planning problems are faced by shipping companies in dealing with empty container management. A brief review of the literature on the inland repositioning of empty containers is presented afterward. Then, we describe the problem of the inland repositioning of empty containers. The following section is dedicated to the description of how we model the problem and to the presentation of the mathematical model. Then, computational tests are performed by a mathematical programming solver. Finally, conclusions are drawn and research perspectives are mentioned.

Challenges in empty container repositioning

Container shipping companies control global maritime networks and operate in inland networks of regional scale to provide door-to-door transportation for their customers, who are divided into two categories: importers and exporters.

Importers need to receive goods to carry out their industrial and commercial activities. Their goods are carried in containers, which are unloaded from vessels at ports and moved to their final destination. The inland distribution of loaded containers to customers can be performed by truck alone or by intermodal services, such as rail and truck or inland navigation and truck. The choice between these options depends on customer requirements: trucking transportation is faster than intermodal services, but is far more expensive over long distances. After the delivery of loaded containers by trucks, a customer can keep a container without any additional charges for the time specified in the contracts with the shipping company. If a customer keeps a container beyond the specified time period, a per diem fee is charged. Importers return empty containers, which must be picked up and moved to inland depots or ports, awaiting future transportation requests.

Exporters must instead ship their goods. They require shipping companies to provide one or more empty containers of a given type, which must be picked up from ports or inland depots and delivered to their location on a specific day. Once containers are loaded, they are shipped to departure ports by trucking transportation or intermodal services.

The direct allocation of empty containers from importers to exporters can be performed only if customers are located close by, they use the same container type and they have compatible time-windows (Jula et al., 2006). Several papers have been recently proposed on the routing of trucks serving importers and exporters by direct allocation (Namboothiri and Erera, 2008; Caris and Janssens, 2009; Xue et al., 2014). However, this is not an exhaustive strategy, indeed, due to directional imbalances in freight flows, the number of importers and exporters in a region is typically different. As a result, many customers cannot be joined in direct allocations and must be served by the closest depot. In this paper we focus on these customers only.

Directional imbalances in freight transportation also result in import dominant regions, where empty containers are in surplus, or export dominant regions, where empty containers are in shortage. To correct this problem, ports play a crucial role. When a surplus takes place in a region, empty containers are moved to ports to be loaded and shipped to export-dominant regions. Therefore, the deficit of empty containers in a region must be met by containers coming from other regions, that is shipping companies need to reposition empty containers between ports. This activity is the so-called maritime repositioning of empty containers, which is performed by vessels navigating well-established routes according to tight schedules (Moon et al., 2010; Song and Dong, 2011; Di Francesco et al., 2013).

Although inland and maritime repositioning are closely connected, they are separately addressed by different departments of shipping companies. These departments often decide independently the movements of empty containers to/from ports and their inventory levels, but optimal decisions from the maritime point of view turn to be suboptimal from the inland perspective. For example, maritime departments are willing to systematically move all empty containers in import-dominant regions from the landside to ports, whereas inland departments would prefer to keep some containers in the landside to serve future exporters (Le, 2003).

In this paper, empty container repositioning is investigated from the point of view of inland departments, while taking into account their maritime counterparts. Our approach includes the transportation of empty containers to/from ports in the inland repositioning problem, but we do not consider in this problem decisions on inventory levels at ports. It should be noted though that some papers on the inland repositioning problem have determined inventory decisions at ports (for instance, Crainic et al., 1993). In that research, authors assume to know how many containers will be available and requested in ports in each period of the planning horizon, but these data are typically imprecise or based on forecasts aimed at realizing efficient repositioning in maritime networks only (Le, 2003).

Our approach is aimed at achieving cost-optimal operations in the inland repositioning of empty containers, and determine the volume of empty flows repositioned to and from ports, to set up surpluses and deficits at ports. The maritime repositioning problem can use this information to determine how many empty containers will be repositioned between ports to meet regional deficits.

Literature review

Although empty container repositioning is typically thought of in terms of the decisions to move these assets from one place to another, daily problems involve a large array of choices such as renting/selling, storing containers and, whenever possible, substituting one container type for another. Given the wide breadth of activities planned by shipping companies, *ad-hoc* decision-making processes seem highly inadequate. As a result, several authors have tackled this problem using Operational Research methods, to enhance the analysis of distribution planning and achieve the best trade-off between operating costs and high quality service. However, existing papers do not capture the wide array of decisions available for shipping companies in dealing with the inland repositioning of empty containers.

Dejax and Crainic (1987) reviewed the early papers on the management of empty flows. They stated that, although this problem has received much attention, insufficient consideration had been given to the development of original models addressing the allocation of empty containers in the context of land distribution systems. They mentioned that few authors have investigated the repositioning of empty containers from surplus ports to shortage ports, using both network and linear programming formulations in a deterministic dynamic environment. Due to continuous advances in efficient algorithms and computer science technology, linear programming models go on to be used even today to solve much more complex models with a reasonable computing effort.

Crainic et al. (1989) discussed the strategic issue of assigning customers to depots in an inland transportation network managed by a maritime shipping company. They proposed an optimization model to minimize the cost of depot opening and empty container transportation.

Crainic et al. (1993) presented a general framework to address the specific characteristics of the empty container allocation problem in the land distribution system of a shipping company. They developed two deterministic dynamic models for the single commodity case and multicommodity variance. Their formulations did not capture the specific opportunities related to the management of the so-called flexible leased containers. No computational result was provided.

Holmberg et al. (1998) investigated the distribution planning of empty cars in a railway transportation system. To reduce the shortcomings of the existing planning process, they proposed a time-extended network optimization model with different car types, assumed to have the same length. Substitution opportunities were not included.

Choong et al. (2002) studied the end-of-horizon effect on the management of empty containers in a land distribution system. They took into account a single container type and, as a result, substitution options were not included. Moreover, company-owned containers were modelled as leased containers, because empty containers could be leased in any time period.

Olivo et al. (2005) proposed a deterministic dynamic optimization model to support empty container repositioning over intermodal networks. Although the authors considered two container types, substitution options were not included. Storage opportunities were allowed at ports only. Finally leased containers were modelled as company-owned containers.

Erera et al. (2005) proposed a deterministic dynamic large-scale optimization model to manage company-owned containers from the point of view of a tank container operator. They took into account both maritime and inland distribution on a continental scale. A single container type was considered and, as a consequence, substitution options were not included. Rental opportunities were not taken into account.

Wang and Wang (2007) implemented an optimization model minimizing transportation costs between ports, inland depots and customers. Storage, substitutions and rental opportunities were not taken into account. Moreover, the number of requests and supplies in ports in each period were taken for granted.

Chang et al. (2008) investigated the effect of substitutions in reducing the cost of empty container distribution in a single period planning horizon. They minimized transportation costs, whereas storage and rental costs were neglected.

Furio et al. (2009) presented an optimization model to deal with the regional level of empty container logistics. Their formulation did not consider substitution options or rental opportunities. Moreover, they used historical data to estimate the number of empty containers to be loaded and unloaded in each port in each period of the planning horizon.

Problem definition

In this section, we describe the main elements and decisions characterizing the inland repositioning of empty containers. Fundamentally, decisions are concerned with where and when logistics operations start and end. These decisions require a large array of information, such as customer requests, available transportation capacities and specific relations to the operating environment (e.g. contractual clauses negotiated with lessors).

Shipping companies serve transportation requests of export customers by allocating empty containers out of their depots. Moreover, empty containers returned by import customers are moved to depots and kept in stock. In this problem setting, the set of depots and the set of customer requests in each period of the planning horizon are known. Each customer is supposed to be served by one inland depot only. As a result, the volumes of empty containers allocated between depots and customers are known and do not represent decisions for this problem.

Therefore, the focus of shipping companies is on the control of a physical network made up of inland depots and ports, as well as transportation links between them. Some depots are used by lessors to provide shipping companies with empty containers. These facilities are linked by rail, inland navigation and truck services. An illustrative network is shown in Figure 4.1. The figure shows three inland depots, represented by circular-shaped nodes, denoted by letters a, b and c. The rhombus-shaped node denoted by letter l indicates a depot where a lessor makes its containers available for the needs of shipping companies. The figure also depicts one port, represented by a square-shaped node and denoted by letter h. All potential links between these facilities are represented by arcs.

The backbone of the inland repositioning system consists of the inland depots. They represent transit facilities for the storage of empty containers (loaded containers are also stored, but this aspect is not addressed in this paper). Empty container stocks are built up in inland

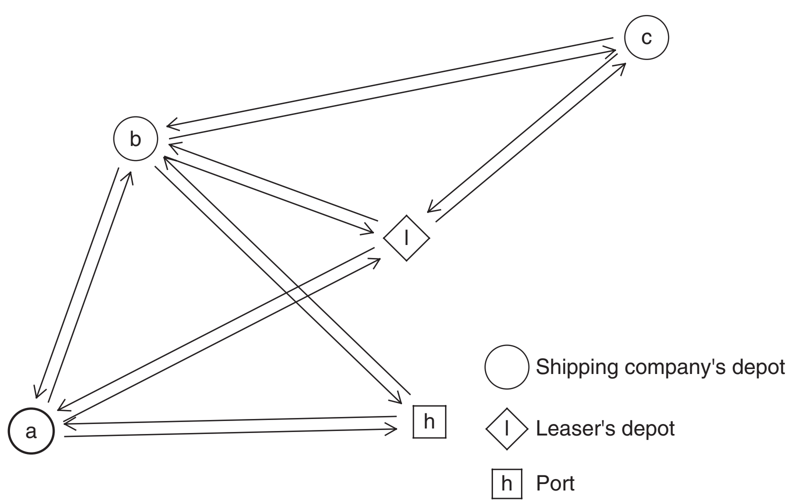

Figure 4.1 Illustrative network with three inland depots, one port and one leaser

depots to put shipping companies in the position of meeting future transportation requests. Empty containers are picked up and returned to depots in order to serve customers. Taking into account their requests, shipping companies must determine the number of empty containers of different types to be stored in inland depots. This number cannot exceed the available capacity for containers, which may come in different types and two main sizes (20 ft and 40 ft).

A number of inland depots are used by lessors to store and provide shipping companies with empty containers. Shipping companies can hire on containers in these depots by paying pick-up fees to meet some transportation requests. Moreover, when flexible containers become unnecessary, shipping companies can return empty containers to the depots of lessors (hire off) by paying drop-off charges. At the operational planning level, one knows the number of lessors working with shipping companies and the locations of their depots. Shipping companies must determine the number of empty containers to be hired on and hired off in the depots of lessors, the time when these containers should be picked up and dropped off and, once they are leased, where they should be shipped.

Ports represent intermodal transit facilities between inland and maritime distribution systems. Empty containers are moved from ports to inland depots, when regional deficits occur, whereas they are hauled in the opposite direction in case of surplus. At the operational planning stage, the set of ports to be considered is fixed, in fact shipping companies know where and when their vessels berth. Shipping companies must decide how many company-owned empty containers of different types must be moved in the different periods of the planning horizon from ports to inland depots and vice versa. It is worth noting that, when these decisions must be made, shipping companies know precisely the number of empty containers available in ports in the first period of the planning horizon. As a result, they cannot ship a number of containers larger than the number of containers available in port in the first period.

In order to introduce transportation decisions between inland depots, we define the demand and supply of empty containers at the depots of shipping companies. In some depots, the number of empty containers requested is larger than the number of available containers. These depots have a deficit of empty containers. We define the empty container demand as the number of empty containers of a given type requested in a given depot at any given time. In other depots the number of company-owned containers returned by customers is larger than the number of requested ones. These depots have a surplus of company-owned containers of different types that become available in different periods of time. We define the supply of company-owned containers as the number of company-owned containers of a given type that become available in a given depot at any given time. They can be assigned to customers to satisfy the demand; stored to meet future requests; or moved to other depots.

Shipping companies can also store leased containers in their own depots to serve transportation requests. Therefore, we define the supply of leased containers as the number of leased containers of a given type that become available in a given depot at any given time. They can be assigned to satisfy the actual demand; stored to meet future requests; returned to their owners; or moved to other depots. Furthermore, empty containers can be hired on and shipped to inland depots to meet at least a part of their demand, wherever this is allowed by rental contracts. These contracts indicate the maximum number of empty containers that can be hired on and hired off per month in a region. Lessors impose drop-off fees when containers are returned by shipping companies. These fees are particularly high in import-dominant regions, where lessors cannot make good business because of the reduced transportation opportunities, and do not want to bear repositioning costs to export-dominant regions. Pick-up fees are applied when containers are leased. These fees are very high in export-dominant regions, where many transportation opportunities need to be served. At this planning stage, one knows the maximum number of containers that can be hired on and hired off per month, as well as pick-up and drop-off fees.

Sometimes, to avoid massive repositioning flows, substitutions can be performed. They consist of serving customers using container types different from the requested ones. Shipping companies can use the supply of company-owned and leased containers to meet the demand for other container types, while paying substitution costs. At the operational planning stage, shipping companies know which container types can be substituted and the relevant substitution costs.

Therefore, time-dependency is a major characteristic of the inland repositioning of empty containers, due to the temporal nature of demand and supply of company-owned and leased containers. Moreover, activities like storage, transportation and inland depot operations naturally start and end in different periods of time. Some decisions are of immediate interest, because they have to be implemented. Nevertheless, a time-extended planning horizon is required to evaluate the impact of current decisions on future system evolution.

However, the opportunity to consider the time-dependent perspective is in conflict with the need to make decisions when there is imperfect knowledge of some problem parameters. Empty container supply is uncertain, because some importers hold containers for several days and it is not *a priori* known when they will become available in inland depots to serve future requests. Moreover, empty container demand is not precise, because unexpected transportation opportunities may arise. What is more, delays and equipment failures represent unexpected events, which may have relevant impacts on empty container repositioning. To estimate uncertain parameters, shipping companies typically collect historical data and build point forecasts.

The modelling structure we propose for the inland repositioning problem is a multi-commodity time-extended network optimization model over a planning horizon, in which every period represents a day. The model must be used in a rolling horizon fashion, i.e. a plan is determined for all the periods of the planning horizon, but only the decisions in the first period of the planning horizon are implemented. Then, in the next period, when new information becomes available, point forecasts must be updated and the model must be run again to implement new decisions.

Mathematical model

In this section, the previous problem is modelled as a deterministic time-extended multi-commodity optimization model. The model considers a finite set D of inland depots, a set H of ports, a set P of container types and a set T of contiguous time-periods. Since contracts with lessors are based on containers leased per month, the planning horizon T is made up of 30 periods, in which each period represents a day. Moreover, let us denote by P_p the subset of P made up of container types different from $p \in P$, which can be used to meet requests of p- type containers. Let also Q_p be the set of container types different from $p \in P$, that can be substituted by p- type containers.

In this paper the number of empty containers returned by importers or requested by exporters is supposed to be known and each customer is served by one depot only. As a result, the flows of empty containers between customers and inland depots are known and the number of empty containers returned or requested by customers can be associated with the inland depots, which are in charge of serving their requests. Therefore, the set of importers and the set of exporters are not defined.

Each inland depot $j \in D$ is represented by three nodes denoted by $j^s_{p,t}$, $j^d_{p,t}$ and $j^r_{p,t}$, where $t \in T$ and $p \in P$. The first node $j^s_{p,t}$ is associated with the number $s^j_{p,t}$ of company-owned empty containers of type $p \in P$, which become available at time $t \in T$ in depot $j \in D$ after the return from importers. The second node $j^d_{p,t}$ is related to the number $d^j_{p,t}$ of empty containers of type $p \in P$, which are required in depot $j \in D$ at time $t \in T$ in order to meet the requests of exporters. The third node $j^r_{p,t}$ is associated with the number $r^j_{p,t}$ of leased empty containers of type $p \in P$, which become available at time $t \in T$ in depot $j \in D$ after the return from importers.

Requests of p- type containers can be served by both company-owned and leased containers. Let us consider a generic depot $j \in D$. Empty containers available in this depot are allocated to transportation requests by arcs from $j^s_{p,t}$ to $j^d_{p,t}$ and from $j^r_{p,t}$ to $j^d_{p,t}$. Therefore, the following decision variables are defined:

- Variable $x(j^s_{p,t}, j^d_{p,t})$ denotes the number of company-owned empty containers of type $p \in P$ allocated in depot $j \in D$ at time $t \in T$ to serve exporters; $c(j^s_{p,t}, j^d_{p,t})$ represents the related cost.
- Variable $x(j^r_{p,t}, j^d_{p,t})$ denotes the number of leased empty containers of type $p \in P$ allocated in depot $j \in D$ at time $t \in T$ to serve exporters; $c(j^r_{p,t}, j^d_{p,t})$ represents the related cost.

Empty containers available in a depot can also be used to meet the demand for another container type. Let us consider a container type $q \in P_p$, which can serve requests of $p \in P$ type containers in depot $j \in D$ at time $t \in T$. To allow the substitution of company-owned containers, we link node $j^s_{q,t}$ to node $j^d_{p,t}$. Substitution of leased containers is performed by arcs linking $j^r_{q,t}$ to $j^d_{p,t}$. Therefore, the following decision variables are defined:

- Variable $x(j^s_{q,t}, j^d_{p,t})$ denotes the number of company-owned empty containers of type $q \in P_p$ allocated in depot $j \in D$ at time $t \in T$ to serve requests of p- type containers; $c(j^s_{q,t}, j^d_{p,t})$ represents the related cost.
- Variable $x(j^r_{q,t}, j^d_{p,t})$ denotes the number of leased empty containers of type $q \in P_p$ allocated in depot $j \in D$ at time $t \in T$ to serve requests of p- type containers; $c(j^r_{q,t}, j^d_{p,t})$ represents the related cost.

Due to the different sizes of containers, the number of containers of type $p \in P$ requested in depot $j \in D$ at time $t \in T$ may be different from the number of containers of type $q \in P_p$, which can be used to meet this demand. To address this problem, each type $q \in P_p$ is converted to type $p \in P$ using a conversion factor $a_{q,p}$. As a result, $a_{q,p}x(j^s_{q,t}, j^d_{p,t})$ and $a_{q,p}x(j^r_{q,t}, j^d_{p,t})$ can be read as numbers of company-owned and leased containers of type $p \in P$.

Since the number of empty containers coming in and out of inland depots is normally not the same, shipping companies can move empty containers from one depot to another. Let us consider two depots $j \in D$ and $k \in D$ and let us denote by τ the number of periods needed to move empty containers between these depots. To transport company-owned and leased empty containers available in depot $j \in D$ at time $t \in T$ to depot $k \in D$, we link the node $j^s_{p,t}$ to $k^s_{p,t+\tau}$ and the node $j^r_{p,t}$ to $k^r_{p,t+\tau}$. Therefore, the following decision variables are defined:

- Variable $x(j^s_{p,t}, k^s_{p,t+\tau})$ denotes the number of company-owned empty containers of type $p \in P$ moved from depot $j \in D$ at time $t \in T$ to depot $k \in D$ at time $t + \tau \in T$; $c(j^s_{p,t}, k^s_{p,t+\tau})$ represents the related unitary cost.
- Variable $x(j^r_{p,t}, k^r_{p,t+\tau})$ denotes the number of leased empty containers of type $p \in P$ moved from depot $j \in D$ at time $t \in T$ to depot $k \in D$ at time $t + \tau \in T$; $c(j^r_{p,t}, k^r_{p,t+\tau})$ represents the related unitary cost.

Since this study considers a heterogeneous fleet of empty containers of different sizes, the transportation capacity from depot $j \in D$ at time $t \in T$ to depot $k \in D$ at time $t + \tau \in T$ must be evaluated with respect to a given container type. In this paper we refer to the largest container type $\bar{p} \in P$ and we denote by $u(j_{\bar{p},t}, k_{\bar{p},t+\tau})$ this transportation capacity. Each type $q \neq \bar{p}$ is converted to type $\bar{p}$ using a conversion factor $a_{q,\bar{p}}$. For instance, if the largest container type is a 40 ft container, the conversion factor is 0.5 for a 20 ft container and 1 for another 40 ft container.

Empty containers can also be stored to meet future transportation requests. To store company-owned and leased empty containers in depot $j \in D$ between time $t \in T$ and $t + 1 \in T$, we link node $j^s_{p,t}$ to $j^s_{p,t+1}$ and $j^r_{p,t}$ to $j^r_{p,t+1}$. Therefore, the following decision variables are defined:

- Variable $x(j^s_{p,t}, j^s_{p,t+1})$ denotes the number of company-owned empty containers of type $p \in P$ kept in stock in depot $j \in D$ at time $t \in T$; $c(j^s_{p,t}, j^s_{p,t+1})$ represents the related storage cost.
- Variable $x(j^r_{p,t}, j^r_{p,t+1})$ denotes the number of leased empty containers of type $p \in P$ stored in depot $j \in D$ at $t \in T$; $c(j^r_{p,t}, j^r_{p,t+1})$ represents the related unitary cost.

Due to the different sizes of containers, the available storage space in depot $j \in D$ at time $t \in T$ is also expressed in terms of the number of containers of the largest type $\bar{p} \in P$ and is denoted by $u(j_{\bar{p},t}, j_{\bar{p},t+1})$. Each type $q \neq \bar{p}$ is converted to type $\bar{p}$ using a conversion factor $a_{q,\bar{p}}$.

Empty containers can be hired on from lessors and returned when shipping companies do not need them any longer. For the sake of simplicity, this study considers a single lessor, which is modelled for a given container type $p \in P$ by the node l_p. Shipping companies can hire on empty containers of type $p \in P$ and move them to depot $j \in D$ at time $t \in T$ by arcs linking l_p to $j^r_{p,t}$. Moreover, shipping companies can return leased containers of type $p \in P$ available in depot $j \in D$ at time $t \in T$ by arcs linking $j^r_{p,t}$ to l_p. Therefore, the following decision variables are defined:

- Variable $x(j^r_{p,t}, l_p)$ denotes the number of leased empty containers of type $p \in P$ shipped from depot $j \in D$ at time $t \in T$ to the lessor's depot, in order to be returned; $c(j^r_{p,t}, l_p)$ represents the related drop-off cost.
- Variable $x(l_p, j^r_{p,t})$ denotes the number of leased empty containers of type $p \in P$ hired on from the lessor and shipped to depot $j \in D$, where they arrive at time $t \in T$; $c(l_p, j^r_{p,t})$ represents the related pick-up cost.

Furthermore, according to rental contracts, there is an upper bound on the number of containers that can be hired on and hired off in a month in the depots. We denote by $u^{on}_{p,D,T}$ the maximum number of containers of type $p \in P$ that can be leased to serve the set D of depots in the monthly planning horizon T. In addition, let $u^{off}_{p,D,T}$ be the maximum number of containers of type $p \in P$ that can be off-hired from the set D of depots in the monthly planning horizon T.

A set H of ports is considered to provide inland depots with empty containers when deficits of these assets occur on the landside, or to receive empty containers when there is a surplus in the region. Each port $h \in H$ is modelled for a given container type $p \in P$ and time $t \in T$ by a node denoted by $h_{p,t}$. To allocate company-owned containers of type $p \in P$ available in port $h \in H$ at time $t \in T$ to inland depot $j \in D$ at time $t + \tau \in T$, we link node $h_{p,t}$ to node $j^s_{p,t+\tau}$. To reposition company-owned containers from the inland depot $j \in D$ at time $t \in T$ to port $h \in H$ at time $t + \tau \in T$, we link $j^s_{p,t}$ to $h_{p,t+\tau}$. Therefore, the following decision variables are defined:

- Variable $x(j^s_{p,t}, h_{p,t+\tau})$ denotes the number of company-owned empty containers of type $p \in P$ moved from depot $j \in D$ at time $t \in T$ to port $h \in H$ at time $t + \tau \in T$; $c(j^s_{p,t}, h_{p,t+\tau})$ represents the related transportation cost.
- Variable $x(h_{p,t}, j^s_{p,t+\tau})$ denotes the number of company-owned empty containers of type $p \in P$ moved from port $h \in H$ at time $t \in T$ to depot $j \in D$ at time $t + \tau \in T$; $c(h_{p,t}, j^s_{p,t+\tau})$ represents the related transportation cost.

Due to the different sizes of containers, the transportation capacity from depot $j \in D$ at time $t \in T$ to port $h \in H$ at time $t + \tau \in T$ is expressed in terms of the number of containers of the largest type $\bar{p} \in P$. This capacity is denoted by $u(j_{\bar{p},t}, h_{\bar{p},t+\tau})$. Each type $q \neq \bar{p}$ is converted to type $\bar{p}$ using a conversion factor $a_{q,\bar{p}}$. We also denote by $u(h_{\bar{p},t}, j_{\bar{p},t+\tau})$ the transportation capacity from port $h \in H$ at time $t \in T$ to depot $j \in D$ at time $t + \tau \in T$ with respect to the largest container type $\bar{p} \in P$.

Moving, storing, substituting and leasing containers may not be sufficient to meet the total demand. Therefore an additional variable is defined:

- Variable $x(j^d_{p,t})$ represents the shortage of empty containers of type $p \in P$ in depot $j \in D$ at time $t \in T$; $c(j^d_{p,t})$ is the related unitary cost.

To clarify system dynamics, Figure 4.2 shows a time-extended network made up of three depots, denoted by letters *a*, *b* and *c*; one port, denoted by letter *h*; and one lessor denoted by letter *l*. The depots and the port are replicated in the three periods of the planning horizon for the two container types, denoted by letters *p* and *q*. In Figure 4.2, *p*- type containers can substitute *q*- type containers, whereas the reverse substitution is not allowed.

Figure 4.2 also shows present decisions that are made immediately by continuous black lines, past decisions by continuous grey lines, and future decisions by discontinuous black lines. Since the model is to be used in a rolling horizon fashion, present decisions are represented by arcs leaving from nodes in period 1.

Let us now switch to the mathematical formulation. Company-owned containers available in a depot in a period can be assigned to transportation requests of the same type or used for substitutions. Moreover, they can be kept in stock or moved to ports or other depots. So, we have:

$$
\begin{aligned}
& x\left(j^s_{p,t}, j^d_{p,t}\right) + \sum_{q \in Q_p} x\left(j^s_{p,t}, j^d_{q,t}\right) + \sum_{k \in D}\left[x\left(j^s_{p,t}, k^s_{p,t+\tau}\right) - x\left(k^s_{p,t-\tau}, j^s_{p,t}\right)\right] \\
& + x\left(j^s_{p,t}, j^s_{p,t+\mathbf{1}}\right) - x\left(j^s_{p,t-\mathbf{1}}, j^s_{p,t}\right) \qquad (1) \\
& + \sum_{h \in H}\left[x\left(j^s_{p,t}, h_{p,t+\tau}\right) - x\left(h^s_{p,t-\tau}, j_{p,t}\right)\right] = s^j_{p,t} \qquad \forall j^s_{p,t} \in D, \forall p \in P, \forall t \in T
\end{aligned}
$$

The first term on the left hand side of equation 1 represents the assignment of the supply of company-owned containers of type $p \in P$ to the demand. The second term is the sum of the substitutions of

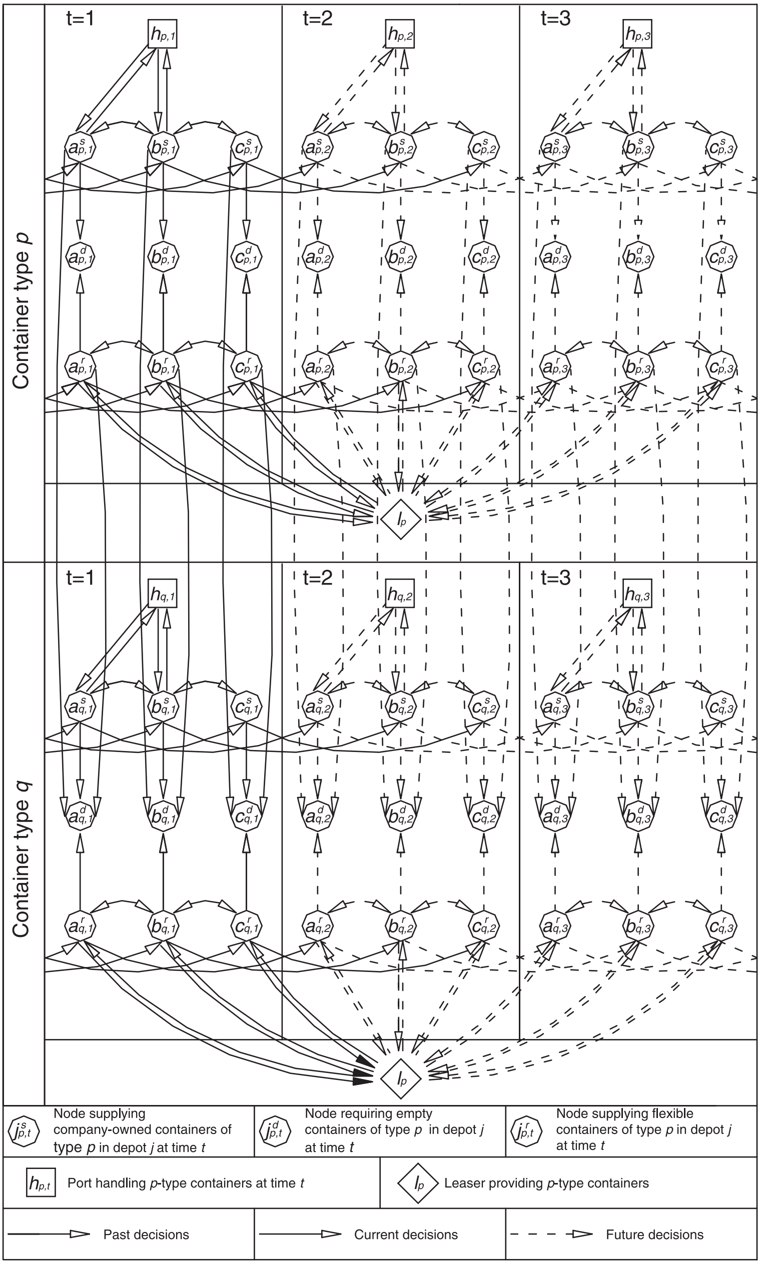

Figure 4.2 A time-extended network with company-owned and rented containers of two types

company-owned containers different from type $p \in P$ with p- type ones. The third term denotes the sum of all company-owned containers moved from depot $j \in D$ to depot $k \in D$ and vice versa. The forth and fifth terms are the inventory levels of company-owned containers of type $p \in P$ in depot $j \in D$ at time $t \in T$ and $t-1 \in T$. The sixth term is the sum of the number of company-owned containers moved from depots to ports and vice versa. The term in the RHS of the equation is the supply of company-owned containers of type $p \in P$ in depot $j \in D$ at time $t \in T$.

The demand for empty containers in a depot in a period can be met by company-owned and leased containers available in this depot, by substitutions of company-owned and leased containers. So, we have:

$$x\left(j^s_{p,t}, j^d_{p,t}\right) + x\left(j^r_{p,t}, j^d_{p,t}\right) + \sum_{q \in P_p} a_{q,p} x\left(j^s_{q,t}, j^d_{q,t}\right) + \sum_{q \in P_p} a_{q,p} x\left(j^r_{q,t}, j^d_{q,t}\right) + x\left(j^d_{p,t}\right) = d^j_{p,t} \quad \forall j^d_{p,t} \in D, \forall p \in P, \forall t \in T \tag{2}$$

The first and second terms of equation 2 represent the assignment to the demand of the supply of company-owned and leased containers, respectively. The third and fourth terms denote the substitution of company-owned and leased containers of p- type with container types different from $p \in P$. The fifth term is the shortage of empty containers in depot $j \in D$ at time $t \in T$. The term in the RHS of eq. 2 is the demand of empty containers of type $p \in P$ in depot $j \in D$ at time $t \in T$.

Leased containers of a given type, available in a depot in a period, can be assigned to transportation requests of the same type or different types, moved to other depots or stored. They can also be off-hired and on-hired, according to rental contracts. So, we have:

$$\begin{aligned} & x\left(j^r_{p,t}, j^d_{p,t}\right) + \sum_{q \in Q_p} x\left(j^r_{p,t}, j^d_{q,t}\right) + \sum_{k \in D} \left[x\left(j^r_{p,t}, k^r_{p,t+\tau}\right) - x\left(k^r_{p,t-\tau}, j^r_{p,t}\right) \right] \\ & + x\left(j^r_{p,t}, j^r_{p,t+1}\right) - x\left(j^r_{p,t-1}, j^r_{p,t}\right) \\ & + x\left(l_p, j^r_{p,t}\right) - x\left(j^r_{p,t}, l_p\right) = r^j_{p,t} \qquad \forall j^r_{p,t} \in D, \forall p \in P, \forall t \in T \end{aligned} \tag{3}$$

The first term of eq. 3 represents the number of leased containers of type $p \in P$ assigned to the demand; the second term is the sum of the substitutions of leased containers, different from type $p \in P$, with p- type ones; the third term denotes the sum of all leased containers moved from depot $j \in D$ to depot $k \in D$ and vice versa; the forth and fifth terms are the inventory levels of leased containers of type $p \in P$ in depot $j \in D$ at time $t \in T$ and $t - 1 \in T$; the sixth and seventh terms are the number of leased containers moved from depots to the lessor and vice versa. The term in the RHS is the supply of leased containers of type $p \in P$ in depot $j \in D$ at time $t \in T$.

Shipping companies cannot hire on a number of empty containers larger than the amount indicated in rental contracts. Hence, we have:

$$\sum_{t \in T} \sum_{j^r_{p,t} \in D} x\left(l_p, j^r_{p,t}\right) \leq u^{on}_{p,D,T} \qquad \forall p \in P \tag{4}$$

Moreover, in a given month, they cannot hire off a number of empty containers larger than the amount indicated in rental contracts. So, we have:

$$\sum_{t \in T} \sum_{j^r_{p,t} \in D} x\left(j^r_{p,t}, l_p\right) \leq u^{off}_{p,D,T} \qquad \forall p \in P \tag{5}$$

Transportation capacities must be considered, in order to limit the number of company-owned and leased containers that can be moved between inland depots:

$$\begin{aligned} & x\left(j^s_{\bar{p},t}, k^s_{\bar{p},t+\tau}\right) + x\left(j^r_{\bar{p},t}, k^r_{\bar{p},t+\tau}\right) + \sum_{q \in P \mid q \neq \bar{p}} a_{q,\bar{p}} x\left(j^s_{q,t}, k^s_{q,t+\tau}\right) \\ & + \sum_{q \in P \mid q \neq \bar{p}} a_{q,\bar{p}} x\left(j^r_{q,t}, k^r_{q,t+\tau}\right) \leq u\left(j_{\bar{p},t}, k_{\bar{p},t+\tau}\right) \qquad \forall j,k \in D, \bar{p} \in P, \forall t \in T \end{aligned} \tag{6}$$

The first and second term of relationship 6 represent the number of company-owned and leased containers of type $\bar{p} \in P$ moved from depot $j \in D$ at time $t \in T$ to depot $k \in D$ at time $t + \tau \in T$. The third and fourth terms denote the number of company-owned and leased containers of type different from $\bar{p} \in P$ moved from depot $j \in D$ at time $t \in T$ to depot $k \in D$ at time $t + \tau \in T$. The term in the RHS is the transportation capacity between $j \in D$ and $k \in D$.

Transportation capacity constraints must also be considered, to limit the number of company-owned containers moved from depots to ports and vice-versa:

$$\begin{aligned} & x\left(j^s_{\bar{p},t}, h_{\bar{p},t+\tau}\right) + \sum_{q \in P \mid q \neq \bar{p}} a_{q,\bar{p}} x\left(j^s_{q,t}, h_{q,t+\tau}\right) \leq u\left(j_{\bar{p},t}, h_{\bar{p},t+\tau}\right) \\ & \qquad \forall j \in D, \forall h \in H, \bar{p} \in P, \forall t \in T \end{aligned} \tag{7}$$

$$x\left(h_{\bar{p},t}, j^{s}_{\bar{p},t+\tau}\right) + \sum_{q \in P | q \neq \bar{p}} a_{q,\bar{p}} x\left(h_{q,t}, j^{s}_{q,t+\tau}\right) \leq u\left(h_{\bar{p},t}, j^{s}_{\bar{p},t+\tau}\right) \quad \forall j \in D, \forall h \in H, \bar{p} \in P, \forall t \in T \tag{8}$$

Moreover, shipping companies cannot ship on the landside a number of containers larger than the stock available in port at the beginning of the planning horizon, when t takes the value of 1. If we denote by $s^{h}_{p,1}$ the number of empty containers of type $p \in P$ available in port $h \in H$ at time $t = 1 \in T$, this constraint can be expressed as follows:

$$\sum_{j \in} x\left(h_{p,\mathbf{1}}, j^{s}_{p,\mathbf{1}+\tau}\right) \leq s^{h}_{p,\mathbf{1}} \quad \forall h \in H, \forall p \in P \tag{9}$$

The number of empty containers stored in each depot must not exceed the available storage space, expressed by the number of containers of the largest type $\bar{p} \in P$. So, we have:

$$\begin{aligned} & x\left(j^{s}_{\bar{p},t}, j^{s}_{\bar{p},t+\mathbf{1}}\right) + x\left(j^{r}_{\bar{p},t}, j^{r}_{\bar{p},t+\mathbf{1}}\right) + \sum_{q \in P | q \neq \bar{p}} a_{q,\bar{p}} x\left(j^{s}_{q,t}, j^{s}_{q,t+\mathbf{1}}\right) \\ & + \sum_{q \in P | q \neq \bar{p}} a_{q,\bar{p}} x\left(j^{r}_{q,t}, j^{r}_{q,t+\mathbf{1}}\right) \leq u\left(j_{\bar{p},t}, j_{\bar{p},t+\mathbf{1}}\right) \\ & \forall j \in D, \bar{p} \in P, \forall t \in T \end{aligned} \tag{10}$$

The first and second term of expression 10 represent the number of company-owned and leased containers of type $\bar{p} \in P$ in stock in depot $j \in D$ between time $t \in T$ and $t + 1 \in T$. The third and fourth terms denote the number of company-owned and leased containers of type different from $\bar{p} \in P$ in stock in depot $j \in D$ between time $t \in T$ and $t + 1 \in T$. The term in the RHS is the storage capacity of depot $j \in D$.

Finally, we minimize shortage, transportation, storage, substitution, on-hiring and off-hiring costs by:

$$\begin{aligned} \min \sum_{t \in T} \sum_{p \in P} \Bigg\{ & \sum_{j^{d}_{p,t} \in D} c\left(j^{d}_{p,t}\right) x\left(j^{d}_{p,t}\right) + \Bigg[\sum_{j^{s}_{p,t} \in D} \Bigg(\sum_{k^{s}_{p,t} \in D} c\left(j^{s}_{p,t}, k^{s}_{p,t+\tau}\right) x\left(j^{s}_{p,t}, k^{s}_{p,t+\tau}\right) + \\ & + \sum_{h \in H} c\left(j^{s}_{p,t}, h_{p,t+\tau}\right) x\left(j^{s}_{p,t}, h_{p,t+\tau}\right) + \\ & + c\left(j^{s}_{p,t}, j^{s}_{p,t+\mathbf{1}}\right) x\left(j^{s}_{p,t}, j^{s}_{p,t+\mathbf{1}}\right) + c\left(j^{s}_{p,t}, j^{d}_{p,t}\right) x\left(j^{s}_{p,t}, j^{d}_{p,t}\right) + \sum_{q \in Q_p} c\left(j^{s}_{p,t}, j^{d}_{q,t}\right) x\left(j^{s}_{p,t}, j^{d}_{q,t}\right) \Bigg) \Bigg] + \\ & + \sum_{h \in H} \sum_{j^{s}_{p,t} \in D} c\left(h_{p,t}, j^{s}_{p,t+\tau}\right) x\left(h_{p,t}, j^{s}_{p,t+\tau}\right) + \Bigg[\sum_{j^{s}_{p,t} \in D} \Bigg(\sum_{k^{s}_{p,t} \in D} c\left(j^{s}_{p,t}, k^{s}_{p,t+\tau}\right) x\left(j^{s}_{p,t}, k^{s}_{p,t+\tau}\right) + \\ & + c\left(j^{r}_{p,t}, j^{r}_{p,t+\mathbf{1}}\right) x\left(j^{r}_{p,t}, j^{r}_{p,t+\mathbf{1}}\right) + c\left(j^{r}_{p,t}, j^{d}_{p,t}\right) x\left(j^{r}_{p,t}, j^{d}_{p,t}\right) + c\left(j^{r}_{p,t}, l_{p}\right) x\left(j^{r}_{p,t}, l_{p}\right) + c\left(l_{p}, j^{r}_{p,t}\right) x\left(l_{p}, j^{r}_{p,t}\right) + \\ & + \sum_{q \in Q_p} c\left(j^{r}_{p,t}, j^{d}_{q,t}\right) x\left(j^{r}_{p,t}, j^{d}_{q,t}\right) \Bigg) \Bigg] \Bigg\} \end{aligned} \tag{11}$$

The objective function 11 contains all variables and costs defined above. All variables are requested to be integer.

It is worth noting that this model does not present flow conservation constraints associated with ports. This characteristic helps remove inefficiencies and illogicalities arising in regional networks. For example, in import-dominant regions empty containers returned by importers are typically moved to ports and, when new transportation opportunities arise, they are hauled back to exporters in the landside (Le, 2003). These back-and-forth movements generate inefficiencies, such as congestion and environmental impacts (Jula et al., 2006). Our model prevents empty containers from being moved to ports if transportation opportunities are expected to arise in the landside. If demands at ports were taken into account, the number of empty containers available for customers in the hinterland would be reduced and some transportation opportunities would be lost.

Finally, we must point out that the model does not assume that ports have enough capacity to handle any container flows to achieve cost-optimal operations in the landside. For example, in import dominant regions there may be congested ports, unable to absorb additional empty containers from the landside. One way to deal with this issue in this model is to set transportation capacities from inland depots to ports according to their ability to receive containers.

Since all constraints in this linear model reduce to flow conservation and capacity constraints, efficient optimization algorithms can be adopted to solve the problem.

Experimentation

A major requirement of inland repositioning is the need to make decisions rapidly. Typically, when no decision support system is adopted, this planning phase is a time-consuming activity for shipping companies, due to the large inland networks under their control. It takes several hours, because storage, inter-depot balancing flows, substitution options, on-hire and off-hire opportunities form a wide array of decisions to be made.

What is more, the decision-making process is particularly awkward in this issue, because information at hand can change suddenly. For instance, due to last-minute bookings of very important customers, some depots may face a container shortage and might not be able to satisfy their requests. As a result, decisions made before that moment must be changed. Therefore, it would be highly beneficial for shipping companies to determine repositioning plans in a short time, when no new information is expected to turn up.

In this section, we aim to show that realistically sized instances of the proposed model can be solved within time limits imposed by planning operations. Therefore, we consider a realistic network made up of 15 inland depots, 1 lessor and 2 ports. We consider a planning horizon made up of 30 periods and 14 container types as shown in Table 4.1. Since storage capacity is expressed in terms of 40 ft containers, Table 4.1 shows conversion factors between container types. Moreover, Table 4.1 indicates which substitutions are allowed.

To generate demand and supply values for each period, depot and container type, several customer requests are randomly generated. Each

Table 4.1 Container types: conversion factors and substitution options

Container type	**Conversion factors**	**Substitutions**
40 ft high cube	$a_{q,p} = 1$	No substitution for this container type
40 ft general purpose	$a_{q,p} = 1$	It can be replaced by a 40 ft high cube container
20 ft general purpose for heavy goods	$a_{q,p} = 0.5$	No substitution for this container type
20 ft general purpose	$a_{q,p} = 0.5$	It can be replaced by a 20 ft container for heavy goods
40 ft flat	$a_{q,p} = 1$	No substitution for this container type
40 ft open top	$a_{q,p} = 1$	It can be replaced by a 40 ft flat container
20 ft flat	$a_{q,p} = 0.5$	No substitution for this container type
20 ft open top	$a_{q,p} = 0.5$	It can be replaced by a 20 ft flat container
20ft refrigerated	$a_{q,p} = 0.5$	No substitution for this container type
40ft refrigerated	$a_{q,p} = 1$	No substitution for this container type
20ft ventilated	$a_{q,p} = 0.5$	No substitution for this container type
20ft tank	$a_{q,p} = 0.5$	No substitution for this container type
40ft tank	$a_{q,p} = 1$	No substitution for this container type
20ft open side	$a_{q,p} = 0.5$	No substitution for this container type

request consists of a number of loaded containers of a given container type, which must be shipped from a port to an importer or from an exporter to the port. The container type of each request is randomly generated from those of Table 4.1. The number of containers in a request is randomly generated by a uniform distribution from 1 to 3. For each importer request, we generate, by a uniform distribution over 50 periods, the time in which empty containers become available in the associated depot. Similarly, for each exporter request, we generate, by a uniform distribution over 50 periods, the time in which empty containers must be picked-up from the related depot. Aggregating across all transportation requests, the values of demand and supply are calculated for each depot, each container type and each period. To reduce beginning and end effects caused by this generation of demands and supplies, the 50 period planning horizon is truncated: the first 10- and the final 10 periods are eliminated, resulting in the final 30 period planning horizon.

We solve instances by Cplex 11.1, running on a 2 CPU Xeon processor E5450 3.00 Ghz 1.333 Mhz, RAM 16 Gb. Cplex is a commercial programming engine for mathematical optimization problems. It employs state-of-the-art algorithms and techniques to solve mixed integer programming problems. It includes a pre-solve algorithm for problem size reduction, sophisticated branching and cutting-plane strategies and feasibility heuristics.

Computational tests are shown in Table 4.2. The columns indicate, for every instance, the number of container types, the number of decision variables and the time spent by Cplex to optimally solve every instance.

Table 4.2 shows that Cplex exhibits excellent performance in terms of user waiting time. In all cases, it took only a few seconds to instantiate

Table 4.2 Instances solved by Cplex

Instance	**Number of container types**	**Number of variables**	**Time for Cplex (s)**
P1	2	18948	0.23
P2	4	37938	0.59
P3	6	56928	1.07
P4	8	75918	1.53
P5	10	94908	3.72
P6	12	113898	3.79
P7	14	132888	5.17

and optimally solve each instance. This interval of time is suitable for the needs of shipping companies. If they can determine repositioning plans in a short time, significant savings can be achieved in the workload, vis à vis manually determined repositioning plans. Moreover, shipping companies will be in a position to accept last-minute bookings or changes in customer requests, because they would be capable of promptly determining high-quality decisions in a short time. As a result, empty containers could be effectively repositioned and shipping companies could operate profitably in their highly competitive industry. To conclude, these tests show that the model presented here represents a promising decision support tool for shipping companies in dealing with the inland repositioning of empty containers.

Conclusions and future research

In this paper, we have investigated the inland repositioning of empty containers managed by shipping companies that provide intermodal transportation services. We have illustrated the possible options that can be adopted to address this problem: inventory, transportation and substitutions of company-owned and leased containers. Although inventory and transportation are common in the related literature, this is not the case of substitutions, which are usual practices in several shipping companies for specific pairs of container types.

A new optimization model is presented for this problem. Some constraints are introduced to consider storage spaces and transportation capacities for a heterogeneous fleet of empty containers. The model provides shipping companies with generality in the selection of which pairs of container types are involved in substitutions. The proposed model can determine when and where containers should be hired on and hired off, taking into account clauses imposed by rental contracts. What is more, the model determines the flows of empty containers shipped to and from ports such that cost-optimal operations are achieved in the landside. Such flows will be used to set demand and supply values at ports to address the maritime repositioning issue. Although the model is quite complex, particularly due to substitution mechanisms, it can be quickly solved to optimality by a state-of-art solver within suitable times for the needs of shipping companies.

Due to the fast solution times, a relevant research perspective is to join inland and maritime networks in a deterministic environment and compare global operating systems to separated structures with inland and maritime components.

Moreover, we aim to consider explicitly the uncertain nature of some problem parameters, such as future supplies and demands of empty containers at inland depots. The uncertainty of problem parameters could be faced by stochastic programming approaches. Different scenarios will be generated to represent possible system futures linked by non-anticipative conditions. Since scenarios blow up significantly problem dimensions, standard solvers may be no longer adequate to solve these instances. Therefore, we also aim to develop specialized resolution techniques based on decomposition methods exploiting the inner algebraic structures of stochastic models. Finally, a comparison between Stochastic Programming approaches and Adjustable Robust Optimization methods (Erera et al., 2009) will be investigated.

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5

The ISPS Code and the Cost of Port Compliance: An Initial Logistics and Supply Chain Framework for Port Security Assessment and Management

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Following a description of ISPS and non-ISPS security initiatives, the main risk factors and security threats to ports are identified and analysed, with a focus on the risks stemming from non-tangible assets, flows and processes. Similarly, the various economic approaches to risk management and cost control in shipping are reviewed, and their shortcomings highlighted from the perspective of port logistics and supply chain security. By adopting a channel orientation to ports, the paper suggests that the subject of port security must shift from the current agenda of port-facility security to the wider context of port supply chain security, with a view to ensuring superior security standards and practices in ports and across their supply chain networks. Based on the rationale of logistics integration and supply chain partnership, a conceptual framework to port security is proposed through integrating and optimising three initial models relating, respectively, to channel design and process mapping, risk assessment and management, and cost control and performance monitoring.

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Introduction

The 1st of July 2004 was the big deadline when the international shipping community had to comply with the International Ship and Port Facility Security (ISPS) code, a set of security measures and procedures that have been drafted and developed by the IMO in the awake of the 11th of September 2001 terrorist attacks in the USA. The ISPS code is the most important global security initiative ever, with impacts affecting the entire international shipping industry and beyond. The implementation of the code will test the ability, reliability and liability of active members across the logistics and supply chain system (shippers, carriers, ports, freight forwarders, NVOCCs, logistics providers, etc), but also external members such as governments, insurance companies (both Hull and Machinery (H&M) insurers and Protection and Indemnity (P&I) underwriters), and maritime education and training (MET) institutions to meet security requirements while ensuring efficient and cost-effective movements of goods, cargo and other associated flows and processes. The immediate challenge to the shipping community is how to finance the costs of the ISPS implementation, incorporate and adjust them to pricing and marketing strategies while maintaining their market shares and achieving reasonable profit margins. The long-term challenge involves adjusting relations with suppliers and customers so as to ensure agile and competitive supply chains capable of overcoming risk and vulnerability threats while still delivering value to ultimate customers and users.

Ports are complex and multipart organisations in which institutions and functions often intersect at various levels. It is very important to recognise this strategic role of ports because although security measures have targeted a variety of entities and facilities across the international shipping and logistics community, ports stand as the only node/link that can bring together all these institutions, functions, assets, processes and flow-type elements. Thus, the scope and dimensions of port security go beyond the IMO agenda of facility security to include the wider framework of logistics and supply chain security.

Moreover, as the new security provisions start being widely accepted and implemented, a corresponding framework of security assessment and risk analysis need to be developed, tested, and successfully managed. The current legal framework does not provide an integrated approach to port security, since there is no provision for operational or organisational procedure for port planning and management, let alone for partnership arrangements among port supply chain members. In this respect, it is instructive to note that there are good examples in the maritime industry where an integrated approach has been developed and collectively implemented, thus providing typical benchmark models for security assessment and management in ports. For instance, the standard framework for maritime safety and environmental protection incorporates legal tools (UNCLOS, SOLAS, MARPOL, ISM code, etc) and management procedures (formal safety assessment (FSA) and integrated coastal zone management (ICZM)), involving various maritime interests around safer shipping, sustainable development, and waterfront regeneration.

Following the introduction of the ISPS code and other rafts of security measures, the current paper attempts to analyse the subject of port security and risk assessment from the perspective of logistics and supply chain management (SCM). It examines major security threats to ports and proposes an initial framework for risk assessment and management; while reviewing conventional approaches to cost control and highlighting their drawbacks in the context of port supply chain security. The author argues that the introduction of the ISPS code, although prompted by policy makers, can contribute towards closer supply chain partnership among the traditionally conflicting trade and logistics members, with ports being at the centre of these integrative and collaborative arrangements.

Review of security initiatives targeting ports

The IMO package of security measures involves changes to the Safety of Life at Sea (SOLAS) 1974 Convention, including the new XI-2 chapter related to ship security and the new ISPS code. Other statutory instruments have been developed and implemented at national and regional levels, with the US security initiatives being the most significant.

ISPS for ports explained

The ISPS code is divided into two parts. Part A, which came into force on the 1st of July 2004, establishes the new international framework of measures to enhance maritime security by introducing mandatory provisions (IMO, 2002). It outlines the obligations and responsibilities of contracting governments, ports, ships and shipping companies and introduces the various schemes and initiatives to be established by them on individual and shared bases. Part B is a non-compulsory guidance detailing procedures to be undertaken in order to comply with the provisions of chapter XI-2 of the SOLAS convention and of Part A of the code. Although the provisions of part B are voluntary, some contracting governments such as the USA are already implementing them on a mandatory basis.

As far as ports are concerned, the ISPS code is applicable to port facilities serving 500+ gross tonnes ships engaged in international voyages, but contracting governments are given the option to extend the application of the code to other types of ports and terminals. The code sets three security levels ranging from low to high in proportion to the nature and scope of the incident or the perceived security threat. Ports and port authorities are required to develop and implement enhanced facility security plans (PFSP) for each level as set and approved by the governmental authority within whose territory the port is located. They accordingly need to provide the necessary financial, human and information resources, including the designation of a port facility security officer(s) (PFSO), and also the appropriate training drills and exercises for the PFSO and other security personnel. PFSP are based on the outcome of the port facility security assessment (PFSA), a 'risk-analysis' scheme undertaken by contracting governments, or authorised security organisations, in order to assess the vulnerability of port facilities against security threats and the consequences of potential incidents. Unlike ships and shipping companies, ports do not require international certification apart from a statement of compliance delivered and regularly reviewed by contracting governments.

Non-ISPS security initiatives

As mentioned above, the most significant non-ISPS security initiatives are those introduced by the United States government. Most of these measures are incorporated in the US Maritime Transportation Act (MTS) of 2002, and involve both mandatory and voluntary ISPS provisions (DHS, 2003). The MTS Act includes new port-related measures that go beyond what has been agreed at IMO. Among these are the requirements for transportation security cards for port personnel, and the development of a system of foreign port security assessments. The latter requirement empowers US authorities to bar access to their ports for vessels arriving from unsafe or blacklisted ports. Hence, foreign ports bound to US trade need ultimately to comply with all provisions of the ISPS code, including part B. Although no guidance for these assessments has yet been provided, the rules seem to work similarly to those of the ISM code and port state control and thus one may assume that they fit into new IMO security standards.

In addition to the MTS act, the US introduced a number of non-binding voluntary programmes for the international shipping community involved in the US trade. Although these measures primarily target vessels and cargoes (and the derived information and payment flows), they also apply to non-American ports at which a ship (or her cargo) calls prior to reaching US waters. Thus, inbound non-US ports will either have to comply with these rules or lose the American market. The two main programmes relevant to ports in this regard are the Container Security Initiative (CSI) and the Customs–Trade Partnership Against Terrorism (C-TPAT) (CBP, 2004). The two schemes introduce a number of rules that aim at improving security against terrorism by targeting the movement of container-cargo (CSI) across the entire supply chain (C-TPAT). CSI bilateral agreements allowing US customs to target foreign-port containers bound for the US have already been signed with several mega-ports which, as of July 2003, accounted for 66% of container imports to the US (GAO, 2003). Similarly, thousands of C-TPAT partnership agreements have been established between the US customs and individual private participants (Lloyd's List, 2003a). C-TPAT plans were initially limited to manufacturers and shippers but they have been opened up recently to other categories of private businesses along the supply chain, including carriers, forwarders, brokers, ports and terminal operators. Under a C-TPAT partnership agreement, participants need to provide reliable and verifiable security information in exchange of preferential treatment during customs inspections and expedited procedures. Specific C-TPAT initiatives relevant to ports include Operation Safe Commerce (OSC) and the Smart and Secure Tradelanes (SST), with the latter currently being undertaken by the largest global terminal operators (HPH, P&O Ports and PSA) (AAPA, 2004). The 24-h advance vessel manifest rule or the '24-h rule' is a major security requirement under which carriers or their agents have to submit a cargo declaration for each US-bound container 24 h before loading at the foreign port. This measure, applicable to containers both transited by and imported to the US, is probably the most controversial among all initiatives in that it acts against logistical optimisation and operational flexibility, but more importantly it may distort competition between different market players, including ports (UNCTAD, 2004a).

Following the US initiative, several non-ISPS programmes were introduced by other governments on a unilateral or a multilateral basis. Examples include Canada's own 24-h rule, the Secure Trade programme in the APEC Region (STAR) for Asia Pacific, the EU PROTECT system for dangerous goods, the ASEAN ports association's shared security database programme and a number of WCO/ILO international conventions.

As illustrated in Table 5.1, ISPS measures reflect a combination of ISM/IMDG codes and ISO 9000/14000 series and thus the ISPS code can be seen as a new quality standard for security management in shipping and ports.

Scope and nature of security threats to ports

New dimensions to port security under the threat of terrorism Just as past maritime disasters (Exxon Valdez, Erika, etc) have fostered further dimensions to environmental management, so has the 9/11 attack to maritime security:

- Firstly, physical assets of the transport and logistics system are perceived not only as targets but also as means to carry out terrorist attacks (Johnston, 2004). Vehicles and ships, goods and cargo, equipment and facilities can all serve as weapons of destruction and terrorism. The same applies to non-physical components, such as information and payment flows that can be used as communication and financial resources by terrorists. The latter aspect is very essential in the context of risk analysis since it adds on a new dimension to maritime security.
- Secondly, with domestic issues being increasingly linked to international terrorism, previously perceived different risk levels have now been equated and altered up to the maximum global scale. As it has been revealed recently, drug smuggling, cargo theft, piracy, illegal immigration and human trafficking are all used by inter-connected local cells as a means of financial, operational and organisational structuring of international terrorism. Ports throughout the world need therefore to perceive and manage security threats through integrating local/domestic threat-level into a global awareness-level.
- Thirdly, the response to a large security attack should remind us of the wider impacts on international trade and transport, but also on global logistics and production systems. For instance, the immediate US response to the 9/11 attack (closing borders, shutting down the traffic system and evacuating government/company buildings) has caused huge delays and disruptions; with many domestic companies purchasing, outsourcing, manufacturing, and selling products and services on a global and world- wide basis (Sheffi, 2001). The economic and financial cost of such disruptions will be overwhelmingly high if an attack is to involve strategic cargoes such as oil and gas

Table 5.1 Purpose and relation between the ISPS code and other safety/quality management programmes

	ISM code	**IMDG code**	**ISO 9002 series**	**ISPS code**
Aim	Safety of ships and pollution prevention	Movement, operation and mgt of dangerous cargo	Quality assurance of products and services	Security of maritime network, and prevention of terrorism threats
Target	Marine mgt. and shipboard operation	Ship/port facilities, cargo operations and mgt	Contractual relationship between customer/ supplier	Ship, port and mobile off-shore facilities, ship/ port operations and mgt.
Completion	Capacity to meet safety and pollution prevention	Capacity of the system of safe transport and handling of dangerous goods	Demonstrate ability of marine management and shipboard operation to meet customer requirements	Ability of participants to meet security requirements, and react to changing security levels
Means	Implementation of the safe operation of ships and pollution prevention	Safe procedures for classification and segregation of cargo, emergency plans	Implementation of a quality assurance system	Implementation of part A of the code and chapter X1-2 of SOLAS. Regional implementation of part B
Scheme of certification	Company assessment: doc. of compliance Ship assessment: safety mgt. certificate	Implementation of IMDG Code and annex 2 of MARPOL convention	Company and ships assessment: quality system certificate	ISSC, SSA and SSP for ships and companies. Local accreditation of PFSA and PFSP for ports
Maintenance of certification	Follow-up assessment each year, re-assessment after 3 years	No specific provision	Surveillance on company every 6 months, all ships during 3 years. Re-assessment after 3 years	Up to 5 years for ISSC and intermediate verifications. Period of validity for the statement of compliance of PFSP to be decided by contracting government

supplies, or target key networks such as busy ports (transhipment, network or multimodal ports) and maritime links (eg straights of Gibraltar and Malacca, Suez and Panama canals).

- Finally, as the threat of international terrorism is far from being over, firms should manage and organise their logistics and supply chains under increased risk and uncertainty. Companies should acknowledge the vulnerability to terrorism of both in-house logistics and shared supply chain networking systems and thus rely more on agile and collaborative relationships. This is to suggest that the traditional fragmented and conflicting channel relationships in ports and shipping must be replaced by closer partnership arrangements.

Security threats and risk factors in ports

Ports throughout the world have developed in different ways with a combination of economic, spatial, political, social, and even cultural and military influences, and thus no clear pattern of institutional or functional attributes of ports can be established. However, in the context of international shipping and logistics, ports are identified as key locations where various members of the logistics and trade systems can meet and interact, and thus they are the most likely to be targeted by terrorists. Moreover, due to their close spatial interactions with large city-agglomerations and seashore tourist attractions, ports may also be the subject of large environmental disasters or deliberate maritime/intermodal accidents, hence adding extra security threats and further complicating security and risk management systems. Two main components should be examined while assessing risk factors in ports, physical assets and facilities *versus* non-physical flows and processes.

Assets, facilities and physical movements of cargo

The first set includes vessels; inland vehicles and their equipment; port assets and facilities (both infrastructure and superstructure); goods and cargo (both in ports and onboard ships and vehicles); shore- and ship-based personnel as well as other individuals within the port estate (operators, users, etc). Apart from cargo, all other assets (vessels and vehicles, people, equipment and facilities) do not pose a serious threat to security if systematically and safely monitored. Assuming that ports effectively invest in and successfully implement integrated security systems, then any potential risk can be identified and properly dealt with when applicable. In addition to enhancing security plans and procedures, ports can also undertake a number of measures to lower or eliminate security threats, ranging from regularly checking and reviewing port facilities, to detaining ships/vehicles and restricting or denying access to port premises.

Cargo and cargo movement, on the other hand, are of a higher security threat to ports than that of all other assets combined. Transported cargo has different forms (liquid, dry bulk, break bulk, unitised, etc) and it can also change forms while in ports or at intermodal interfaces. Cargo also entails a high volume of complex movements and operations while in ports, including loading and discharging operations; trans-shipment; storage and warehousing; logistics services and value-added activities. As in the case of Less than Container Load (LCL) consignments, goods are handled, stored and shifted many times before being shipped to or from the port, thus generating complex and highly vulnerable cargo-flow patterns and processes.

Non-physical flows and processes

The second set of risks refers to non-tangible flows associated with vehicle/ cargo movement and operations in and around ports. Apart from physical flows of cargo, capital and payment and information flows are all common to commercial-cargo ports and thus they can all be used as a means of financing, communicating and/or providing logistical support by and for terrorists. The major challenge in this respect lies in that the derived risk is usually perceived at different levels amid supply chain members, including ports. While some shippers strive to secure highly integrated supply chains, through, for instance, heavily investing in secure IT and communication systems, many manufacturers still trade at arms-length arrangements, hence running higher vulnerability and risk exposure. But even when relatively good levels of protection are put in place, shippers cannot always ensure highly secured distribution channels, with many of their shipments nowadays being trans-shipped, temporarily stored and/or mixed with other cargo before reaching the ultimate customer. The role of ports in gathering and detecting all these flow-types is very central to security-risk analysis, and thus much emphasis should be placed on assessing the interactions in ports of non-tangible flows and processes.

Cost-control approaches and their relevance to security-risk management in ports

Review of early estimates of ISPS cost implications on ports

Cost structures in shipping and ports are generally perceived in terms of fixed and variables costs; capital and operating costs; direct and indirect costs, etc. For instance, ship costs are divided into voyage and port costs, capital costs and running costs. In ports, costs are usually broken down into four elements: land costs, capital/infrastructure costs, equipment/ superstructure costs, and labour and running costs.

The USCG has estimated the cost implications of security compliance on US ports to reach $1.1 billion for the first year and $656 million each year up to 2012 (Containerisation International, 2003a). Based on these estimates, the OECD produced a report on the global economic impacts of the new security measures (OECD, 2003). The report expected more than $2 billion initial investment and 1$ billion annual expenditure just for developing country ports alone (Lloyd's List, 2004). Table 5.2 summarises the works of USCG and OECD with regard to the costs of compliance in ports. Other relevant works include the Booz Allen simulation exercise (BAH, 2002); the Anderson report on loss– earnings during US west coast port lock-out (Anderson, 2002);

Table 5.2 Summary of OECD and USCG estimates of ISPS cost compliance for ports

	Nature of estimates	**Initial costs**	**Annual costs**	**Indirect costs**
PFSA	US port costs (USCG)	23	1	0
	Global port costs (OECD)	27.9	0.8	0
PFSP	US port costs (USCG)	23	1	0
	Global port costs (OECD)	27.9	0.8	0
PFSO	US port costs (USCG)	335	335	
	Global port costs (OECD)	Undetermined	Undetermined	Undetermined
Security training/drills	US port costs (USCG)	17	52	Undetermined
	Global port costs (OECD)	Undetermined	Undetermined	Undetermined
Security staff/ equipment	US port costs (USCG)	565	146	Undetermined
	Global port costs (OECD)	Undetermined	Undetermined	Undetermined
Total ISPS	US port costs (USCG)	963	509	Undetermined
	Global port costs (OECD)	Undetermined	Undetermined	Undetermined

the Lloyd's Ship Manager survey for shipowners (Lloyd's List, 2003b); and the BDP survey of shippers on the costs of the 24-h rule (Financial Times, 2004).

Review of the economic approaches to cost control and analysis

In the economic discipline, cost assessment of new schemes and initiatives is generally undertaken at three different levels of analysis:

- First as a project appraisal and risk analysis of investment decisions, applicable to our case when new security provisions are translated into port investments. Here, discounted cash-flow (DCF) models are used to assess port profitability (NPV and IRR), and analyse uncertainty and risk associated with investment decision-making (eg sensitivity analysis, dynamic and discrete modelling, simulation, etc).
- Second as a premium-price analysis, whereby new security costs are added to the price of port and shipping services. These costs are typically assessed by analysing market response to risk-return performance, referring, for instance, to the variations in freight rates and insurance premiums (Cullinane, 1991; Kavussanos and Marcoulis, 2001; Gong *et al,* 2002).
- Third as a cost–benefit analysis (CBA) for optimal regulatory decisions. This is relevant in our case when ports want to know how far they need to adhere to non-mandatory security programmes. CBA is the most standard method to identifying the optimum benefit–cost ratio, usually by contrasting loss–earnings or the cost of failure against the benefits of compliance (Dorfman, 1993). Alternative methods include cost–efficiency analysis (CEA), a complementary method to CBA when the economic benefits cannot be quantified (Tietenberg, 2000); the revealed preference method (RPM); and the stated preference method (SPM), both used to evaluate the monetary values of externalities and non-marketable goods (Ma, 2002).

In the maritime sector, CBA/CEA methods have first been introduced by the FSA framework and later adopted in most subsequent works; (OECD, 1996; Drewry Shipping Consultants, 1998; Cremers and Chawla, 1999; Li and Cullinane, 2003). The FSA is probably the most systematic and comprehensive framework for risk management in the field of maritime safety and environmental protection. It was developed by the UK maritime and coast- guard agency (MCA) and later incorporated into IMO interim guidelines for safety assessment

(MCA, 1996; IMO, 1997). The FSA methodology consists of a five-step process: hazards identification, risk assessment, risk management (alternative options), CBA, and decision-making; and three tools of analysis: the 'brainstorming' technique for hazard identification, the Delphi method for soliciting and collating expert judgement, and the CBA approach for cost estimation and risk control (Peachey, 2001).

As far as ports as concerned, few valid attempts have addressed the subject of cost analysis and risk assessment. Among these, worth mentioning is the work of Billington (2001), who successfully adjusted and applied the FSA approach to the subject of port safety. Some studies on port efficiency and impact analysis could also fall within this category. Port efficiency is defined as the ratio between input (cost) and output (revenue) and it could be a valid tool for cost assessment and risk management (Boscke and Cuttino, 2003; Sanchez *et al,* 2003). However, measures of port efficiency or performance indicators use diverse techniques of analysis, often with inaccurate and inconsistent results (Bichou and Gray, 2004). There are indeed several obstacles against applying the economic approach of cost analysis to integrated port operations and management, let alone to the subject of security assessment and risk management in ports and across the network of their users, customers and suppliers.

Limitations of the economic costing approach to port security

One of the main drawbacks of the economic approach to maritime transportation is the false premise that freight transport is somehow separate from other activities of the firm and, in the context of SCM, from the activities of a network of firms and businesses. Although based on a truly economic concept treating transport as a derived demand, this approach disintegrates transport from other logistics components such as purchasing, production, inventory management and marketing. This is typically illustrated in the field of maritime security, whereby the perception of the risk and the response to it are usually disintegrated from the cross-functional and inter-institutional interactions that are taking place in international shipping and logistics. As pointed out by Alderton (2002), maritime security has long been considered as a sub-system of safety, whereby the nature of the risk was perceived at the functional level (eg cargo theft, stowaways, drug smuggling, piracy, etc) and the response to it undertaken at the fragmented institutional level (port contingency plan, ship safety management system, etc), thus failing to integrate the risk element in the aggregate port logistics and SCM.

There are number of arguments against both the accuracy of the above figures and the relevance of the methodology used to estimate them. Primarily one may question the validity and generalisability of the pricing systems used to calculate individual and aggregate costs, but equally the failure to consider properly cost implications on the efficiency of port logistics and supply chain systems. Five arguments are identified as challenging the relevance of the economic costing approach to port supply chain security.

Considering security as a sub-category of safety

In the last three decades or so, the maritime economics literature has studied the interaction between the economic system and the maritime safety and environment system, on the assumption that the latter encompasses or is equivalent to security. Nevertheless, one may challenge this approach in that it ignores the complex and far-reaching aspects of maritime security. In the context of international shipping and logistics, the new dimensions of security go beyond the IMO framework of facility security (PFSA, PFSP, PFSO, etc.) to include the wider concept of supply chain security, with the role of ports changing from a facility type to a logistics and supply chain type. Table 5.3 illustrates the differences between the IMO framework of port facility security *versus* the extended scope of port supply chain security.

Overlooking complexities and dissimilarities among world ports

Security measures directed towards ports are far more difficult in terms of cost assessment than those targeting ships and shipping companies. Not only ports throughout the world are very dissimilar in terms of organisational, operational and management systems, but also security measures targeting them vary in time, space, scope and nature:

- Institutional and organisational discrepancies among world ports and terminals hinder any attempt to cost-assess them homogenously. Port ownership models tend to be a combination of public/private and centralised/decentralised variations. Hence, the distribution of security costs between central/local governments on the one hand, and public/ private operators on the other hand, is impossible to calculate on a global basis.
- Physical, operational and management differences between ports, and even within a single port, constitute a serious limitation to cost compilation. PFSA, PFSP and PFSO implementation costs will likely vary

Table 5.3 Port-facility security *versus* port-supply chain security

	IMO framework Port-facility security	**Extended supply chain framework Port- supply chain security**
Nature and scope of security–risk	Physical assets in ports and at the sea/shore interface	Physical assets of the logistics and transportation system, Vehicle and cargo movements throughout the supply chain, Associated non-physical flows: capital, payment and information
Legal framework	ISPS code provisions for ports	ISPS code all parts and provisions included, C-TPAT, CSI, OSC, 24-h rule, various private initiatives, other national and regional programmes, etc
Participants	Port authorities, contracting governments, international agencies (mainly IMO and ILO)	Port authorities and port community members, contracting governments and various government agencies, shippers, ocean and intermodal carriers, logistics providers, foreign ports, facilitators and intermediaries, international agencies (IMO, WCO, UNCTAD, WTO, ILO, etc)
Operational and spatial framework	Nautical approach, sea/ shore interface, port operations	The entire logistics/supply chain route from cargo/vehicle port of origin to the final port of destination

by type and size of port facilities (berths, terminals, sheds, etc); traffic and throughput figures; ship/cargo types; and nature/scope of land-side operations (trans-shipment, storage/warehousing, intermodal arrangements, etc).

- Port-resource systems also vary considerably, and while some ports may benefit from existing facilities and resources, others will need huge initial investments and capital inputs. Port financing models should also be considered when assessing the cost of compliance, for example, subsidised *versus* non-subsidised ports, regulatory restrictions *versus* free access to private equity, type of concession agreements with private operators and users, etc.
- Another major problem is that there is no international benchmark or compensation scale for computing ISPS costs among world ports. Capital and operating costs already vary significantly between ports

(eg differences in labour pay, interest rates, depreciation and tax systems, etc), which makes it very difficult to construct cost analyses on average-global approximations. In a similar vain, security measures targeting ports differ by scope, nature and level of compliance. For instance, while some ports choose to comply only with compulsory provisions (ISPS part A), others may consider implementing part B and other voluntary programmes. The cost of compliance will therefore vary accordingly.

- Finally, although ISPS and non-ISPS initiatives span across various aspects of port security, some measures provide general guidance without fully explaining the scope and procedure of their implementations. For instance, the PFSO provision does not indicate whether it is a sole dedicated position or just an added responsibility to an existing function. Ports and port operators may therefore interpret this requirement differently, hence resulting in variable cost and investment-decision models.

Disintegrating ports from other members of the logistics and supply chain system

In addition to equating complex and dissimilar models of world ports, the main flaw of the conventional approach stems from the separation of port authorities from other institutional members, the clustering of which forms what is commonly referred to as the port community. In the typically fragmented port and shipping industry, the question arises on the allocation of costs or benefits. In other words, who will bear the cost or gain the benefits of ISPS port compliance? In a typical CBA model, the results of a regulation implementation can be entirely different from one entity to another. However, in the context of logistics and SCM, port security is a shared responsibility between all members of a collaborative and integrated supply chain. Superior port management is the aggregation of performances of all port community members, and thus a failure from any member to meet effectively security requirements will jeopardise the competitiveness and performance of the entire port community. It is therefore in the interest of all parties to endorse and successfully implement security programmes, even when the latter entail cost contributions from members who are not directly targeted by security measures. The same logic applies to extended channel partners (shippers and ocean carriers) and even to outside members such as customs authorities, all of which must work in a collaborative spirit to ensure superior security compliance against other port systems or channel-type arrangements (eg other forms of intermodal transport not involving ports such as land-bridges).

Ignoring the cost of operational redundancies and supply chain disruptions

Since the 9/11 attacks, there has been a rising interest in investigating the impacts of security threats on logistics and supply chain efficiencies. Most studies concluded that the additional security measures would result in significant productivity losses, but they should ultimately favour collaborative and agile supply chains (Bowersox and Closs, 2002). In shipping and ports, productivity losses could stem from implementing new security provisions such as the 24-h rule, and would inevitably lead to a number of inefficiencies ranging from operational redundancies such as ship detention and cargo delays, to supply chain disruptions such as longer lead times, higher inventory levels, and less reliable demand and supply scenarios.

Cost spin-off and exponential computations of security expenses

By trading at arms-length, market players in the shipping industry usually transfer costs to each other, with the ultimate customer/user (usually shippers and cargo interests) incurring much of the aggregate cost. Actors within the international shipping industry have already reviewed their pricing strategies to compensate for the new security costs. Early figures suggest average increases of 5% for port tariffs; 4% initial costs and 2% thereafter for maritime freight costs; between $25 to $60 levying charges per B/L; and up to $40 per B/L for the 24-h rule (Containerisation International, 2003b; UNCTAD, 2004b). Nevertheless, in a highly disintegrated and fragmented industry, there is no guarantee that the additional security charges will accurately reflect the true incremental costs incurred by each of the members, including ports. Evidence from past practices suggests that market players try to generate extra profits by transferring costs to each other (Evers and Johnson, 2000; Fung *et al,* 2003), and there is already proof of this with the introduction of new security charges (Lloyd's List, 2003b). The combination of such practices with the perceived conflict of interests between different market players generally leads to exponentially biased cumulative security costs whereas, against this background, significant cost reductions could be achieved by interacting on the basis of integrative and collaborative supply chain arrangements.

Initial framework of port security assessment

Prior to considering the development and application of risk management techniques to port security, it is important to recognise the nature and limitations of the regulatory context in which the maritime industry operates. When managing risk through legislation, newly introduced regulatory instruments usually fail to provide a compelling framework of risk assessment and management. At best, the IMO and other international organisations establish a set of general guidelines to be first interpreted by contracting governments, or authorised organisations such as classification societies, and then forwarded to the shipping-community participants for compliance and implementation. In very few cases, however, individual states/participants take the lead in developing standards for carrying out risk assessment or for defining risk assessment criteria (eg the FSA framework for maritime safety). In the field of security legislation, the US Operation Safe Commerce (OSC) is probably the most comprehensive initiative targeting supply chain security, but the OSC does not provide a methodology for risk management, nor for cost control and effectiveness. As the FSA was developed for maritime safety, a similar systematic approach is needed for maritime and port security.

This paper proposes an initial framework to port security assessment (IFPSA) by adopting a channel approach to the relationship between the integrated port management system and the security-risk management system. The proposed framework aims at providing ports and port-community members with a valid tool for risk assessment and management. It introduces three initial models to be investigated and improved by them via a three-step integrative process. The IFPSA approach draws some parallels with the FSA methodology, but differs from it in many aspects:

- The IFPSA approach adopts a channel orientation to ports by integrating active port and supply chain members into the process of security assessment and management. It identifies vulnerabilities at each step of the supply chain, develops and tests, through a risk-pooling (or risk- sharing) strategy, the best policies and procedures to ensure secure and cost-effective port operations management.
- Brainstorming techniques used *a priori* in the FSA for hazards identification, would typically be carried out *a posteriori* in the IFPSA methodology. As traditional port management still lacks familiarity with the concepts and applications of logistics and SCM (Tongzon, 1995; Bichou and Gray, 2004), it might fail to recognise and properly integrate channel and flow processes if assigned the task of initially identifying and categorising supply chain vulnerabilities. To rule out this possibility, the IFPSA presents port-community members with initial logistics models to be investigated, developed, and adjusted

by them according to the specific characteristics of each port-facility and flow-type component.

- The IFPSA proposes a combination of stakeholder analysis (SHA) and logistics/SCM measurement techniques for the purpose of cost control and effectiveness. As pointed out earlier, the risks associated with security threats are more inherent in moveable assets and associated flows (both physical and non-physical) than in fixed assets and equipment. Thus, the CBA/CEA techniques used by the FSA prove to be less relevant in the context of supply chain security in ports.

IFPSA methodology

The technique used in this approach is to present port-community managers with an initial framework of security assessment (IFPSA) for examination and adjustment by them, leading to an improved and valid framework. The IFPSA provides three initial models each corresponding to a step or stage in an integrated process. The first model relates to process mapping of port operations, the second to risk assessment and management, and the third to cost control and performance monitoring. The successful combination of the three optimal models will provide the best options for decision-making and implementation.

Step 1. Process mapping: Design of port supply chain processes

The contemporary role of ports exceeds the simple function of services to ships and cargo. Apart from their role as traditional sea/land interfaces, ports are good locations for value-added logistics, and also serve as central networking sites where various trade partners can meet and interact. The essence of logistics and SCM is an integrative approach to the interaction of different processes and functions within a firm, extended to a network of organisations for the purpose of cost reduction and customer satisfaction (Stank *et al,* 2001). The conceptualisation of the port business in terms of logistics and SCM translates various port operations into flows and processes related to a chain of activities of other supply chain members, so as to optimise the management of the entire chain rather than that of individual entities.

Model 1 presents port managers with a framework of process mapping and relationships to accommodate all operational and management flows within and around ports. The design of the supply chain focuses on the location of decision spots and the objectives of the chain (Mourits and Evers, 1995). In our case, this is done at two levels of port management. The first level corresponds to internal logistics integration, whereby the interactions of port functions and institutions are translated into physical and non-physical flows. Physical flows combine ship/vehicle and cargo movements across various port assets and facilities, whereas non-physical flows encompass the derived capital, payment and information flows. The second level refers to external supply chain integration, whereby the port system is linked to the activities of supply chain partners at both seaside and landside directions. Using flow-type configurations (Figure 5.1) as a guidance, it is possible to design, trace and scrutinise various functional and institutional interactions within each port and terminal, as well as across their extended supply chain networks.

Although not covered in this paper, it is worth mentioning that the literature on supply chain provides four main categories of design models: deterministic analytical models, stochastic analytical models, economic models, and simulation models (see Cohen and Lee, 1989; Towill, 1991; Lee *et al,* 1993; Christy and Grout, 1994). It is therefore possible to expand the subject of port design by involving one or a combination of the above analytical models. As far as maritime security is concerned, some specialised software packages already exist, for example, the Lloyd's Register See-threat programme, the DHS/USCG CSI model,

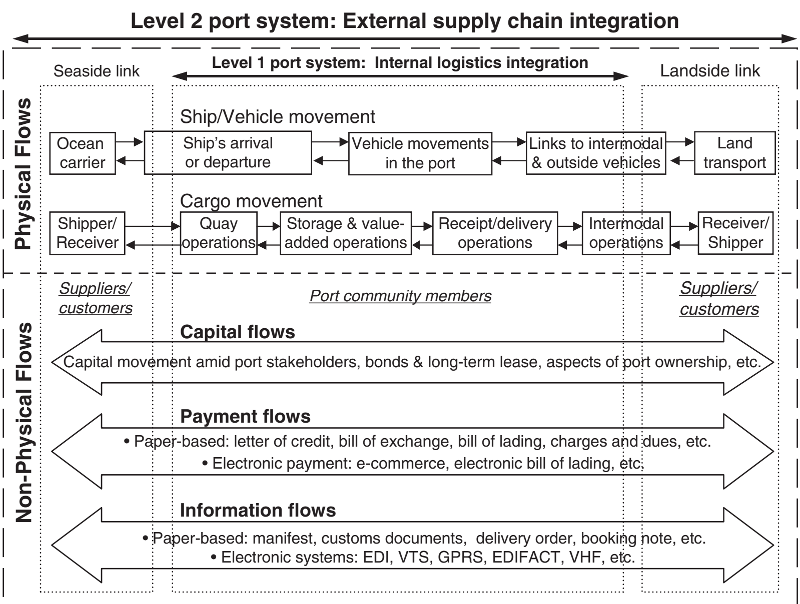

Figure 5.1 Process mapping and design of port internal and external systems (model 1)

and the port of Rotterdam toolkit; but they only address single ship or port security provisions (eg SSA, PFSP, CSI, etc).

Step 2. Vulnerability identification, risk assessment and management

As outlined above, the threat of international terrorism has fostered further scope and dimensions to port security. Thus, when trying to identify risk factors in ports, particular attention should be given to the combination of asset and cargo-flow components that provide the highest economic, trade and human output concentrations. The merit of model 1 lies in that it spots risk factors at the level of each logistics and supply chain process, a feature that a preliminary brainstorming analysis may fail to notice. Instead, brainstorming would be used *a posteriori* in combination with model 1 in order to identify different vulnerabilities and categorise and assess them by flow- and channel-type.

Model 2 proposes a logical framework of risk/vulnerability identification and assessment in ports. The methodology consists of an event-tree chart of individual vulnerability-situations, the combination of which corresponds to an incident-scenario (a physical damage, a supply chain disruption or usually both), with varying consequences at different stages of the logistics and supply chain process. Analysis of the outcomes of an incident-scenario, including the port response to it, may be based on event-tree analysis methods, but other supply chain modelling techniques can also be used (eg Delphi technique, action research methodology, benchmarking analysis, game theory, dynamic modelling, etc). In either case, port managers need to rely on their expert judgements as no historical data for facility/supply chain incidents in ports exist. In situations of disagreements or conflicting standpoints, independent participants (eg external consultants or landlord-port authorities) should arbitrate to ensure a neutral and objective perception of event risks and hierarchical rankings. The same applies to the prediction of the frequency of occurrence of each possible outcome. The combination of frequency of occurrence with the severity of the outcome would provide the risk inherent in each scenario of a port supply chain process.

Figure 5.2 illustrates a basic example of how to link different vulnerabilities in a port supply chain in order to predict different incident-scenarios and assess their respective outcome/consequence levels. For the purpose of simplification, the port supply chain system is narrowed down into three major sub-systems, namely the port operational system (ship and cargo operations), the upstream sea-link system (ie ships are at the port or at berth, but no ship operation or cargo handling

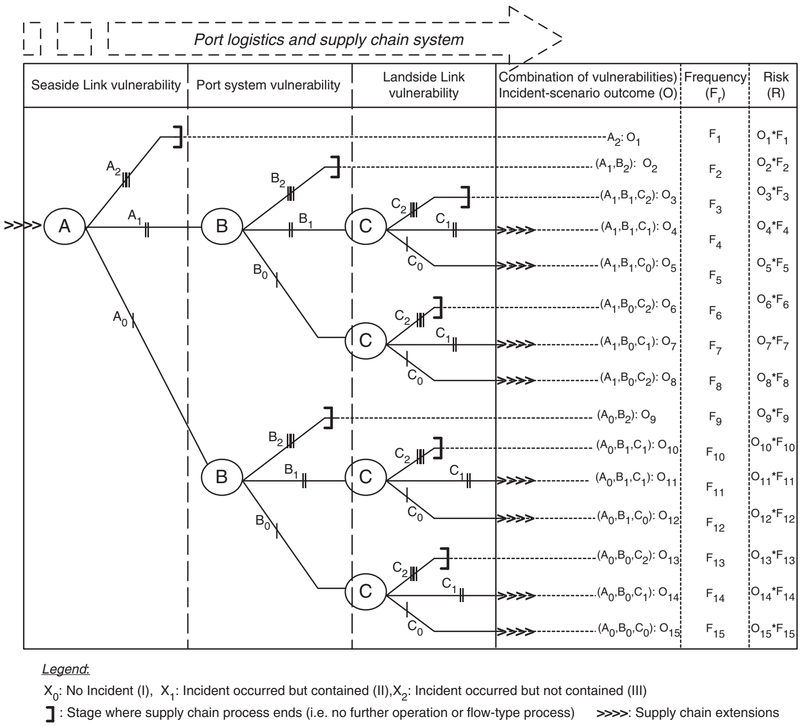

Figure 5.2 Event-tree configuration for vulnerability identification and scenario-assessment in ports (model 2)

is performed) and the downstream land-link system corresponding to intermodal operations at the port/land interface. Similarly, the number of vulnerabilities are reduced to one per sub-system, for example, risks stemming from a ship collision with a port facility (A), a dangerous-cargo explosion when at a port warehouse (B) and an accident involving intermodal land vehicles (C). Three possible events can take place for each vulnerability-situation: (i) no security-incident occurs, (ii) incident occurs but contained with limited damage and (iii) incident occurs but not contained. Both in (i) and (ii) the physical flow continues to the next step, but in (iii) the supply chain process stops at the incident stage with no further operation. The combination between vulnerability-situations and possible events provides the total number of incident-scenarios; with the ideal scenario (O_{15}: $A_0B_0C_0$) corresponding to no incident, failure or delay across the entire supply chain. Each scenario should be assessed against its perceived consequence and frequency of occurrence to calculate the final risk expressed as follows:

$$\text{Risk } (Ri) = \text{consequence/output of an incident } (Oi) \times \text{frequency of occurrence } [F_{r(i)}]$$

The output from Figure 5.2 provides a risk profile showing supply chain vulnerabilities and possible scenarios for a security-incident to occur. Risk management continues directly from model 2 by categorising and grading scenario-risks (*R*) according to their overall threat potential using a rating scale system, say from (1) for minor to (5) for severe (or from 1 to 3 to fit into the ISPS provisions of security levels). Plans and measures to properly respond to an incident, or to prevent its occurrence, should be undertaken on a collaborative basis so as to ensure agile and proactive supply chains. In the context of the ISPS code, these plans could serve as PFSPs, with model 2 being equated to an aggregate combination of PFSAs. The effectiveness of these measures is tested at each stage of the supply chain using a cause–effect relationship, with alternative courses of action (B-type plans) put in place in case of a delay or failure in the response system.

Step 3. Cost control and performance monitoring

Earlier in this paper, we outlined the limitations of the maritime economics approach in disintegrating ports from other members of the trade and logistics system. We also underlined the shortcomings of CBA and CEA techniques in the context of port logistics and SCM. Model 3 proposes an alternative method for security-cost control and analysis in ports using a combination of an SHA and logistics and SCM measurement techniques.

SHA was introduced in the early 1980s to correct CBA/CEA deficiencies particularly with regard to cost sharing and distribution (Freeman, 1984). It is designed to identify the key players (stakeholders) of a project or a regulation, and assess their interests and power differentials for the purpose of project formulation and impact analysis. Several procedures have been proposed for SHA implementation, with the World Bank four-step formula (stakeholders identification, stakeholders interests, power and influence inter-relationships, and strategy formulation) being the most recognised and widely used (World Bank, 2001).

SHA intersects with the logistics and SCM approach by offering a neutral, multi-institutional and systematic framework of analysis. It also recognises the aspects of channel control and power in shaping future strategy formulation and decision-making. Nonetheless, it fails to recognise a true channel orientation allowing traditional boundaries of intra- and inter-company activities and processes to be crossed. Moreover, there is little consideration of the role of integrative and collaborative strategies in reducing overall costs to the benefit of all stakeholders and supply chain members. The following cross- functional and inter-organisational cost systems are considered, alongside with the SHA method, for cost management and performance monitoring of port supply chain security:

- *Activity-based costing (ABC):* ABC proposes an evaluation of the costs of a firm's activities based on the actual resources and time consumed to perform them, and allows the causal relationships between expenses to be observed (Kaplan and Cooper, 1998). Furthermore, this costing system can identify the additional services provided by suppliers, such as product design and development that add value to the final product and reduce internal costs such as inspection and handling.
- *Total cost analysis* (*TCA*)*:* TCA analysis is a structured approach for understanding the total cost associated with logistics services. The costing method proposes a trade-off analysis among different internal functions to minimise total costs, while at the same time maintaining customer satisfaction (Lambert *et al*, 1998). Originally designed to support acquisition and planning decisions for assets and activities within the firm, TCA was extended to external logistics performance by integrating various flows and processes in the supply chain.
- *Value chain analysis* (*VCA*)*:* The core idea of VCA is to break up the chain of inter-related activities throughout the supply chain into strategically relevant segments in order to understand the behaviour of costs and the sources of differentiation. VCA can be performed by one firm taking an external perspective, or jointly by supply chain cooperating members on the basis of cost and information sharing (Dekker, 2003).
- *Balanced scorecard* (*BSC*)*:* The BSC is composed of key measures that reflect the specific factors that are expected to drive future performance. The Kaplan and Norton (1996) original BSC model combines four dimensions of performance measurement: financial, customer, internal business processes, and learning and growth. The mix of financial and non-financial measures should cover different and complementary functional areas. Thus, the BSC is more a performance and SCM system than just a costing system.

There are number of other logistics and SCM metrics, but the techniques mentioned above are probably the most suitable for costing and managing cross-functional activities or processes at the inter-firm supply chain level. Indeed, these systems overcome the limitations of the conventional approach by providing a comprehensive framework that combines both cost-based and performance-based tools of analysis.

Model 3 provides an initial framework to costing and performance management, based on the combination of the SHA method and the above logistics tools of analysis. The model reads from the top and is structured around a three-stage formula. First, various security provisions undertaken, or being considered, by the port are identified and listed by institutional and functional port component. In each case, where security provisions involve more than one facility or entity, the SHA method will be used to redefine and re-categorise security measures on the basis of stakeholders' interests, power and influence. These measures are then pooled and cost-assessed on the basis of information and risk sharing, process integration and collaborative arrangements. ABC, TCA, and VCA will be performed to eliminate waste expenses across the supply chain and ensure optimal costs reduction, while a combination of BSC and other supply chain analytical tools (benchmarking, brainstorming, simulation, etc) will be used to monitor port-security performance on the basis of proactive, dynamic and agile supply chains. The use of benchmarking and quantitative methods should cover the assessment of incremental external effects (benefits and costs of security-risk externalities) and their quantification into monetary and objective values. Finally, a new configuration of cost assessment and distribution will emerge by allocating a share of the reduced costs to each port supply chain participant. For instance, and as illustrated in Figure 5.3, A1 corresponds to the security-cost borne by firm A in performing function 1, while (B2 + B3) refers to the cost share of entity B in undertaking activities 1 and 2.

Decision-making: optimisation of the three initial models

Decision-making corresponds to strategy formulation in view of the application of the IFPSA and optimisation of the three initial models. The IFPSA methodology developed in this paper is primarily aimed at decision-making and strategic planning for ports, but it can also serve as a security assessment and risk analysis for a range of port interests, 'stakeholders', or 'supply chain' members including contracting governments and private terminal operators. The aim is to approach the subject of port security from a logistic and SCM approach, hence allowing for integrative process management and close partnership

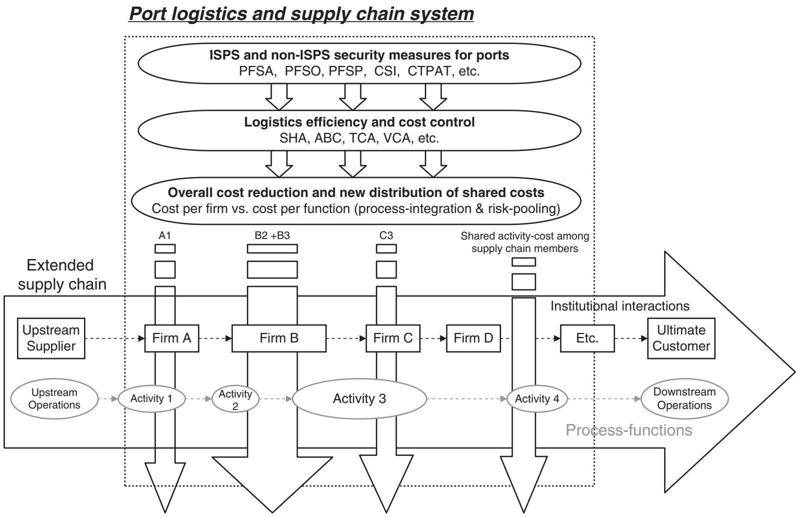

Figure 5.3 Cost control and distribution across port supply chain components (model 3)

arrangements. For instance, the financing of new security measures can be undertaken jointly by a panel of port supply chain members through, for instance, loan-syndication schemes, sharing-user agreements and/or private– public partnerships. This will allow for cost sharing and distribution among the various institutional participants, but more importantly it will ensure security compliance for the benefit of all channel members. Lessons should be learnt from strategic alliances in liner shipping, whereby huge cost-savings were achieved thanks to closer operational, technical and commercial partnerships (Slack *et al*, 2002). In a relatively volatile port industry, an advanced form of cooperation among port members is necessary to provide first-class services that fit into new security standards.

Conclusion

The aim of the paper was to analyse the subject of port security from the perspective of logistics and supply chain management in the light of the introduction of the ISPS code and other security measures for ports. The paper introduces an initial framework of security assessment and risk analysis capable of reflecting the logistics scope of port operations, and complementing, if not replacing, the conventional methods of cost analysis and performance monitoring. The focus is to shift the subject of port security from the current agenda of facility-security to an extended framework of supply chain security.

Many areas associated with the new security measures and their impacts on port competition and industry rivalry were not covered in this paper. However, one can already suggest that ports conforming to the new security standards will be accredited for best-practice compliance and best-class benchmark for performance monitoring, cross-comparison, and competitive benchmarking. Superior port compliance can serve as a good tool for gaining competitive advantage, but also as a successful differentiation strategy and a higher barrier to imitation within an industry increasingly running the risk of commoditisation and foot-loose arrangements. The issues of channel control and power, and the risk of distorting fair competition among ports, often to the detriment of ports in developing countries, need to be addressed thoroughly in both theory and practice (Haralambides *et al*, 2001; Haralambides, 2002). The same is true for regulatory and policy issues where the introduction of international initiatives based on domestic interests (US-driven security measures) marks a break- through, but also entails a great danger, in terms of diverging from the multilateral approach by which the international maritime community has traditionally been structured and regulated. It is instructive to note that in the USA itself, a more balanced approach between efficiency benefits from a deregulated environment and security requirements from a regulated environment is currently undertaken by policy makers (Johnston, 2004). In port security, such an approach has taken the form of cooperative arrangements between private operators and public regulators in developing, financing and implementing the various security programmes and initiatives (AAPA, 2004). Such mechanisms do not, however, exist at the international maritime level, and for ports in particular.

Finally, we stress that the framework and methods given in this paper are primarily illustrative and not intended to be conclusive. A more definitive analysis, for example, for a given port or for regional/national policy issues, requires the availability of specific marked analyses and project development plans and costs much beyond the information and resources available in this paper. The results of the present study could serve as a framework to point the way forward and highlight the potential for integrative and collaborative logistics and supply chain management, with a view to increasing security awareness, standards, and practices across the international port and shipping community.

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6
Governance in Seaport Clusters

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Seaports can be meaningfully analysed with a cluster perspective. In this perspective, seaports are regarded as concentrations of economic activity related to the arrival and service of ships and cargoes at ports. This perspective has two main advantages: first, it draws attention to forces of agglomeration and disagglomeration in seaports. Some seaports are able to become concentrations of logistics activities, commercial centres, 'information hubs' and 'shipping hubs', while others do not attract such activities. The cluster perspective allows for an analysis of such processes of agglomeration. Second, the cluster perspective enriches existing theories on governance in seaports. The analysis of governance in seaports has mostly been limited to the role of the port authority. Notwithstanding the central role of port authorities in ports (port clusters), we argue that a port authority is one 'arrangement' to improve the governance in clusters, but not the only 'arrangement'. Other arrangements include the formation of associations, the development of public-private partnerships and the use of networks. The literature on governance in clusters provides a broad analytical framework. This framework has implications for analysing the important and complex issue of the role of port authorities in seaports. In this paper, we deal in depth with the issue of cluster governance in seaports and illustrate our approach to cluster governance with an analysis of the port of Rotterdam.
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Introduction

Seaports are not just nodes in a transport chain, but may be seen as regional clusters of economic activities. Central in the cluster perspective is the recognition that the development of individual firms in a cluster depends crucially on the development of the cluster as a whole.[1]

Ports have always been clusters of economic activity. The arrival of *cargo* and *ships* in ports has always attracted related economic activities such as shipping, forwarding and other transport activities. These activities locate in seaports precisely because seaports are transport nodes. Furthermore, seaports are attractive locations for logistics activities, such as storage, assembling, re-packing and consolidating. Ports are also industrial zones. Because of the necessity to store commodities such as oil, coal and iron ore in seaports, some *production* activities, including chemical and steel production, are frequently located in seaports. Ports are also centres of trade. For some commodities, such as steel, grains and oil, trading takes place in the same place as storage, because buyers and sellers either want to inspect the product, or because information on shipping prices is elementary for trading companies.

Thus, cargo-handling activities, transport activities, logistics activities, *specific* production activities and *specific* trading activities are strongly inter-related. These activities are therefore 'port cluster activities' (see de Langen (2004) for a more detailed analysis). Table 6.1 shows the specialisation index of various port cluster activities in Rotterdam. This index shows the relative concentration of particular industries in Rotterdam. A score of 2 means that the number of firms in Rotterdam is twice the national average. Table 6.1 shows the relative concentration of most port cluster activities in Rotterdam.

In this paper, we deal with the issue of cluster governance in seaport clusters and illustrate our approach with an analysis of the port of Rotterdam.

First, we briefly discuss the theoretical foundations of the cluster governance concept and second, results of a survey among 43 cluster experts in Rotterdam on the governance of Rotterdam's port cluster are presented. We finalise the paper with conclusions.

Quality of cluster governance

Apart from well-known physical factors such as location, maritime accessibility and hinterland infrastructure, the *governance* of seaports is an important determinant of their performance (see de Langen, 2004).

Table 6.1 Relative concentration of port cluster activities in Rotterdam

	Activity description	**Specialisation index**
Cargo handling	Marine cargo handling	7.7
	Port and harbor operations	4.7
Transport	Freight transportation arrangement	4.6
	Inland water freight transportation	4.0
	Coastal freight transportation	3.8
	Other support activities for water transportation	3.7
	Deep sea freight transportation	3.2
Logistics	Support activities for transportation	3.0
	Process, physical distribution and logistics consulting services	0.7
Manufacturing	Industrial gas manufacturing	4.9
	Pipeline transportation of crude oil	3.5
	Petroleum refineries	3.4
	Petrochemical manufacturing	3.1
Trade	Petroleum and petroleum products wholesalers	1.8
	Chemical products wholesalers	1.4
	Metal and mineral (except petroleum wholesalers)	1.0

An analysis of the governance of seaports has mostly been limited to the role of the *port authority*. Notwithstanding the central role of port authorities in ports, we argue that an analysis of governance in seaports requires attention for the role of (private) firms. Institutional economic literature offers a useful framework for analysing advantages and disadvantages of alternative governance mechanisms and provides a basis for analysing the roles of port authorities.

We define cluster governance as 'the mix of, and relations between, various mechanisms of coordination used in a cluster'. The *quality* of governance differs between clusters. The quality depends on the *level of coordination costs* and the *'scope'* of 'coordination beyond price'. *Low* coordination costs and *much* coordination beyond price improve the quality of governance.[2]

When the benefits of coordination are *distributed unequally*, when (the threat of) *opportunistic behaviour* prevents coordination or when benefits of coordination are *uncertain*, coordination beyond price does not arise *spontaneously* or *instantaneously,* even when benefits of coordination exceed costs. Therefore, there is in general a lack of coordination beyond price and more coordination beyond price improves the quality of the governance of clusters.

Based on a literature review, we distinguish four variables of the quality of cluster governance (Figure 6.1). Each of these is discussed below.

Trust

In clusters where the level of trust is high, (average) transaction costs are relatively low, because of low costs to specify contracts and low monitoring costs. Furthermore, costs of coordination beyond price are lower and as a consequence, more coordination beyond price will arise. Finally, specific investments are more viable when partners trust each other, since the risk of opportunistic behaviour is lower. Thus, specific investments for partners are more likely to occur in 'high trust clusters'.

The level of trust in a cluster is influenced by *reputation effects*. If reputation effects are strong, abusing trust has negative effects and therefore a culture of trust is sustained. This reputation effect has both an economic and a social aspect: *firms* strive for a good reputation because it yields positive returns, *managers* strive for a good reputation because it yields social status and personal career opportunities.

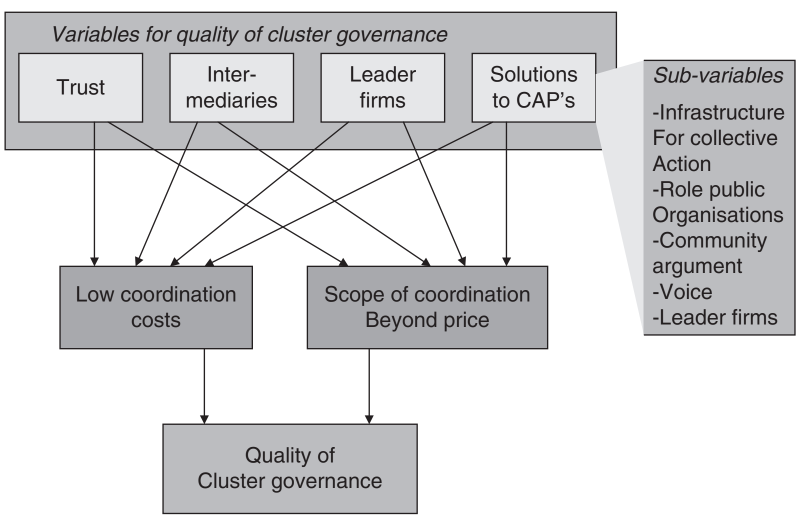

Figure 6.1 Four variables of the quality of cluster governance

Intermediaries

The presence[3] of intermediaries in a cluster lowers coordination costs and expands the scope of coordination beyond price, for three related reasons. First, they provide a 'bridging tie' (McEvily and Zaheer, 1999) between two or more otherwise not connected exchange partners. Second, intermediaries reduce coordination costs because they 'connect cognitions'. Intermediaries can bridge cognitive differences between firms that operate in different market environments. This role of connecting cognitions is especially important in clusters given the fact that clusters are characterised by a 'cognitive division of labour' (Belussi and Gottardi, 2000).

Third, intermediaries reduce the costs of starting and disentangling relationships (Nooteboom, 2000). Some intermediaries specialise in enabling cooperation (in projects). Such intermediaries lower coordination costs and reduce the threat of opportunism.[4] Haezendonck (2001) shows that firms in the port of Antwerp regard the presence of intermediaries as a strength of this port cluster.

Leader firms

Leader firms are 'strategic centres with superior coordination skills and the ability to steer change' (Lorenzini and Badenfuller, 1995). The behaviour of leader firms influences the performance of the cluster as a whole, because leader firms have both the *ability* and *incentive* to invest in the competitiveness of a whole network of firms. We identify three investments of leader firms with positive effects (these can be termed 'leader firm externalities') on other firms in the cluster:

- internationalisation;
- innovation;
- contribution to solving collective action problems (Olson, 1971).

Thus, leader firms can enable or even enforce cooperation and for that reason add to the performance of clusters.

Collective action in clusters

The 'problem' of collective action (Olson, 1971) is relevant in clusters. Even when collective benefits of cooperation exceed (collective) costs, such cooperation does not (always) develop spontaneously. Different CAPs (Collective Action Problems), such as education and training and innovation[5] are relevant in clusters. In each cluster, the 'collective action regime' (CAR) to solve a specific CAP can be analysed. In this context, a regime can be defined as a 'relatively stable collaborative agreement that provides actors with the capacity to overcome collective action problems'.

Different *modes of coordination* play a role in a regime. We distinguish six general modes of coordination (Hollingsworth and Boyer and Williamson, 1985): markets, hierarchies, interfirm alliances, associations, public–private bodies and public bodies.

None of the different modes of coordination is 'structurally superior'; each mode has advantages and disadvantages. Consequently, different modes have a specific *domain,* and play a different role in a regime.

The role of different coordination mechanisms, as well as the relation between these mechanisms, differs between regimes. The mix and roles of different coordination mechanisms in a regime is *path dependent.*[6] Past investments in a regime lead to high adaptation costs (Westlund, 1999). Furthermore, a regime defines the 'rules of the game' which are thus taken for granted. Finally, firms do not have the incentive to change a regime.[7] *Therefore, relatively inefficient regimes can persist.* Consequently, governance regimes differ substantially, between countries, industries and clusters (Hollingsworth *et al.*, 1994). Hollingsworth *et al* (1994) even argue that differences in regimes are central in the competition between clusters. They argue that *'economic competition is increasingly becoming competition over different systems of production'* (Hollingsworth *et al*, 1994, p. 38).

The quality of a regime

We identify five (cluster specific) variables of the quality of a regime. First, the *presence of an infrastructure for collective action* adds to the quality of a regime, because such an infrastructure provides opportunities to solve CAPs. The infrastructure for collective action consists of three kinds of organisations: *associations, public–private organisations and public organisations.*[8] *Associations* are well equipped to solve CAPs, since they act in the interest of all their members*; public organisations* can contribute to solve CAPs because they aim to generate collective benefits, and *public–private partnerships,* as an arrangement, with involvement of both public organisations and associations, acting in the interest of their members, can also help in overcoming CAPs.[9] Associations and public–private organisations do not develop automatically but, when they exist, they provide a fertile ground for solving CAPs.

Second, the *role of public organisations in a regime* influences the efficiency of the regime. Public organisations can play a role in solving CAPs but, unlike private institutions, they are not primarily driven by economic incentives. Public organisations can be 'prospective partners' capable and willing to contribute to solving CAPs but they can also be organisations with a very modest involvement in solutions to CAPs.

Third, *voice* (Hirschmann[10]) of firms is important because associations, public and public–private organisations do not adapt automatically. They face only limited 'selection pressure' and as a consequence, adaptation is more likely when firms use their voice. Since adaptations improve the quality of a regime,[11] 'voice' adds to the quality of a regime.

Fourth, the *validity of a community argument* adds to the quality of a governance regime (Bennet, 1998), since a higher willingness to invest in the 'port community' enables better solutions for CAPs. Fifth, the role of *leader firms* increases the quality of the regime, because leader firms have incentives and resources to invest in CAPs.

Collective action in seaports

A CAP can be identified on the basis of two (related) criteria: first, investments should have benefits for a large number of firms in the cluster and second, benefits cannot be priced effectively. CAPs are especially relevant for port clusters because one broad 'port service' exists. This port service is a combination of the services of different firms, such as pilots, towage firms, terminal operators, hinterland transport companies, transport service providers and transport intermediaries. All these companies benefit from a competitive port service, and contribute to the port service. None of the companies can fully appropriate the full benefits of a high quality port service. We discuss five CAPs[12] that are likely to be relevant in seaports.

A first CAP is innovation. *Innovation regimes*[13] influence the size of 'knowledge spillovers' (Edquist, 1997, Cooke, 1998; and Panniccia, 1999). Innovation regimes differ between clusters and these differences affect performance (Belussi and Gottardi, 2000). *Associations* can play a role as knowledge intermediaries. Members of associations have (indirect) access to a large network of firms possessing knowledge and information. Public–private knowledge institutes and public research centres are also included in an innovation regime.

Training and education is a second CAP.[14] Associations can engage in providing education and collective bargaining for education. Furthermore, associations monitor the quality of the 'education and training infrastructure', consisting of public and public–private education institutes.

Internationalisation is a third CAP. Internationalisation of firms is predominantly a market-driven process, but the local embeddedness of firms in a cluster[15] can be a barrier for internationalisation. This barrier arises because of 'lock-ins', ties that 'blind' (Pouder and St. John, 1996) and a closed inward orientation (Porter (1990) terms such clusters 'insular clusters').

Internationalisation requires firms in clusters to be included in external 'open' networks (Blackburn *et al*, 1993). External networks guarantee that a cluster remains open for new developments. Such networks increase the 'propensity to change' (Best, 1990).

Associations can play a role in an internationalisation regime, for instance by providing information, by monitoring export regulations, by organising collective representation and by acting as a 'bridging tie'. A public port authority can engage in similar activities to reduce the barriers to internationalisation.

Marketing and promotion is a fourth CAP. Marketing and promotion activities have in general a twofold goal: first, to attract *companies* to the port cluster and second, to attract *cargo* to the port. Both activities have collective good characteristics: all firms benefit indirectly (and sometimes directly) from these marketing efforts, but for individual firms benefits do not exceed costs. Therefore, the marketing of the port is a 'collective good'.

Hinterland access is a fifth CAP. Hinterland access is crucial for the attractiveness of seaports (Kreukels and Wever, 1998). The quality of hinterland access depends on investments of firms in the port cluster. However, no individual operator can fully appropriate the benefits of a good hinterland access, but a variety of firms in the cluster benefit from it. These firms – and the port authority[16] – could benefit from collective action.

An important issue in this respect is the role of *inland nodes* in a port network. Van Klink (1995) convincingly argues that ports aiming to optimise their hinterland access should create port networks with inland nodes. The port authority, together with private port operators and other stakeholders could co-invest in such hinterland nodes. In practice, many port authorities and firms in the port cluster do invest in hinterland nodes, examples including Marseilles in Lyon, Amsterdam in Duisburg and Hamburg in a variety of eastern European countries. Such investments can be analysed as the outcomes of a 'hinterland access regime'.

Cluster governance in the port of Rotterdam

In this section, we present an empirical case study of the port of Rotterdam. We interviewed 43 port experts[17] in the port of Rotterdam.

First, we deal with the importance of cluster governance for the performance of the cluster (Table 6.2). In the next four subsections, we discuss the empirical results for the four variables that influence the quality of cluster governance. Sixth, we briefly discuss the role of the port authority in Rotterdam and end with conclusions.

The importance of cluster governance in Rotterdam's seaport cluster

The interviewed experts were asked to indicate the relative importance of the four variables of cluster governance, by ranking them. These results are given in Table 6.3.

Table 6.3 shows that the presence of trust and leader firms are the most important variables. The presence of intermediaries is regarded as not really important, while solutions to CAPs are moderately important.

Trust in Rotterdam's port cluster

Virtually, all cluster experts agree with the proposition that trust is important for the quality of cluster governance and, as discussed above, argue that trust is the most important 'governance variable'. The cluster

Table 6.2 The importance of cluster governance

Proposition	Agree	Disagree	No option
Differences in the governance of clusters influence the performance of that cluster	43[a]	0	0
The development of port clusters is the result of the interplay of market forces and (inter) national policies. The quality of local governance does not have a substantial affect on the performance of a cluster	3	40[a]	0

[a]Significantly different from the scores of the other variables. By significant we mean less than 5% change that such a difference arises with random responses.

Table 6.3 The importance of four governance variables

Variable	Score
Trust	1.7
Presence leader firms	2.0
Solutions for CAP's	2.8[a]
Presence of intermediaries	3.5[a]

[a]See Table 6.2 footnote.

experts evaluated the port of Rotterdam and its main competitors, Antwerp and Hamburg, with regard to the presence of trust. The results are given in Table 6.4.

This table indicates that the experts judge Rotterdam as a port cluster where the level of trust is low. Both competing ports do better in this respect.

Leader firms in Rotterdam's port cluster

Virtually, all cluster experts also agree that the presence of leader firms is an important determinant of the quality of cluster governance. The experts evaluated the three competing ports as given in Table 6.5.

Antwerp is evaluated the most positive, Hamburg has the lowest score. In general, the experts indicate that all three ports do score relatively good with regard to leader firms.

Intermediaries in Rotterdam's port cluster

With regard to intermediaries, a significant majority of the experts agree with the presumed positive effect of intermediaries on cluster governance, but nine out of the 43 disagree. Those that agree also indicated the relative importance of six intermediaries (see Table 6.6).

This table indicates that the forwarder is the most important intermediary in the port cluster. Furthermore, all intermediaries that 'control' cargo are more important than the other three, including the associations. The score of associations is relatively low: they are not regarded as important intermediaries in the port cluster. Antwerp comes out best

Table 6.4 Presence of trust

	Rotterdam	**Antwerp**	**Hamburg**
Trust	0.8[a]	1.8[b]	1.7[b]

Evaluation of the experts (scores ranging from –5: very bad to +5: very good).
[a] Significantly worse than in both competing ports.
[b] Significantly better than in worst port.

Table 6.5 Presence of leader firms: evaluation of the experts

	Rotterdam	**Antwerp**	**Hamburg**
Presence of leader firms	2.0	2.3[a]	1.5

[a] Significantly better than in worst port.

Table 6.6 The relative importance of six port intermediaries

Intermediary	**Rank**
Forwarders	2.0[a]
Non-asset-owning logistics service providers	2.9[b]
Ship's agents	3.0
Associations	4.0
Commodity traders	4.2
Shipbrokers	4.4

[a] Significantly higher score than the other five intermediaries.
[b] This group of intermediaries are significantly more important than the other three.

Table 6.7 Intermediaries: evaluation of the port experts

	Rotterdam	**Antwerp**	**Hamburg**
Presence of intermediaries	2.1	2.5[a]	1.7

[a] Significantly better than in worst port.

Table 6.8 CAP's in Rotterdam's port cluster

Issue	**Collective action problem**	
	Relevant	**Not relevant**
Training and education	38[a]	3
Marketing and promotion	37[a]	4
Hinterland access	37[a]	4
Innovation	29[a]	12
Internationalisation	13	28[a]

[a] Significant majority.

while Hamburg is judged to be less well endowed with intermediaries. Furthermore, all three ports have relatively high scores (see Table 6.7).

Solutions for CAP's in Rotterdam's port cluster

Finally, we discuss the quality of solutions for collective action problems. Out of the five proposed CAP's in seaports, the cluster experts judged four as relevant (see Table 6.8).

The activities of different actors in the port cluster of Rotterdam are summarised in Table 6.9.

Table 6.9 shows that for these four 'regimes', various cooperative initiatives have been taken. This validates the expert judgements that

Table 6.9 Activities of different actors in the port cluster of Rotterdam

Regime	Private	Public–private	Association	Public
Marketing and promotion	Individual marketing and promotion efforts	RPPC is an association that is public–privately funded	The Rotterdam port promotion council (RPPC), organise business tripls and hosts guests of the port	Rotterdam representatives public funding of RPPC
Training and education	Company schools (ECT and shell used to have a school, but outsource training and education). However, firms do a lot of 'hands-on training' in-house	Education centre EIC is financed by public and private actors to provide schools with information and education of the port industry. KMR aims to improve the knowledge and education infrastructure in the port of Rotterdam	Deltalinqs, the association of port firms, invest in EIC and a 'University chair port economics'	Rotterdam Transport Schools (RTS) is a cooperation of four major providers of port- and transport-related education in Rotterdam
Hinterland access	Firms operating trucks, rail shuttles and barges ECT investing in inland nodes	PCR-RIL, institution to improve the efficiency of services to hinterland modes	Lobby activities of various associations, including Deltalinqs	Investment by the port authority in hinterland terminals in Hungary strategic partneships with inland nodes
Innovation	Some firms invest in innovations. Especially for small- and medium-sized firms, investment in innovation is limited	Connekt, an organisation that encourages and provides incentives for innovations in the transport industry	Deltalinqs has a limited involvement in stimulating innovations	The port authority encourages innovation of firms, but does not provide direct incentives

Table 6.10 Solutions to CAP's: evaluation of the experts

	Rotterdam	Antwerp	Hamburg
Solutions to CAP's	1.0	2.2[a]	1.6

[a] Significantly better than in worst port.

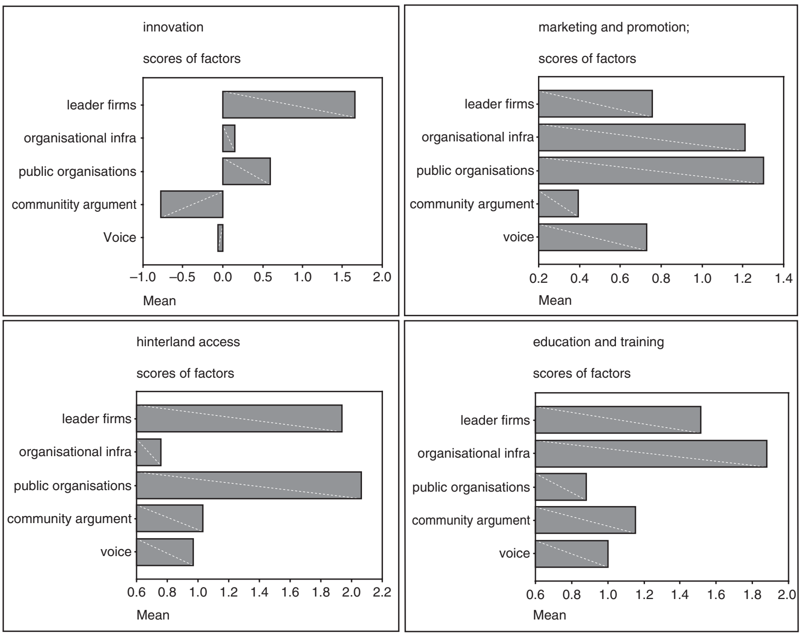

Figure 6.2 The scores of four regimes in Rotterdam's port cluster

these issues are collective action problems in the first place. The fact that a number of cooperative initiatives have developed does not imply that solutions to CAP's are effective. In Figure 6.2, for each regime, the five variables discussed above are evaluated, on a scale of –5 (very bad) to +5 (very good).

These results indicate that the solutions to the four CAPs are judged as moderate. With regard to innovation, the quality of leader firms is judged as good, whereas the infrastructure for collective action and the community argument (willingness to participate in collective innovation projects) are evaluated negatively. For marketing and promotion, the organisational infrastructure (Rotterdam Port Promotion Council) and the role of the public organisations are positively evaluated. With regard to hinterland access, especially the low score of the organisational infrastructure is worth mentioning. The organisational infrastructure for training and education is evaluated more positively.

Compared to both Hamburg and Antwerp, the respondents judge the quality of solutions for collective action problems as relatively poor (see Table 6.10).

Conclusions

In this paper, we argue that an analysis of the governance in port clusters adds to our understanding of port competition and port performance. We have presented an analytical framework for analysing (port) cluster governance. The quality of the governance of a cluster depends on the level of transaction costs in a cluster and the 'scope of coordination beyond price'. Four variables influence both: the presence of leader firms, the presence of intermediaries, the level of trust, and solutions to collective action problems. Cluster governance can be evaluated by analysing those four variables. In this approach, port authorities are no longer centre stage; they do play an important role in the governance of the cluster, but their role is inter-related with the activities of private firms, associations and public–private organisations. The scope of activities of the port authority has thus to be analysed in this broader framework.

The cluster governance framework is applied to the port cluster of Rotterdam. Through semi-structured interviews with port experts, the opinions of those experts with regard to a wide number of cluster governance issues have been collected. The empirical results validate the relevance of the cluster governance approach. Further empirical results include:

- the role of forwarders as intermediaries in port clusters cannot be overestimated. They are by far the most import intermediary in the port cluster;
- leader firms can make an important contribution to the quality of cluster governance. Rotterdam, Hamburg and Antwerp are relatively well endowed with leader firms;
- trust is the prime determinant of the quality of cluster governance. According to the port experts the level of trust in Rotterdam's port cluster is significantly lower than in both Hamburg and Antwerp;
- collective action problems are relevant in seaports. The most important CAP is the hinterland accessibility, other relevant CAP's are innovation, training and education, and marketing and promotion;

- in an overall comparison of the quality of cluster governance between three competing ports (Rotterdam, Antwerp and Hamburg), port experts from Rotterdam judge Antwerp as a port cluster with the best governance, significantly better than both Rotterdam and Hamburg.

The framework and empirical results presented in this paper provide a basis for further empirical research. Among the interesting research avenues are: a comparative analysis of port clusters, a comparative analysis of the roles of port authorities as cluster managers, and an analysis of the role of leader firms in port clusters, with special attention for the possible roles of leader firms in ports in developing nations.

Notes

1. For these reasons, we claim that the performance of a port cannot be understood when a port is analysed as a transport node, or an element of a logistics chain. Such a perspective neglects the interdependence of various economic activities that cluster together in seaports.
2. Given the presence of regulations that prevent collusion.
3. The presence of intermediaries in a cluster offers advantages because the costs of using a local intermediary are lower than the costs of using an intermediary outside the cluster. Furthermore, intermediaries are likely to have a dense local network and client base.
4. The above-mentioned reasons are the 'raison d'être' of many intermediaries. However, their presence in an industry is a different issue than their presence in a (regional) cluster.
5. For each specific cluster, different issues are relevant, issues such as an education regime and an innovation regime are widely regarded as relevant for the performance of clusters.
6. Campbell *et al* (1991) argue that 'When actors have already established associations (y) and thus the capacity for selecting far sighted cooperative strategies, they can more easily devise new multilateral governance mechanisms than actors from a sector, where short sighted bilateral mechanisms dominate the governance regime (Campbell *et al*, 1991, p. 331). This shows the path-dependence of regimes.
7. Instead of investing in the quality of regimes firms can also leave the cluster when regimes are not efficient or 'free-ride' on the investments of others.
8. The coordination mechanisms markets, hierarchies and interfirm alliances are used in clusters, but are used for transactions within a firm or between a limited number of firms. These coordination mechanisms are not suited for solving CAPs. Other kinds of institutions, such as discussion platforms and informal are not truly elements of an infrastructure for solving CAPs.
9. Public–private organisations and public organisations can be regarded as elements of the infrastructure for collective action (of a cluster) if they are established to generate *cluster-specific collective* benefits.

10. Hirschman (1970) discusses three possible reactions when confronted with an unsatisfactory situation (in his case working conditions): exit, voice and as a third possibility, 'silence'. The first two are sources of pressure, the third is not. When applied to association members, exit means that firms do not use services of associations. Exit does not directly contribute to the quality of a regime.
11. Campbell and Lingberg write with regard to changing a regime that 'actors eventually select a new governance regime as streams of action intermingle in complex ways. Trial and error learning as the result of spontaneous interaction may predominate in some instances (…). In this sense, selection is very much a process of muddling through. In other cases, deliberate coordinations among organisations will take the place of, or supplement, trial and error' (Campbell and Lingberg, 1991, p. 331). This illustrates that adaptation of regimes is far from spontaneous.
12. Four of these five issues are relevant for clusters in general, hinterland accessibility is a port-specific governance issue. These five issues are important but not the only five issues. Other relevant issues include the relation between port and city and port expansion.
13. Cooke (1998) uses the term 'regional system of innovation', Brackzyk *et al* (1998) the term 'regional innovation systems'.
14. Since labour is mobile, all firms in a cluster benefit indirectly from investments in training and education.
15. Albertini (1999) argues that internationalisation is indeed to some extent a 'collective process': 'the main transformation process can be identified in the evolution of the district from closed contextual 'community networks' to 'semantic' and 'market' networks – that are open and integrated with the global economy' (Albertini, 1999, p. 113).
16. Public authorities are generally deeply involved in safeguarding the quality of accessibility, through investing in infrastructure, infrastructure utilisation, and spatial planning.
17. These experts are selected on the basis of three criteria: job position, years experience in the port industry and involvement in cluster governance. A first selection of about 38 was made in cooperation with Professor Welters, former director of the port association. This list with experts was supplemented based on the suggestions of the port experts. Overall, 43 of the 49 experts on the list were interviewed and filled out a questionnaire.

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7

The Size Economies and Network Efficiency of Large Containerships

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Following a long period in which the maximum size of containerships grew only slowly the last three years had seen a large increase to over 7,000 TEUs. A modern version of the old McKinsey view of 1967, that large ships imply huge size economies and the increasing use of concentrated hub and spoke networks, also seems to be regaining strength. The aim of this paper is to challenge these views. The authors argue that size economies in ships at the upper end of the spectrum are relatively weak; and constraints to growth in port access, container handling and network operations will become increasingly severe beyond about 10,000 TEUs. I will also argue that end-to-end services (including pendulum-style operations) will continue to provide the basis of the networks operated by large vessels, and that hub and spoke operations are simply part of the overall scene.

Introduction

Following a long period in which the maximum size of containerships grew only slowly the last three years has seen a large increase to over 7,000 TEUs. Some carriers and port authorities are also contemplating the possibility of a further increase to 15,000 TEUs within a decade. A modern version of the old McKinsey view of 1967, that large ships imply huge size economies and the increasing use of concentrated hub and spoke networks, also seems to be regaining strength. The aim of this paper is to challenge these views. I will argue that size economies

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in ships at the upper end of the spectrum are relatively weak; and constraints to growth in port access, container handling and network operations will become increasingly severe beyond about 10,000 TEUs. I will also argue that end to end services (including pendulum style operations) will continue to provide the basis of the networks operated by large vessels, and that hub and spoke operations are simply part of the overall scene.

The paper starts with a historical review of the development of the fleet. It goes on to consider the physical dimensions of vessels in relation to increases in capacity. The following section deals with the difficulties encountered in the port sector in providing access for larger vessels, and the problems involved in providing the faster container handling capabilities required. The paper then considers ship operating strategies. The first of these concerns the use of specialised end to end services as a method of reducing the number of ships in the string, thus providing an alternative route to cost savings, and the second relates to the advantages in keeping within a maximum ship size at which large vessels can access a wide range of ports and provide for direct distribution to a number of ports in each trading hinterland.

Growth of the fleet

The capacity of the world fleet of cellular containerships has grown very rapidly since 1994. Data from the Clarkson Containership Register, presented in Table 7.1, shows that (following seven years, from the end of 1986 to 1993, when growth averaged about 8% per annum) the rate picked up to 11 % in 1994, 13% in 1995 and some 15% in both 1996 and 1997. The order book as of January 1998 provided for a further 20% increase most of which was scheduled for 1998 and 1999. As a result the fleet will double between 1994 and the year 2000. This is the strongest burst of growth in the last two decades. The only period approaching it in terms of rate was the mid 1980s, but that was on a much smaller base.

The growth of container traffic is not the subject of this paper. Nevertheless, there is now an expectation that we are entering a period of reduced economic and trade growth. If this is so, trends in the development of larger vessels will be put on hold. In the longer term, for a world economy growing at a moderate rate, one would not expect the rate of growth of container traffic to be less than about 5% per annum, and even this rate (which is quite low in historical terms) would require a doubling of fleet capacity in fourteen years.

Table 7.1 Composition of the containership fleet by size

Fleet at the Start of year	Feeder 100–499		Feedermax 500–999		Handy 1,000–1,999		Sub-Panamax 2,000–2,999		Panamax 3,000 & Over		Post-Panamax 4,000 & Over		Total		Growth %
	No.	**TEU**	**No.**	**TEU**	**No.**	**TEU**	**No.**	**TEU**	**No.**	**TEU**	**No.**	**TEU**	**No.**	**TEU**	
1980	249	61431	137	100642	200	275689	66	165499	6	18291			658	621552	
1981	258	66285	149	108930	219	304046	92	229112	8	24323			726	732696	17.9
1982	273	71602	159	114936	227	314689	94	234820	11	33785			764	769832	5.1
1983	293	78762	178	128758	247	341963	101	251380	12	36801			831	837664	8.8
1984	310	84663	203	146299	275	381543	119	292284	13	39817			920	944606	12.8
1985	318	87487	222	159576	293	407380	140	345776	20	66927			993	1067146	13.0
1986	340	96036	241	173441	322	447105	153	376913	30	106847			1086	1200342	12.5
1987	345	98110	250	180814	341	475859	178	441827	42	145203			1156	1341813	n.8
1988	352	100563	254	183926	352	490963	187	463801	57	193347			1202	1432600	6.8
1989	360	102687	260	188577	363	505742	195	484899	72	245973	5	21700	1255	1549578	8.2
1990	365	104575	269	195047	373	520905	209	520309	83	287449	5	21700	1304	1649985	6.5
1991	369	106143	276	200455	405	565299	221	551591	95	332126	5	21700	1371	1777314	7.7
1992	386	111555	284	206978	430	599789	236	591555	110	387502	6	26127	1452	1923506	8.2
1993	388	112407	301	220286	459	635951	246	617737	126	444594	12	52596	1532	2083571	8.3
1994	388	113086	302	220551	507	687793	257	646415	148	529234	12	52596	1614	2249675	8.0
1995	402	118018	320	231996	570	781760	266	668235	175	632534	15	65862	1748	2498405	11.1
1996	429	128222	354	253563	620	850691	280	701923	209	741474	31	141800	1917	2817673	12.8
1997	432	132905	409	291657	678	928988	300	751699	237	865588	53	261959	2106	3232796	14.7
1998	460	140588	453	322762	736	1029160	342	853759	271	998747	73	373405	2335	3718421	15.0
Orders Jan 98	42	15503	84	57355	128	183057	61	144974	42	165327	32	185910	389	752126	
98 plus orders														4470547	20.2

Source: CLarkson Containership Register 1998.

Size structure and lags in the take up of large vessels

Details of the size structure of the fleet are also presented in Table 7.1. The three largest sectors are shown to be the handy size up to 2,000 TEUs, sub Panamax up to 3,000 TEUs, and Panamax from 3,000 to 4,400 TEUs.

The data picks up the story in 1980 and shows that, although the fleet of large vessels grew significantly in the 1980s, the really heavy emphasis on them is actually a phenomenon of the mid and late 1990s. The latest order book shows continuing concentration at the top end of the scale, Containerisation International's newbuilding review for 1998 indicating that, at the end of the year, vessels loading 4,000 TEUs and above accounted for almost 60% of the total of 406,000 TEUs contracted for delivery over the next two years. *(C. L February 1999.)*

The growth of average ship size

The growth of average TEU capacity since 1980 is shown in Table 7.2, which looks first at the fleet of all ships of over 100 TEUs and second at the larger classes of over 2,000 TEUs. The average of all ships did not change much in the early 1980s, but since then it has grown steadily between 30 and 50 TEUs per annum to the present level of 1,590 TEUs. The class of

Table 7.2 Growth of average ship size

Year End	No. of Ships	No. of TEUS	Avg. (TEUS)	Avg. >2,000 TEU
1980	744	736216	990	2534
1981	785	774596	987	2558
1982	856	844328	986	2550
1983	948	953251	1006	2516
1984	1023	1076916	1053	2579
1985	1116	1206841	1081	2643
1986	1187	1348647	1136	2668
1987	1235	1440326	1166	2693
1988	1288	1557304	1209	2767
1989	1338	1658839	1240	2793
1990	1405	1786168	1271	2821
1991	1483	1930235	1302	2856
1992	1560	2088333	1339	2904
1993	1636	2263917	1384	2946
1994	1756	2494388	1420	2994
1995	1923	2832341	1473	3088
1996	2106	3232796	1535	3185
1997	2339	3719135	1590	3245

Source: Derived From Table 1.

ships of over 2,000 TEUs includes most of the Main Line vessels, (those employed on the east-west axis linking Europe, north America and Asia), plus those employed on other long end to end routes, and the larger feeder vessels. The rate of growth from 1983 onwards is still relatively moderate, ranging between some 35 and 90 TEUs per annum, to reach the 1998 level of 3,245 TEUs. Over the period from 1980, the TEU capacity of this class grew sixfold whilst average ship size grew by only some 30%.

Characteristics and capacities of large ships

The path of development

Sea Land was the first carrier to build Panamax beam containerships in the late 1960s, but the Europe Far East ships which defined the Panamax class of large vessels were launched in 1972. They were of 289 m L.O.A., 32.3 m. beam and 13 metres maximum draft. Capacities were up to some 50,000 d.w.t. and between 2,600 and 3,000 TEUs, and service speed was about 26 knots.

Stowage efficiency

The fact that for many years ships stayed within Panamax limits did not stop the growth of capacity, which was substantially increased by virtue of a series of improvements in design and stowage. Much greater use was made of the weather deck with an increase in the number of rows from 12 to 13 and in the number of tiers from 3 to 5. There was also a reduction in the space allowed for cell guides and increase in the number of rows below deck from 10 to 11. Finally, there was an increase in length to 294 m. overall and an increase in draft to 13.5 m. Taken together these developments allowed an increase in slot capacity, to over 4,400 TEUs. The progression is traced in Table 7.3. Improvements in stowage were not, however, limited to the largest ships, and there was similar progress across the size spectrum.

There was also an increase in deadweight capacity to around 60,000 d.w.t. for most ships built in the 1980s and to as much as 67,700 d.w.t. for some of the ships built in the 1990s. Some 5,000 d.w.t. can be attributed to an increase in maximum draft, the largest vessels being all rated at 13.5m. There would also have been some gains from the increase in length plus changes in hull form consequent upon a reduction in speed. Nevertheless the size of the overall gain in weight carrying capacity is somewhat surprising given the small increase in principal dimensions, and it may be that for the early ships the deadweight capacity was rather underestimated.

Table 7.3 Trends in maximum d.w.t. (capacities and principal dimensions of largest vessel launched each year)

Present Name	Year	d.w.t.	TEUS	d.w.t./TEU	LOA m.	LBP m.	Beam m.	Draft m.
Sea-Land Navigator	1970	31303	2361	13.26	247.58	237.80	27.49	11.14
Li hue	1971	38656	2128	18.17	240.09	220.68	30.54	10.70
London Maersk	1972	49590	2804	17.69	289.57	273.97	32.34	12.98
Paris Maersk	1973	49593	2804	17.69	289.57	273.97	32.34	13.03
MSG Rita	1974	35520	2068	17.18	264.52	248.01	32.24	12.04
Anna Maersk	1975	37129	1984	18.71	239.28	223.17	30.56	11.52
Kasuga I	1976	44538	2326	19.15	289.50	273.00	32.24	12.23
Nedlloyd Houtman	1977	49262	3005	16.39	258.70	247.40	32.31	13.03
S. A. Winterberg	1978	50819	2464	20.62	258.50	247.38	32.31	13.15
S. A. Waterberg	1979	50027	2464	20.3	258.50	247.38	32.31	13.15
President Eisenhower	1980	47841	2522	18.97	260.26	245.24	32.26	12.53
Maersk Tokyo	1981	53540	3734	14.34	269.78	261.25	32.26	13.02
Leda Maersk	1982	53690	3016	17.8	269.78	261.25	32.26	13.03
Leise Maersk	1983	53310	3016	17.68	269.98	261.25	32.29	13.03
Nedlloyd Holland	1984	58869	4534	12.98	289.52	279.00	32.31	12.68
OOCL Innovation	1985	58869	4534	12.98	289.52	279.00	32.31	12.68
Ever Given	1986	53240	3428	15.53	269.68	253.00	32.20	11.63
Ever Glamour	1987	53240	3428	15.53	269.68	253.02	32.21	11.63
Marit Maersk	1988	60639	3922	15.46	294.11	284.37	32.28	13.50
Mette Maersk	1989	60900	3922	15.53	294.11	284.37	32.28	13.50
Hannover Express	1990	67680	4409	15.35	294.00	281.60	32.30	13.50
Leverkusen Express	1991	67680	4409	15.35	294.00	281.62	32.30	13.50
Hanjin Osaka	1992	62681	4024	15.58	289.50	273.64	32.20	13,00
Essen Express	1993	67680	4422	15.31	294.00	281.60	32.25	13.50
Hamburg Express	1994	67680	4422	15.31	294.00	282.00	32.25	13.50
OOCL California	1995	67765	4960	13.66	276.02	262.00	40.00	14.03
Regina Maersk	1996	84900	6418	13.23	318.24	302.27	42.80	14.00
Sovereign Maersk	1997	93390	7060	13.23	346.70	331.50	42.00	14.50

Source: Derived from Clarkson Containership Register.

Post panamax & super post panamax ships

The basic details of post Panamax fleets are shown in Table 7.4. APL's post Panamax vessels launched in 1988 made the breakthrough into the new era. They had a beam of 39.4 metres, allowing three more rows of containers and giving sixteen across on the weather deck. But they were shorter than the Panamax class so that, at 4,340 TEUs, capacity was no greater. Indeed APL explained at the time that the aim of its design was to provide for better stability, reduced ballast requirements, the lifting of loading constraints and an improvement in cargo handling. At the same time the ships achieved an ideal length to beam ratio, fine lines and good propulsive efficiency. The increase in beam opened up a potential for a large increase in capacity, but this was not at first exploited. Over the period from 1988 to 1995, there were permutations in length, beam and draft, the size of the largest ship growing modestly to around 5,000 TEUs.

A large increase in capacity has occurred in the last three years with the introduction by P&O, Nedlloyd, and Maersk Line, respectively, of three classes of super post Panamax ships. In the P&O Nedlloyd ships, the main change is that length increased from the previous post Panamax maximum of some 280 m. up to 300 m. Beam increased to 42.8 m to

Table 7.4 Post Panamax and Super Post Panamax (capacities and principal dimensions)

Beneficial Owner	No of Ships	Year	TEUS	Dwt	d.w.t./ TEU	LOA m.	LBP m.	Breadth m.	Draft. m.
A.P. Moller	6	1996–97	6,418	84,900	13.23	318.24	302.27	42.80	14.00
	9	1997–99	7,060	93,390	13.23	346.72	331.50	42.00	14.50
Evergreen	14	1996–2000	5,364	63,388	11.82	285.00	268.00	40.00	12.70
Hyundai	6	1992–94	4,411	61,152	13.86	275.00	263.00	37.19	13.62
	7	1996	5,551	69,900	12.59	274.60	263.00	40.00	13.50
APL	5	1988	4,340	54,665	12.60	275.14	260.81	39.41	12.73
	6	1995–6	4,832	66,500	13.76	276.30	262.00	40.00	14.00
NYK	3	1994–95	4,743	63,163	13.32	299.95	283.00	37.10	13.00
	5	1997–98	5,750	71,500	12.43	299.90	287.00	40.00	13.00
OOCL	8	1995–97	4,960	67,100	13.53	276.02	262.00	40.00	14.03
Hanjin	7	1996–99	5,300	68,500	12.92	279.00	265.00	40.30	14.00
P&O Nedlloyd	2	1994–95	4,112	55,238	13.43	279.12	265.00	37.75	13.03
	4	1998	6,674	87,900	13.17	299.90	283.80	42.80	14.00
COSCO	6	1997	5,250	69,900	13.31	280.00	267.00	39.80	12.50
NOL	6	1997–98	4,900	66,000	13.47	272.05	258.00	40.00	12.50
Mitsui O.S.K.	5	1995	4,800	62,905	13.11	300.00	283.00	37.10	13.00
NSCA	3	1999	4,400	58,300	13.25	270.00		40.00	
MISC	2	1992-95	4,469	61,428	13.75	275.10	263.00	37.19	13.62
CGM	1	1991	4,427	62,277	14.07	275.66	261.42	37.10	14.00

Source: Clarkson Containership Register.

allow one more row of containers across, and maximum draft increased by 0.5 m. to 14.0 m. This took weight capacity to 87,900 d.w.t. and space capacity to 6,674 TEUs. In the case of Maersk Line, for the first six of a series of fifteen ships, there was the same increase in beam and draft, but an increase in length overall to 318 m. In completing the series, Maersk increased length to 346.7 m. and draft to 14.5 m. to attain the published capacities of 105,000 d.w.t. and 7,060 TEUs. At 13 tonnes per TEU these ships would, however, have the d.w.t. capacity to lift 8,000 TEUs.

Containership prices

Lloyds Shipping Economist have published price data for certain sizes of newbuildings based on Far Eastern yards, and this is presented in Table 7.5. The most striking feature of the series is the variation in newbuilding prices over time as a function of market conditions and exchange rate effects. Following the boom of the early 1980s, the period 1985 to 1988 was one of weak market conditions. Prices picked up in 1989 and peaked in 1991. Since then they have fallen back somewhat and the price of 3,500 TEU ships fell away in 1994 and 1995. Looking across the columns of costs per TEU in Table 7.5, the figures confirm size economies in capital costs, although they are rather uneven. They

Table 7.5 Containership prices 1980–1995

Year End	**Handy 1,600 teu/NB**			**Sub Panamax 2,500 teu/NB**			**Panamax 3,500 teu / NB**		
	$m.	**Cost/TEU**	**% Change**	**$m.**	**Cost/TEU**	**% Change**	**$m.**	**Cost/TEU**	**% Change**
1980	33	20625							
1981	36	22500	9						
1982	32	20000	–11						
1983	36	22500	13						
1984	34	21250	–6						
1985	21	13000	–39						
1986	23	14375	11	31	12480				
1987	22	13438	–7	32	12880	3			
1988	24	15014	12	34	13400	4			
1989	34	21289	42	48	19000	42			
1990	37	23082	8	52	20600	8			
1991	45	28236	22	63	25200	22	65	18571	–10
1992	36	22409	–21	50	20000	–21	68	19429	5
1993	34	21065	–6	47	18800	–6	70	20000	3
1994	29	17928	–15	40	16000	–15	50	14286	–29
1995	35	21938	22	49	19600	23	55	15714	10

Source: Lloyd's Shipping Economist (Prices based on Far Eastern yards).

suggest that, other things being equal, a 40% increase in size from 2,500 to 3,500 TEUs would yield a saving of say 10% to 15% in capital costs.

Some more recent prices for post Panamax ships are also available. Containerisation International reported a Yang Ming order for 5,200 TEU ships at US $ 60 million in April 1998, stating that prices were about US $ 10 million lower than one year earlier. Current prices are clearly very depressed.

The cost structure of large containerships

table 7.6 presents data on the cost structure of modern Panamax and super post Panamax ships, with capital costs estimated at US $ 60 m. and US $ 100 m., respectively. On a daily basis, Panamax port costs amount to just over US$ 27,000 and costs at sea are about US$ 38,500. For the super post Panamax ships, costs are some US$ 43,800 and US$ 52,500, respectively.

Table 7.6 Estimated daily costs for Panamax and super post-Panamax ships

Costs	**Panamax**	**Super Post Panamax**
	US $	**US $**
Capital Costs per day	18886	31477
I & M @ 3.5%.	6000	10000
Total	24886	41477
Fuel		
Main engine (US $ per day)	11250	18750
Aux. Engine (US $ per day)	600	600
Daily Fuel at Sea	11850	19350
Crew		
Daily Cost	1714	1714
Total in Port	**27200**	**43791**
Total at Sea	**38450**	**62541**
Capital Cost %		
In port	0.91	0.95
At Sea	0.65	0.66

Capital Costs
Assumed Prices: Panamax US $ 60m; Super Post Panamax US $ 100 m.
Discounted for 25 year life @ 10% rate of interest.
Converted to daily basis at 350 days per annum
Fuel
Panamax: 150 t.p.d. @ US $ 75 per tonne
Super post Panamax: 250 t.p.d. @ US $ 75 per tonne
Crew
20 men at an average of US $ 30,000 p.a.

On the above basis over 90% of ship costs in port and some two thirds of ship costs at sea are accounted for by capital costs. Fuel costs at sea obviously represent an important element, but smaller vessels of modern design, sailing a little slower, can achieve comparable fuel efficiency. Crew costs are now a small element and size economies in this sector will not be of great importance. Clearly savings in initial capital costs are required to provide significant size economies for the larger vessels.

Lightweight and Propulsive Efficiencies

Methods of preliminary ship cost estimation based on engineering data have long been available to naval architects and used to produce families of standard designs. The calculations start with preliminary design and proceed to estimation of steel weight, outfit, engine requirements, and special equipment, and thence via standard costing for these components, to reach a total for the ship. Results can be expressed in a matrix showing capital costs with size on one axis and speed on the other. Individual size economies curves are, then, available by looking down the size axis and holding speed constant. More realistically, it is also possible to compare options allowing variations in both size and speed. Using this approach in the late 1970s, with preliminary design studies carried out by Burness Corlett & Partners, the result was obtained that, with speed constant, capital costs increased at 0.7 times the increase in size. Similarly, with size held constant capital costs rose broadly in *line* with speed (Gilman S 1980).

It is beyond the scope of this paper to update this data. However, Clarkson's Register has data on lightweight for some 10% of container ships, and broad indications of relative efficiency can be obtained from this sample. To take account of changes in Stowage, a distinction has to be made between the general increase in efficiency over time of all vessels and the economies relating to size and speed within any given period. Returning to the matrix of capital costs, improvements in stowage efficiency would lead to a downwards shift in the whole set. This should be distinguished from the relationships within the matrix which determine the economies of size and speed at a given point in time.

Table 7.7a provides the data on lightweight for a sample of large containerships built between 1972 and the present day. The Tokyo Express (rated at 3,010 TEUs and some 48,000 d.w.t.) – represents the Panamax ships built for the Europe-Far East route in the early 1970s. This was 24,000 l.w.t. of which some 16,500 tonnes would have been steel weight, 3,000 tonnes outfit, 3,000 tonnes machinery, and up to about 1,500 tonnes container arrangements.

Table 7.7a Ship capacities and dimensions in relation to L.W.T.

Vessel Name	Year	LWT	TEUS	Dwt	LOA m.	Breadth m.	Draft m.
1972							
Bremen Express	1972	24,080	2,984	47,733	287.61	32.20	12.79
Tokyo Express	1972	24,080	3,010	47,733	287.71	32.31	12.79
1975–1980							
OOCL Exporter	1976	19,711	2,535	41,587	270.77	30.50	11.52
MSC Alice	1976	15,463	2,512	38,984	252.20	30.50	10.89
MSC Katie	1977	15,463	2,544	38,908	252.20	30.51	10.90
MSC Edna	1977	15,463	2,516	38,686	252.20	30.51	10.91
Bunga Suria	1979	23,057	2,770	49,149	267.00	32.24	13.02
1985–1990							
Houston	1985	16,322	2,536	53,726	243.44	32.26	13.00
Veracruz	1985	14,731	3,161	44,448	241.00	32.20	12.50
MSC Brianna	1986	15,416	2,966	43,403	244.00	32.20	12.52
Choyang Vision	1986	15,301	2,966	43,403	244.00	32.26	12.52
Anahuac	1987	15,664	3,209	45,892	249.00	32.26	12.50
OOCL Fair	1987	14,731	3,161	44,448	241.00	32.20	12.50
OOCL Fortune	1987	14,746	3,161	44,433	241.00	32.20	12.50
OOCL Honour	1989	19,861	3,494	45,880	275.70	32.21	12.00
OOCL Hope	1989	19,858	3,494	45,570	275.70	32.28	12.02
1992–1995							
Bunga Pelangi	1992	21,787	4,469	61,776	276.00	37.10	13.62
Zhong He	1994	19,890	3,764	51,280	275.09	32.20	11.52
Yuan He	1994	19,890	3,764	51,280	275.09	32.20	11.52
Teng He	1994	19,890	3,764	51,280	275.09	32.20	11.52
Norasia Hong Kong	1994	14,775	3,066	41,570	242.00	32.24	11.98
Norasia Sharjah	1994	14,775	3,066	41,570	242.00	32.20	12.00
OOCL Hong Kong	1995	24,611	4,960	67,637	276.01	40.00	14.03
NOL Sardonyx	1995	21,574	4,388	66,647	294.10	32.25	13.50
Bunga Pelangi Dua	1995	21,787	4,469	61,428	275.10	37.19	13.62
Colombo Bay	1995	19,631	4,236	59,147	292.15	32.20	13.03
Chesapeake Bay	1995	14,788	3,467	45,170	246.45	32.20	12.52
1996–1997							
NOL Tourmaline	1996	21,672	4,369	59,780	294.10	32.20	13.00
MSC Alexa	1996	16,123	3,301	51,000	243.00	32.25	13.20
Ever Unique	1997	24,018	5,364	63,388	285.00	40.00	12.70
Ever Dainty	1997	21,731	4,211	55,604	294.13	32.22	12.60

Source: Derived from Clarkson Containership Register.

The NOL Sardonyx is a modern Panamax vessel, with similar dimensions, which is 22,600 l.w.t., the reduction in weight probably being accounted for by efficiency gains across the board (reduced engine weight, smaller crew and accommodation deck.) However, as a result of the improvements in stowage, capacity is much increased at 4,388 TEUs. Weight carrying capacity also increases to 66,000 d.w.t. Turning to the post Panamax vessels, the Ever Unique – built in 1997 with its 24,018 l.w.t. is very close to that of the Tokyo Express, but it is rated at over 63,000 d.w.t. and (on the basis of a low weight per TEU) at 5,564 TEUs. It is somewhat surprising that (within the self selected sample for which data is provided), in spite of the huge increase in capacity, no vessels are shown with a significantly greater l.w.t. than the Panamax ships of the early 1970s.

Coming down the size range to the medium sized vessels, the MSG Alexa shows what is required today to provide the early full Panamax capacity. This ship is 243 m. in length overall, has a full Panamax beam of 32.3 m. and 13.2 m. draft. At these dimensions, it has 51,000 d.w.t. capacity and is rated at 3,301 TEUs; but the l.w.t. is only 16,123 tonnes, about two thirds that of the Tokyo Express.

The analysis is continued in Table 7.7b which shows two efficiency ratios, TEU per tonne lightweight per day at sea, and TEU miles per tonne of fuel. The former uses lightweight as a rough proxy for capital costs, its expression in terms of TEU miles per day enabling a comparison of performance at sea over a range of ship sizes and speeds. The analysis shows a sample of modern Panamax and post Panamax ships yielding between 109 and 134 TEU miles per tonne lightweight per day at sea. Compact Panamax ships built in the 1990s compare very well, the four ships showing between 111 and 143 miles per l.w.t. As would be expected, given their lesser stowage efficiency, the older vessels are much less efficient, the early Panamax ships providing 71 TEU miles per l.w.t. and the medium sized vessels between 59 and 77 TEU miles.

Looking across the modern range from compact Panamax to post Panamax ships, the figures show some variation within classes, but they do not show any greater capacity in relation to l.w.t. Differences in the approach to TEU ratings and speed could have some effect; thus, two final columns in Table 7.7b simply show deadweight and TEU capacities divided by lightweight, these being the most straightforward and robust indices available from the data set. Even here the compact Panamax ships have high ratios of capacity to l.w.t. This even applies further down the scale, modern ships of between 1500 and 2000 TEUs having the highest ratios of all.

There are a number of possible explanations for this. There could be some errors in the data, although given the consistency of the results this seems rather unlikely. Alternatively, the explanation could be that in the range from medium to large vessels rather stronger and heavier

Table 7.7b Fuel and LWT efficiency

Fuel and LWT Efficiency Vessel Name	Year	LWT	TEUS	D.W.T.	Speed	Cons p.d.	TEU nm/ m.t.	TEU nm/ LWT	DWT/ LWT	TEUS/ LWT
Super Post Panamax										
Maersk Sovereign	1998		7,060	93,390	25.00	205	20,663			
P & 0 Nedlloyd	1998		6,674	87,900	24.50	250	15,697			
Post Panamax										
Ever Ultra	1996	24,018	5,364	63,388	25.00	201	16,012	134	2.64	0.22
OOCL Hong Kong	1995	24,611	4,960	67,637	24.00	188	15,197	116	2.75	0.20
Bunga PeLangi	1992	21,787	4,469	61,776	24.00	144	17,876	118	2.84	0.21
Large Panamax										
NOL Sardonyx	1995	21,574	4,388	66,647	24.50	173	14,914	120	3.09	0.20
NOL Tourmaline	1996	21,672	4,369	59,780	24.50	152	16,901	119	2.76	0.20
Colombo Bay	1995	19,631	4,236	59,147	23.40	125	19,032	121	3.01	0.22
Ever Dainty	1997	21,731	4,211	55,604	25.00	186	13,584	116	2.56	0.19
Zhong He	1994	19,890	3,764	51,280	24.00			109	2.58	0.19
Compact Panamax										
MSC Alexa	1996	16,123	3,301	51,000	22.60	105	17,052	111	3.16	0.20
New York Senator	1995	14,788	3,467	45,170	23.50	91	21,487	132	3.05	0.23
Ville de Vela	1994	13,352	3,538	42,085	22.50	89	21,466	143	3.15	0.26
OOCL Honour	1989	19,861	3,494	45,880	22.50	118	15,989	95	2.31	0.18
Manzanillo	1996	13,972	3,398	42,938	23.30	105	18,097	136	3.07	0.24
Anahuac	1987	15,664	3,209	45,892	21.00	92	17,580	103	2.93	0.20
OOCL Fortune	1987	14,746	3,161	44,433	21.00	89	17,900	108	3.01	0.21
Eagle Malaysia	1985	14,727	3,161	40,978	21.00	89	17,900	108	2.78	0.21
OOCL Fidelity	1987	14,702	3,161	44,477	21.00	89	17,900	108	3.03	0.22
Early Panamax										
Tokio Express	1972	24,080	3,010	47,733	23.80	183	9,395	71	1.98	0.13
Early Medium Size										
Med Keelung	1983	13,784	2,054	30,701	21.60	82	12,985	77	2.23	0.15
Gibraltar Bridge	1983	13,784	2,054	30,646	21.60	93	11,449	77	2.22	0.15
Malacca Bridge	1982	13,784	2,054	30,637	21.60	82	12,985	77	2.22	0.15
Ming Star	1980	13,784	2,054	31,251	21.40	93	11,343	77	2.27	0.15
MSC Clorinda	1981	15,249	1,978	30,790	21.00	104	9,586	65	2.02	0.13
Zim Colombo	1970	14,245	1,852	29,204	19.00	91	9,280	59	2.05	0.13

Source: Derived from Clarkson Containership Register.

structures are required as size and speed increases, preventing overall savings in weight from being obtained. The lower prices per TEU slot of larger vessels could then be derived from economies in overheads and labour, and relatively lower proportions of the more expensive components (in the propulsion system, accommodation deck, automation and navigation equipment etc.). Very keenly quoted prices for the largest vessels, and policies with respect to subsidy could also have an effect. No data was available for the new super post Panamax vessels, but there is some data from the bulk sector which suggests that there may be increases in capacity in relation to l.w.t. in the larger size ranges of over say 80,000 d.w.t. If this carries over to the container sector, the new super post Panamax vessels would have good ratios of capacity to l.w.t.

Table 7.7b shows very significant gains over time in TEU miles per tonne of fuel, with modern vessels from compact Panamax ships upwards being twice as efficient as the old Panamax class. This gain comes partly from improvements in stowage efficiency and partly from improvements in propulsive efficiency *per se*. Among the modern ships, compact Panamax vessels again compare quite well with the larger classes. There is data for the super post Panamax ships, but the P&O Nedlloyd and Maersk ships are further apart than one would expect. The measurements are supposed to relate to normal service conditions, but there is some scope for interpretation as between the trial and service conditions, and a variation of this magnitude for modern vessels is likely to be related to differences in the conditions under which the measurements were taken rather than in propulsive efficiency *per se*.

The port sector

Economies of ship size at sea and diseconomies in port

Provided that larger ships (with size economies) can operate at adequate load factors and without additional time in port, both capital and operating costs of the vessels are reduced. Because size economies should reduce both the scale of the initial investment as well as ship operating costs, even a shallow curve may still provide a strong incentive to build larger ships.

Increased costs are found in the port sector, in both sea access channels and basic infrastructure. Sea access costs depend very much upon the hydraulic regime of the port as this determines the natural depth of water and the costs of capital and maintenance dredging. Other infrastructure costs relating to land and access to inland modes are also site related. Given national and/or local government subsidy for port infrastructure in some areas, the structure of port prices, the negotiating power of large carriers, the size economies of larger terminals and competition between ports there may not be a clearly identifiable premium, across the upper ranges, for the use of larger vessels. Carriers, have to take account of port constraints when developing their new designs, but they have engaged in a dialogue with the ports which has encouraged them to provide a capability for new and larger generations of ships.

Container handling performance

Improvements in cargo handling performance are a basic pre-requisite for the efficient use of larger vessels. The rule of thumb has been that cargo handling performance should rise in proportion to the increase in the size of the vessel, so that round trip times remain constant. If this were to fail and an extra ship were required to maintain frequency, the size economies of larger vessels would be substantially offset. Even on a long route like Europe to the Far East the extra vessel would add some 12.5% to fleet costs.

It could be that the carrier could avoid the need for the extra vessel by sailing faster, or operating on a more concentrated itinerary, shortening the round trip distance, and making more use of feeders and long overland hauls. But, higher speed involves higher capital and fuel costs, whilst more concentration in main line itineraries involves extra feeding and inland transport as well as additional handling. Since feeder ship costs and transport costs in the inland modes are high, this would also represent an important disadvantage.

The increase in ship size does not bring with it a natural increase in cargo handling potential. On the contrary it tends to make things more difficult. Ship length increases by much less than in proportion to capacity, if it increases at all, so that no more cranes can be deployed, and the increases in beam, which are the main means by which greater capacity is obtained, lengthen the average crane cycle. To combat this, ever faster cranes are required, as well as improvements in terminal operations in general, to support the "pressurised" ship shore operation.

To define the requirement for cargo handling performance of the latest vessels. Table 7.8 calculates the number of hours of container handling required for Panamax, post Panamax and super post Panamax vessels, at various cargo handling rates and on the basis of a three crane operation. The Table shows that the super post Panamax ship requires sustained handling rates of at least 30 moves per hour, to bring the additional time in port down to a moderate level.

Table 7.8 Container handling time for large containerships

	Panamax	Post Panamax	Super Post Panamax
TEUS	4400	5500	7060
Round Trip container exchanges	17600	22000	28240
Moves at 50:50 split	13200	16500	21180
Reduction for Load Factor of 0.9	11880	14850	19062
Re stows @ 5%	12474	15592	20015
Hours at 20 moves per hour	624	780	1001
Days with 3 cranes (60 hours per day)	10.40	12.99	16.68
Hours at 30 moves per hour	416	520	667
Days with 3 cranes (60 hours per day)	6.93	8.66	11.12
Days with 5 cranes (100 hours per day)	4.16	5.20	6.67
Hours at 40 moves per hour	312	390	500
Days with 3 cranes (60 hours per day)	5.20	6.50	8.33
Days with five cranes (100 hours per day)	3.00	4.00	5.00

Turning to actual round trip performance on the itineraries presently operated, the Maersk Line super post Panamax ships have a nine week round voyage between Europe the Far East and Japan, with the itinerary including, in autumn 1998, 17 calls:

Felixstowe, Europoort, Bremerhaven, Gothenburg, Felixstowe, Europoort Algeciras, Singapore, Hong Kong, Kaohsiung, Kobe, Nagoya, Yokohama, Kaohsiung, Hong Kong, Singapore, Algeciras, Felixstowe.

This shows double calls in Europe at both Europoort and Felixstowe, and in Asia at Hong Kong, Singapore and Kaohsiung. Examination of the L.S.I. Seasearcher records shows that the ships maintain a high degree of regularity and accomplish most port calls within one or two days. This is an extensive rather than a concentrated itinerary.

The P&O Nedlloyd super post Panamax ships, operate an eight week round voyage from north Europe to Japan direct, that is with only one intermediate call at Singapore. The autumn 1998 itinerary was as follows:

Southampton, Europoort, Hamburg, Southampton, Europoort, he Havre, Singapore, Nagoya, Tokyo, Shimuzu, Singapore Southampton

The Voyage Records show that these vessels are also performing in a satisfactory manner. Both classes of vessels appear to spend somewhat longer in port in Europe than smaller sized vessels and make more double calls; this indicates some pressure in the loading and discharge operations.

Access requirements

Crane outreach

So far as port access is concerned, the main additional requirement of super post Panamax vessels is for gantries which can accommodate their 42.8 m beam. Ports have been equipping with post Panamax cranes for some years and have gradually increased the specification in anticipation of a growth in vessel beam. A detailed statistical review of the crane fleet is available in Containerisation International supplements (C. 1. 1977).

Some 5m. has to be added to the beam of a large ship to obtain the outreach of the crane required to service it. Thus, for a ship of 42.8m beam, about 48m. outreach is required. The C.I. analysis showed that of some 2,542 gantry cranes in service and on order in August 1997, 345 had an outreach from the seaward crane rail of over 48 m., being classified as super post Panamax. Of these 129 were in service and the remaining 216 on order. This defines the forward provision in terms of the crane fleet needed to facilitate entry into service of a new generation of vessels requiring the current level of trading flexibility.

Perhaps surprisingly, there is not much of a cost premium for additional crane size and outreach, and this has been the case for a number of years. The trend towards larger cranes continues. In 1977 Rotterdam installed cranes of 56 m outreach, whilst Pasir Panjang is now installing cranes at 55 m. Thus, we can see the beginnings of a provision for yet broader beam vessels, with up to as many as twenty containers across on the weather deck and a capacity of up to 10,000 TEUs.

Ship operating draft and access to port ranges

Although large ships with 13m draft at full load have been around for many years, in the early years there were not many of them. The pressure on ports has increased markedly in recent times with the growth in the fleet of large ships, the increase in draft to 13 m in the compact classes, and the addition of a further 1.5 m. to 14.5m. maximum draft in the super post Panamax class.

As well as allowing for the draft of the vessel, access channels have to allow up to three metres in for squat by the stern and under keel clearance. One metre under keel clearance is required when the ship is at the berth. The requirements at the port can be ameliorated by the use of the tide, and also by the fact that ships will not always be operating at full load and may arrive at an operating draft some metres below the maximum. Indeed for all ships the design draft, at which propulsive efficiency is optimised, is below the maximum, and for some of the early Panamax ships the difference was between one and two metres. Carriers also use calls at deep draft ports to lighten and top up the vessel and reduce the pressure on other ports in the range.

On the other side of the equation, the increase in the scale of the large carriers and alliances gives them substantial leverage. In choosing their hubs they will wish to make provision for all of their needs. It might not be economic in the narrow sense to make further investments in port access for one service with very large vessels which might on some calls arrive at maximum draft; but if this capability brings with it a large overall throughput and guarantees as to future use, the commercial pressure on ports will be intense.

There is currently ongoing investment in sea access facilities in ports in many areas as a result of which provision for most of the present fleet will soon be broadly adequate. Considering future port provision, maximum draft has not increased much with increases in capacity, and the next stage of growth could probably be accomplished at 14.5 m. However, any further significant increase in draft would create great difficulties in many ports, and would almost certainly restrict the operating flexibility of the ships concerned.

Ship length

Maximum length scarcely changed in all of the developments between 1972 and 1997. As shown above the early Panamax vessels were some 289 m L.O.A. (which eventually increased to 294m.) and every other vessel in the world fleet, except for the latest Maersk series, has been built within 300 m. L.O.A.

An increase in length can make channel navigation and turning difficult in some ports, and where there are problems with length, it may be difficult to do anything about them. Certainly, it could be difficult to alter the bends in channels to accommodate longer vessels, whilst turning basins may be limited by virtue of the sheer lack of space. Further, since terminals have been designed on the premise that ships will be no more than 300 m long, larger vessels could, on occasion, take up two berths and result in uneconomic use of resources. However, operations with the large Maersk ships have indicated that some 350m. L.O.A. can be accommodated.

Network efficiency

The idea of concentrated mother ship itineraries

The increase in ship size, the throughput of the large hubs and the development of new hub centres have raised again the issue of the extent of concentration in itineraries, and the possibility that we may be moving towards a situation in which a very limited number of hubs, supported by feeders, will serve major regions. The analysis above has shown that a development path for vessels can be chosen, where capacity is increased largely by an increase in beam, with draft being held constant, so that sea access limitations will not be a strong centralising factor. Thus, if there is to be more concentration it would have to come from cost savings in hub and spoke operations as compared to the standard end to end services which call at a number of ports in each trading region.

This possibility can be examined in the context of a single port turnaround in Europe on the part of super post Panamax ships, the hub being Rotterdam. The savings in time at sea in Europe from such a strategy are very modest, as by the time the ships have reached Rotterdam they have already passed close by UK and French ports and are only about half a day's sailing time from Bremerhaven. Turning to time in port, it would not be entirely easy for ports to digest full ship turnarounds, particularly of the largest vessels. However, if they could sustain a five crane operation at 600 moves per crane day, handling time would be about three and a half days compared with five and a half for a three crane operation on a multi port rotation. Port access time also has to be taken into account, which could add another day. In total the one port strategy could save some three days of ship costs in port and one day of ship costs at sea. Using the estimated daily costs for these ships shown in Table 7.6, the saving in ship costs for the one port strategy would amount to some US $154,000. There would also be additional port access costs which could bring the total up to US $200,000.

On the other side of the equation, the one port strategy would require additional inland transport or feeder costs for at least half of the capacity of the super post Panamax vessel, or about 7,000 TEUs for inbound plus outbound containers. To get a broad estimate of what might be involved, we can look at these costs on the assumption that the additional movements would be by inland modes to the hinterlands of Hamburg and Bremerhaven. If we make the assumption of 50% of TEUs in forty foot containers, this would amount to some 5,250 movements. Using some recent road and rail rates, indicative costs are calculated in Table 7.10. With a road transport cost of US $0.88 per km., an incremental 150 km would cost US $ 693,000 whilst 200 km would cost US $ 924,000. Rail rates are shown separately for 40 ft and 20 ft boxes, and using the 50:50 split and the lowest rate for each box type, costs for movement to Hamburg or Bremen would cost just under US $ 1,200,000. On this basis incremental costs would be expected to be less than US $500,000 per call or some US $ 26 million per annum for a weekly service.

The precise costs would of course depend upon the actual distribution of the containers, as this would determine modes, actual incremental distances and box balancing requirements. Feeder ships could also be used for distribution, which could be argued to have reduced onward distribution costs. However, the use of feeders is not as easy as it might be imagined. The reloading of feeders on this scale could take some considerable time and increase transit times, and it might be difficult to obtain efficient use of the vessels.

The simple fact is that a multi port rotation around Europe which encompasses a UK port, a north German port and a French port, as well as a basic Benelux call, is not so very much more expensive than a single call at a Benelux port. There is little additional sailing time, and an efficient three crane operation on the multi port rotation does not give huge scope for saving ship time in port by using more cranes at the single port. Improved crane performance at existing ports would reduce this even further. With incremental ship costs of the order of only US $50 per box, the multi port rotation would always be hard to beat.

The general development of transhipment hubs

Transhipment hubs are becoming more important as the Main Line operators extend their networks and move into north south routes. However, the use of transhipment at hub ports should not be seen as an alternative to multi port operations for Main Line Vessels; it co-exists within the same networks.

On Main Line routes, one of the main aims of carriers has been to broaden the scope of direct calls by operating a number of strings with some degree of specialisation in their itineraries. This has been one of the driving forces behind the growth of the Alliances. Another major trend has been in the development of multi route operating patterns (pendulum and round the world}, which can provide certain advantages in cargo balance and operating logistics. Intuitively, there is a tendency to believe that larger Main Line ships imply greater concentration and hub and spoke networks, but this is not the case. The power of the network actually improves as the scope of direct calls with Main Line ships is broadened.

Specialisation in itineraries

The strategy of operating multiple services with some degree of specialisation between them has been with us since the very earliest days of containerisation. It was practised in particular by ACL on the north Atlantic and by Trio on the Europe Far East route. Taken alone the use of larger vessels diminishes the scope for specialised itineraries. Large increases in size reduce the scope for specialisation at any given level of traffic. They do this both by increasing requirements for cargo in the individual ship and by imposing more stringent requirements in relation to port access and handling. Indeed the ACL itineraries were combined to take advantage of a new generation of large ships. However, growth in cargo volumes, the growth in the scale of individual carriers and the use of alliances can offset this factor, and allow specialisation in itineraries to be combined with the use of large vessels.

Alliances have come in for some unfavourable comparison with mergers as a means of achieving a maximum reduction in operating costs. There will be some benefits to mergers which are unavailable to alliances. However, if one examines the operating strategies of multi route alliances, it is clear that they can exploit opportunities for specialisation in itineraries and combine very broad overall distribution and high service quality with a tight control on the number of vessels in each string. These are powerful advantages.

The advantages of specialisation can be seen in an examination of itineraries on the Europe Far East route shown in Table 7.9. On this route, a call at Singapore is universal and win serve all the countries feeding in to that hub including particularly Thailand and Indonesia. Hong Kong, or a close alternative, is almost universal and the routes then specialise in their approach to the rest of Asia.

As of early 1998, the New World Alliance operated four services: a specialised Japan service, a China service which reaches as far north as Shanghai, an Asian service which calls at Hong Kong, Taiwan and Korea and has a supplementary call at Hakata in Japan, and a Mediterranean service which calls at some way ports as well as Port Said, Genoa, Barcelona and Fos. The Grand Alliance had five services: three specialised in Japan, China and Singapore/Hong Kong respectively, one covering China, Korea and Taiwan and one north China and Taiwan (Containerisation International, March 1998).

As a result of specialisation, string size has been held down in many cases to eight vessels, whereas nine was typical some years ago, and the C.I. report showed that this was the case for the services of the New World Alliance. There is even the possibility of further specialisation which could reduce some string sizes to seven ships. This represents a substantial saving and it means that there is an alternative route in the search for cost savings.

Table 7.9 Specialised Itineraries of major alliances (early 1998)

New World Alliance			APL Hyundai Mitsui OSK
	String Size	**TEUS**	
AEX	8	4968	Le Havre Hamburg Felixstowe Rotterdam TEUS Singapore Hong Kong Kaohsiung Kwangyang Busan Hakata Kaohsiumg Hong Kong Singapore.
CEX	8	3979	Southampton Antwerp Bremerhaven TEUS Rotterdam Colombo Singapore Hong Kong TEUS Shanghai Yantian Hong Kong Singapore Colombo.
JEX	9	4807	Rotterdam Hamburg Southampton Le Havre Singapore Kobe Nagoya Shimizu Tokyo Hong Kong Singapore.
Med	8	2413	Busan Kobe Nagoya Yokohama Kaohsiung Hong Kong Singapore Port Klang Jeddah Port Said Genoa Barcelona Fos Port Said Oeddah Singapore Hong Kong Kaohsiung.
Grand Alliance			**Hapag Lloyd P & O Nedlloyd MISC NYK OOCL**
			Southampton Hamburg Rotterdam Klang Singapore Shanghai Yantian Hong Kong (China service).
			Southampton Hamburg Rotterdam Le Havre Singapore Kobe Nagoya Shimizu Tokyo (Japan Service.
			Rotterdam Hamburg Southampton Singapore Hong Kong Qingdao Pusan Kaohsiung (China Korea Taiwan).
			Bremerhaven Rotterdam Hamburg Southampton Singapore Hong Kong Qingdao Kaohsiung N china Taiwan.
			Rotterdam Hamburg Southampton Singapore Shekou Hong Kong (Singapore Hong Kong).

Source: Containerisation International March 1998 - P&ON Sailing Schedule March 1998.

Dimensions of larger containerships

The analysis above has indicated that the port sector is beginning to make provisions for ships of some 50 m. beam with three more rows of containers. These vessels would be up to 10,000 TEUs and, at 13 tonnes per TEU, about 130,000 d.w.t. The main requirements would be for cranes with 55 m. outreach and an increase in container handling performance commensurate with the growth in ship size. Length would probably be in the range of 320 m. to 350 m. and maximum draft would remain at around 14.5 m. This represents a path to increases in ship size, which carriers can explore without excessive loss of trading flexibility or

Table 7.10 Inland mode costs

	Local cost	**$ equivalent**	**Number of moves**	**150 km (@ 0.88/ km)**	**200 km (@ 0.88/km)**
Truck	df11.6 –1.9 per km	0.88–1.01	5250	693000	924000
Rail Rotterdam Hamburg					
20 ft box (in ECU)	211–386	180–329	3500	630000	(N.B.: @ $180)
40 ft box (in ECU)	363–501	310–428	1750	542500	(N.B.: @ $363)
Total				**1172500**	

Sources: Truck – Bakkenist Consultancy Amsterdam: Rail – Optimodal Nederland BV.

the imposition of huge levels of additional investment in sea access, or new style container terminals.

The new generation of super post Panamax ships has raised again the question of the ultimate limits to ship size. A design study for a vessel of 15,000 TEUs was considered by McLellan. The principal dimensions of the ship were 400 m. L.O.A. by 69 m. beam and 14 m. draft. McLellan reviewed many of the constraints in the operation of such vessels including the huge pressure on crane outreach and handling performance. The possible solutions required handling one side of the vessel at a time, or the use of docks which could provide cranes operating from either side, or the development of a new generation of cranes with 75 m. outreach, weighing about 1,500 tonnes (McLellan R G 1997).

For ships of this size there could be infrastructure problems even without the need for increased draft. Turning to operations, container handling rates would have to be doubled, as compared to those of the present super post Panamax class, to allow round trip times to remain competitive and the vessels to be economic in terms of round trip costs. This would be extremely difficult to achieve.

In a variation on this theme, Germanischer Lloyd is studying the economics of 15,000 TEU ships on a two port itinerary between Rotterdam and Singapore, onward transport in the Far East being accomplished by feeder vessels of up to 3500 TEUs. Here, the two port strategy would limit the costs of the new port infrastructure required. However, even if the large mother vessels could be handled efficiently, there would be the problem of re-loading the relays and feeder vessels quickly enough to avoid compromising transit times and overall service quality. And it is not even clear if loading and discharge of the mother vessels in docks would be compatible with efficient movement of containers to the relay vessels.

In my view, a move to 15,000 TEUs would be a much less economic path of development than a continuing emphasis on specialisation, using vessels of up to 10,000 TEUs all of which could retain at least a fair degree of operating flexibility. It would require a radical solution to the handling problem to change this conclusion.

Conclusions

The historical analysis showed that in the period 1972 to 1990, much of the emphasis was on stowage efficiency and the increased capacity that this brought with it. Large ships became much more popular in the 1980s, but the drive for increased size accelerated only in the mid 1990s. This is partly a function of trade growth and partly of globalisation and the increasing size of individual carriers. The current order pattern shows that carriers are continuing to focus on large ships.

The ship lightweight analysis confirmed large gains in stowage efficiency over time: but the indices did not show the expected savings in lightweight in relation to increases in capacity for modern vessels. This is somewhat surprising, but savings in initial capital costs could still be explained by economies in construction within the yard and a lower proportion of the expensive components of the light ship weight. The only other explanation would be a high level of subsidy on large vessels. Nevertheless, there is a suggestion here that the savings in initial capital costs, which represent a large component of size economies, are rather weak.

On the other side of the equation, it appears that ports could provide access for ships of up to 10,000 TEUs, so long as they remained within present draft constraints of 14.5 m., the vessels probably being of some 50 m. beam and up to 350 m. L.O.A. Ships – up to this size could still retain access to a wide range of ports, whilst beyond it radical changes in network structures based on hub and spoke operations would probably be required. This would involve a loss of the distributive capacity of Main Line ships. The analysis of distribution costs around Europe also indicated that Main Line vessel calls at a Benelux, north German and UK port would be likely to be far cheaper than a hub and spoke operation based on Rotterdam alone. This can not be generalised to the all Main Line port ranges, but my view is that a radical shift to hub and spoke operations would be inefficient.

An alternative direction in the search for cost savings is in the operation of more specialised routes which can achieve savings in string size. Coming down from nine to seven ships in Europe Far-East strings, for example, saves just over 20% in ship costs, and ships in the 6,000 to 10,000 TEU range operating traditional style services would in my estimation beat 15,000 TEU ships on limited hub and spoke itineraries, hands down.

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8
Port Infrastructure: An Access Model for the Essential Facility[1]

Lincoln Flor and Enzo Defilippi

This paper analyzes the main consequences for the Peruvian port sector of an access regime that applies to monopolistic infrastructures considered 'essential facilities'. It is based in the 'Coase theorem' and the 'Demsetz approach' and its goal is to make competition viable in markets for services that otherwise would be monopolized by incumbents.

Taking into account information asymmetries between the regulator and regulated firms, access procedures minimize regulatory risk by allowing the former to intervene only when a negotiated agreement is not possible. The regime also facilitates entry and competition by providing incumbents and access seekers with incentives to negotiate access conditions. The threat of a mandate that may punish any party provides incentives for them to reach a Nash Equilibrium. A mechanism for 'for the market' competition it is also devised for situations where this is desirable.

In the port sector, the regime's first consequences suggest an improvement in the competitive and institutional environment of port markets. It also seems to be generating productive and allocative efficiencies, thus contributing to a reduction of Peru's maritime transport costs.

Introduction

The reforms undertaken in several Latin American countries during the1990s led to a reduction of trade barriers and a substantial increase

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in commerce. In this context, reduced tariff barriers increased the relative significance of transport costs in the final value of goods.

Studies conducted by the Inter-American Development Bank have concluded that maritime transport costs are determined, amongst other factors, by port efficiency, and that inefficiencies can act as a potential trade barrier. In this respect, increased private participation in the supply of port services in countries like Brazil, Argentina, Chile, Colombia and Peru, seems to be improving their efficiency. This is shown in the studies carried out by Micco and Pérez (2002), World Bank Institute (2000), and Hoffman (2001), which agree, from different perspectives, that private participation in ports generates further efficiencies.

However, this solution creates the need to deal with the potential loss of efficiency caused by the extension of the terminal operator's monopoly power to the competitive segments of the transport logistics chain. This may occur in countries where port terminals are natural monopolies, because services produced in both monopolistic and competitive markets would be needed to complete the transport logistics chain. In these circumstances, incumbents have both means and incentives to recover profits foregone by regulation in the monopolistic segment through the exclusion or discrimination of competing firms in the competitive ones (Paredes, 1997).

In Peru, the regulator's strategy is to focus on: i) access to the ports 'essential facilities' and the promotion of competition wherever this is possible and, ii) limiting intervention (thus, regulatory risk) to markets where competition is neither feasible nor desirable.

While a similar approach to access was developed by the regulator of ports of the State of South Australia, other regulators have chosen different strategies. After the debate caused by the Green Paper on Seaports and Maritime Infrastructure, the European Community proposed in 2001 a Directive aimed to ensure access to port services, allowing Member States to take specific measures according to their port characteristics and national specificities. In Mexico, access to port infrastructure is ruled by a law (Ley de Puertos), while the 'Superintendencia de Puertos de Colombia' opted for regulating rates for towage and pilotage at Cartagena Port even though there were three competitors in the market.

The issue of access to essential facilities has been developed furthest – from both a theoretical and a practical perspective – in sectors like telecommunications and energy, where there have been noteworthy advances. In the transport sector, in contrast, practice precedes theory. Different ways of analyzing access in the transport industry have traditionally been developed in a unimodal context. In some countries, such as Mexico, access is regulated through separate laws for each type of infrastructure. In other countries, such as Australia (South Australian Independent Industry Regulator, 2002a and 2002b; and South Australian Government, 2001), and the United States, regulators have followed antitrust laws. In Peru, a multi-modal approach has been taken. A multi-modal regulator has the advantage of reducing the risks and costs of regulation, as it uses the same technology and principles to generate a uniform regulatory framework for all transport modes

This paper analyzes the main consequences on port efficiency of an access regime to transport infrastructure introduced in Peru in 2002. Even though at the time of writing (2003) was too soon to make final judgments, the mechanism appeared not only helping to increase efficiency, but also introduced dynamism to public and private sectors, despite the fact that the port concession process was interrupted for political reasons.

The remainder of the paper is structured as follows. The second section presents the conceptual elements that serve as the foundation for the port access model. The third section describes the model and its main consequences on the markets for port services. In the fourth section, the strategies of port operators and service providers are analyzed using game theory, while the fifth section tries to forecast the evolution of port services markets in the light of the new institutional arrangement. Conclusions are presented in the last section.

Competition versus regulation

Providers of port ancillary services such as towage or pilotage need to use infrastructure as an input to produce their services. If infrastructure cannot be reproduced efficiently (as in situations where ports are natural monopolies), it becomes a 'potential bottleneck' or 'essential facility' to the transport chain. Under these conditions, an asymmetric relationship is produced between the entity that manages the 'essential facility' (the terminal operator) and the firms that use it (service providers). In this context, a vertically integrated operator has incentives to deny or discriminate in the provision of access to competing firms to recover profits foregone by regulation. If this occurs, the loss of social efficiency caused by exclusion of competitors may be significant, and higher prices and infrastructure sub-utilization would be expected. This suggests that rules and safeguards are needed to guarantee access to port's essential facilities.

The access regimen adopted in Peru uses a framework based on two main theoretical contributions: the "Coase Theorem" (Coase, 1960) and the "Demsetz approach" (Demsetz, 1968). The Coase Theorem indicates that if property rights are well defined and transaction costs are negligible, negotiation will lead to a better resource allocation than regulation. In this context, government intervention is only warranted when regulation costs are lower than transaction costs of a negotiated agreement.

As will be seen below, the mechanism used in this model limits the participation of the regulator to cases in which access is necessary and the parties do not reach an agreement. Considering the information asymmetry between regulator and regulated firm (the regulator possesses less information regarding costs than the monopolist) the risk of the regulator establishing expensive access conditions for the incumbent creates incentives for him to reach a reasonable agreement with access seekers. This agreement has the characteristics of a Nash Equilibrium (Nash, 1950).[2]

In cases where access is limited to one or few service providers, and there are more access seekers than available infrastructure, the regime, also based in the "Demsetz approach", requires service providers to compete for access rights. If markets are competitive *ex ante*, access is granted to those willing to pay the highest access charges. This solution is efficient because it grants the scarce resource to whoever values it most. If the market is a natural monopoly, the regime grants access to the bidder offering the lowest price to the final user, thereby reducing social costs.

The mechanisms suggested by Coase and Demsetz will result in prices which approach their marginal or average costs (first or second best, depending of the importance of sunk costs), which imply increased productive and allocative efficiency. If efficiency gains in port services are produced systematically, this can reduce maritime transport costs, as suggested by Micco and Pérez (2002), Hoffmann (2002), Sánchez et. al. (2002), and Martínez-Zarzoso, Garcıa Menendez and Suarez Burguet (2002).

A more direct consequence of the model is making port services' markets more 'contestable' (Baumol, Panzar and Willig, 1982). The improved institutional conditions to access the market at the lowest possible transaction costs reduces entry barriers to a point where it is impossible for incumbents to increase margins without creating incentives for the entry of competitors.

It is noteworthy that the entry of an excessive number of competitors may lead to a reduction of incentives to invest in and adequately maintain the infrastructure. This trade-off between competition and investment is particularly relevant in countries like Peru, which have both, the need of more infrastructure and of more competitive markets. In this complex situation, the regime tries to achieve a balance between these two contradicting objectives through the use of market mechanisms, thereby avoiding the risk of congestion and reducing incentives for free riders and "cherry pickers". In other words, promoting competition where it is possible.

The peruvian access model for port infrastructure

The access regulation

In 1998, as part of a program of institutional reforms undertaken by the Peruvian government, OSITRAN (Organismo Supervisor de la Inversión en Infraestructura de Transporte de Uso Público) was created as the regulator for markets that use public transport infrastructure. OSITRAN supervises concession contracts for ports, airports, railways, and highways.

The Access Regulation (the norm that implements the regime)[3] has been in force since January 2002. Its objective is to make competition viable for services that use transport infrastructure as input. Following guidelines for airports and ports established in Australia, the Regulation classifies services as 'essential' or 'complementary', differentiating between them according to whether or not they are an essential link for the transport logistic chain, and the difficulty of duplicating the infrastructure needed to offer them.

For a service to qualify as essential, the following specific questions must be answered affirmatively:

a. Is the service necessary to complete the transport logistic chain?
b. Is it essential to grant access to the infrastructure, because there is no technical or economically viable alternative?[4]

The infrastructure alluded in the second question, is considered an 'essential facility'. Since markets that use non-essential facilities are competitive, conditions to access them are left to be determined by market forces, i.e., through an unregulated negotiation. This ensures that only markets that need regulation are actually regulated, thus reducing regulatory risks.

The list of services considered as essential is flexible and depends on market conditions and on the technology associated with their production.[5] The Access Regulation allows OSITRAN to include or exclude

Table 8.1 Ports: essential services and essential infrastructure

Essential Services	**Essential Infrastructure**
Towage	Adjacent maritime area
Pilotage	Wharfs
Mooring (berthing/unberthing)	Berths
Berthage	Inland maneuvering areas
Wharfage	Fixed cranes, and mobile cranes with location restrictions.
Stevedoring	Weighing machines
Shore handling (ship-store)	Conveyor belts
Weighing	

Source: OSITRAN (2001).

services and infrastructure from the list if the conditions change. In the case of ports, the services and infrastructure considered as essentials are shown in Table 8.1.

For example, towage is considered to be an essential service not only because it is necessary to complete the logistics chain (a ship cannot berth if this service is not provided), but because it cannot be offered unless the provider has access to the berths and the adjacent maritime area (channels and roadstead). Warehousing, on the other hand, is not considered to be an essential service, although it is reasonably necessary to complete the logistics chain, because it can also be provided outside the terminal.

It is important to note that the Access Regulation does not modify concession contracts signed before it entered into force, although it applies if the relevant matters are not specifically covered in the contracts.

Access contract and conditions

The Access Regulation establishes a minimum group of elements that access contracts must contain. The contracts will be kept in a Public Registry, in order to provide with information potential access seekers.

The Regulation also describes situations in which it is reasonable to deny access (as a consequence of technical, physical or economic limitations) and includes guidelines for determining the conditions for granting it, like insurance, technical requirements, and duration, among others. These conditions are the foundations of the 'reasonable access' concept.

In order to determine access charges, the Regulation presents four basic principles to arrive at the optimal charge, which apply regardless the charge is negotiated, the consequence of an auction, or if they are imposed by OSITRAN:

a. Keep the incentives for investment in infrastructure.
b. Minimize the costs of maintaining and operating the infrastructure.
c. Provide incentives for the entry of efficient competitors.
d. Minimize the regulatory cost.

Access Procedures

The access procedure seeks to use market mechanisms to define access conditions, limiting OSITRAN's intervention to cases where access is denied or the parties cannot reach an agreement. The procedure is as follows:

a. The access seeker presents a request for access permission to the terminal operator.
b. If the terminal operator rejects the request, the access seeker can appeal to OSITRAN, which can enact a mandate.
c. If the terminal operator accepts the request, or OSITRAN orders it, the request is publicized, so that other firms can present their applications to provide the same service.
d. If no more requests are presented, or the port operator can grant access to all of the interested firms, terminal operator and access seekers are free to negotiate the access contract.
e. If the number of requests is larger than the capacity of the infrastructure, an auction supervised by OSITRAN must be called.
f. If the terminal operator delays negotiations, refuses to negotiate or if parties negotiate but do not reach an agreement, OSITRAN can enact a 'Mandate of Access' (an order to grant access).

Consequences on port services markets

Some of the Regulation's preliminary effects in the markets for port services were the following:

a. The new access regime effectively increased the contestability of markets for services in the transport modes regulated by OSITRAN. Within these, the greatest impact was in the port sector, due, presumably, to the greater rivalry of providers and the large number of operations involved.

b. Soon after the passing of the Regulation, access requests were presented for towage and mooring services in several ports, as well as for installing cranes and a conveyor belt at the port of Callao.

c. The largest effect was seen in the market for mooring services. Before the Regulation the service was exclusively provided by the terminal operator.

d. One would expect private integrated operators to have incentives to deny access in order to favor its own operations and those of its related firms, and a State-owned company to remain neutral. Nevertheless, it was ENAPU, the State-owned company that tried to delay or restrict access when faced with an imminent loss of its market power, or when it had plans to invest (despite lacking the funds).

e. Market dynamics challenged the authorities, which do not react at the same speed as the private sector. For example, despite the interest shown by several firms to provide mooring services, permission could not be granted because the maritime authority had not defined the technical requirements to issue the licenses.

f. Although the Access Regulation was published in advance for discussion, and the regulator has since made great efforts to publicize it, a large number of service providers still ignore its potential benefits.

g. The Access Regulation encountered considerable opposition from medium and small-sized entrepreneurial organizations, including maritime agencies and stevedoring companies. These markets were highly concentrated into a few large companies having a considerable market share, and many small companies competing for the remaining share, making only modest margins. The opposition may be a consequence of the higher standards now required to obtain access that smaller firms cannot fulfill.

h. Several flaws were identified after the Regulation was passed. The terms for certain procedures were not specified, and OSITRAN had not established an adequate set of sanctions to secure the enforcement of the new regime. As a consequence, ENAPU was successful in delaying every request presented to access the terminals it managed.

Analysis of access strategies

We will now use a game theory approach to analyze the strategies of an incumbent and an access seeker. Figure 8.1 shows the possible outcomes

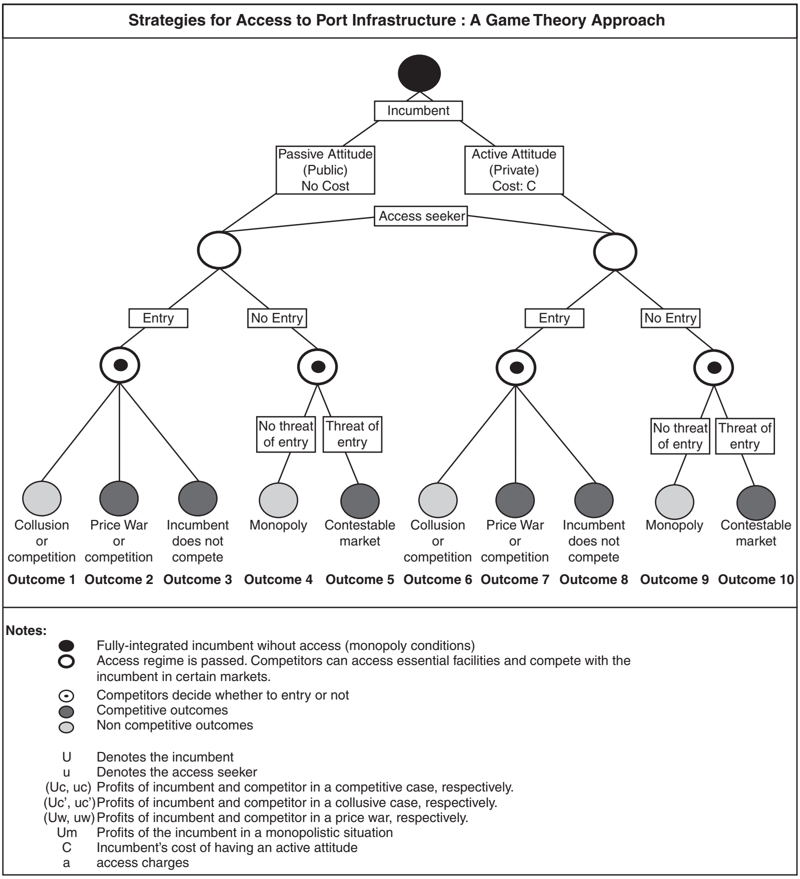

Figure 8.1 Strategies to access port infrastructure: A game theory approach

of this interaction, while Table 8.2 shows the expected profits for both of them.

Initially, the incumbent is the exclusive supplier of port services (fully-integrated). After the Access Regime is passed, he can assume an active or a passive attitude. A State-owned incumbent is expected to be more passive than a vertically-integrated private operator, given that property rights are better defined for the latter. Other factors are the conservative nature of bureaucracy and the lack of incentives for risk taking in the public sector.[6]

At the second stage of the diagram, the incentives created by the access regime make some markets potentially more competitive than

Table 8.2 Table of Profits of Incumbent and access seeker

Situation	**Incumbent**	**Access seeker**	**Outcome**
Collusion	Uc'+a	uc'-a	1
Competition	Uc+a	uc-a	1
Price war	Uw+a	uw-a	2
Competition	Uc+a	uc-a	2
Incumbent does not compete	a	uc-a	3
Monopoly	Um	0	4
Contestable market	Uc	0	5
Collusion	Uc' + a – C	uc'-a	6
Competition	Uc + a – C	uc-a	6
Price war	Uw + a – C	uw-a	7
Competition	Uc + a – C	uc-a	7
Incumbent does not compete	a – C	uc-a	8
Monopoly	Um – C	0	9
Contestable market	Uc – C	0	10

before. Potential competitors may decide to enter (or not) into the market, regardless of the attitude of the incumbent. As a result, ten different strategic outcomes (equilibria) can be reached, out of which six are clearly competitive. Only one anticompetitive result can be achieved, in the case of collusion between incumbent and access seeker. In this case, the expected profits of the collusion (after access charges have been received or paid) will be (Uc+a, uc-a), respectively. However, this outcome would be a less significant problem if the parties cannot guarantee stability of the cartel, which will probably occur if there are no significant barriers to entry.

It is unlikely that outcomes such as a price war (Uw+a, uw-a) will result in a predatory situation if entry barriers are insignificant. Even if the incumbent could temporarily reduce the price of a service below its cost, he would probably be unable to recover his losses after driving competitors out of the market, since any price increase thereafter would encourage entry of new competitors (or re-entry of the firms that had left the market).

If the incumbent decides not to compete, he will in any case receive revenues from access charges, in practice resulting in profits larger than zero. Under this conditions, the incumbent will obtain revenues, but from access charges rather than the supply of services. In this case, the result would be (a, uc-a).

If the incumbent is integrated downstream, he can grant access to third parties on equal terms or try to discriminate in favor of related firms. In the first case, the parties should easily reach an agreement. In the second case, the incumbent faces the threat of a mandate enacted by the regulator plus fines for denying access. This outcome will probably be more expensive than a negotiated agreement and has the potential of generating additional regulatory costs. It is also likely to produce sub-optimal results due to the information asymmetries among the regulator, the incumbent and the access seeker, which can result in a mandate that benefit one party over the other, thus generating more distortions. Nevertheless, undesired results can incentive further negotiations to replace the undesired mandate.

If the number of potential providers is limited, it is possible that an auction will produce different access charges among the competitors. However, this result is not expected to produce inefficiencies since competitors would have incorporated this component into its cost function at the time of the bid.

Another interesting output of the regime is that the increase in the contestability of markets may generate a situation in which a service is provided by just one supplier (probably the incumbent) but at competitive prices, because of the difficulty of increasing margins due to the threat of new entrants. This condition will discipline the incumbent and produce competitive profits (Uc, 0).

In the case in which the incumbent adopts an active attitude, he is likely to incur costs (denoted 'C') in protecting himself against new competitors. These costs can take the form of over-investment, expenditures on lobbying, market research, etc. In this situation, the result will be similar to that obtained when the port operator adopts a passive attitude, with the only difference being 'C'.

A result that does not constitute an efficient equilibrium corresponds to the situation where negotiations are unilaterally delayed or an agreement is not reached. As stated before, in these circumstances the regulator can threaten to enact a mandate, giving the parties a period in which to reach an agreement.

It can be seen that in nine out of ten cases, port markets become potentially more competitive, irrespective of the attitude of the port operator. The only exception is collusion, which has a low probability of occurrence and is likely to be short-lived due to the divergence of cost structures between incumbent and competitor. Viewed from a social perspective, any of the competitive equilibria is desirable, regardless of whether they are reached through negotiation or auction. It is worth noting the incentive caused by the mandate, which will tend to punish the parties if equilibrium is not achieved.

Forecasting the evolution of markets for port services in peru

Bearing in mind the analysis made in the preceding section, it is possible to forecast the impact of the application of the access model on markets in port services:

a. In any case, more competitive markets are expected. The impact will be different in each market and infrastructure mode, and will depend on a number of factors such as market size, degree of initial competition, degree of complementarity with other services, efficient minimum-scale, vertical integration, and others.
b. The model uses transparent mechanisms to set up the conditions under which port services can be supplied using assets provided by others. In this sense, it improves the allocation of property rights, decreases uncertainty and reduces transaction costs. Therefore, it is expected that it will provide an incentive for private firms to compete to carry out investments that cannot be undertaken due to the scarcity of public resources.
c. On the other hand, the access regime was expected to have a minor impact on markets which already had a higher degree of competition, such as towage and pilotage.
d. The access model allows terminal operators to decide to compete or not in several markets, obtaining revenues in any case in the form of access charges. This will have great relevance in their corporate strategies, as they will probably participate only in markets that generate the high rates of return.
e. In several Peruvian ports, tariffs for berthage, wharfage and towage cover certain costs that otherwise would be covered by access charges. It is possible that for some services these arrangements will continue, since allocating infrastructure cost is difficult *per se* (without considering the additional costs generated by having to manage a larger number of tariffs) and proposals to establish non-traditional charges can generate a strong opposition.
f. An important side-effect is that it will no longer be necessary to wait for the completion of the port concession program to obtain some of the benefits of private participation in the supply of public services (at least in those which can be supplied competitively).
g. It is expected that the increased dynamics of the industry will also affect the State-owned port company (ENAPU). The transparent procedure established by the regime reduces discretion and accelerates

decision making, thus increasing the predictability and improving the contestability of markets.

h. In Peru, shipping companies tend to assume the risks of damage caused by misuse of the infrastructure, since stevedoring, towage, and pilotage firms were usually not required to take out insurance policies. The access regime helps to improve risk allocation and to reduce excess costs, since it grants terminal operators the right to require access seekers adequate insurance cover. This increases the incentives for an efficient use of the infrastructure and reduces the misallocation of risk that distorts freight rate calculations.
i. On the downside, it is possible that the Access Regulation would diminish the interest of potential private port operators, who will probably be more willing to take out a concession if exclusive rights to operate certain services in the port were granted.
j. Many costs that make Peruvian ports expensive are not a consequence of the inefficient functioning of markets but have structural causes, such as the limited size of regional economies, the location of Peru with respect to international maritime routes, the absence of infrastructure connecting ports to their hinterlands, etc. The net impact of the regime on freight rates and the costs of port services will depend on the magnitude of the benefits obtained in relation to these structural inefficiencies.

Conclusions

The access regime implemented in Peru uses market mechanisms based in the theoretical contributions of Ronald Coase and Harald Demsetz. Based on these principles, the model aims at promoting competition in services that use essential facilities, while avoiding unnecessary and expensive regulatory interventions.

The first consequences of the regime's implementation suggest an improvement in the competitive and institutional environment in the markets of services that use port infrastructure. Both, incumbents and access seekers are now provided with better incentives to negotiate conditions of access or to compete for an exclusivity right when this is desirable. If the parties do not reach agreement within a reasonable time, the regulator can enact an access mandate that may punish any of the parties, creating incentives for them to reach a Nash Equilibrium. The model seems to be generating productive and allocative efficiencies in port markets, thus contributing to a potential reduction in Peru's maritime transport costs.

Notes

1. This paper obtained the IJME prize at the International Association of Maritime Economists (IAME) Conference 2002. Ciudad de Panamá, November, 2002.
2. A situation of stable equilibrium in which no party has incentives to change strategy.
3. Formally, the 'Reglamento Marco de Acceso a la Infraestructura de Transporte de Uso Público' (Regulatory Framework for Access to Transport Infrastructure in Public Use).
4. According to the essential facilities doctrine (Pitofsky, Patterson and Hooks, 2002), the second requirement should suffice. However, the first question is intended to put the essential facility in the context of the transport logistics chain.
5. A natural monopoly occurs when demand is not large enough in relation to the supply's minimum efficient scale. Therefore, the market for a service can be a natural monopoly in an area where demand is limited and competitive in other where demand is large. Therefore, the list of essential services and essential facilities may not be the same in every port.
6. Nevertheless, many of the large public monopoly ports have been are quite effective in preventing competition even where there are allowances for private facilities, such as in Philippines or India.

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9

Concession Agreements and Market Entry in the Container Terminal Industry

Athanasios A. Pallis, Theo E. Notteboom and Peter W. de Langen

In this paper we describe the capabilities and strategies required for obtaining a concession to operate a terminal in a seaport. The extent to which concession procedures create entry barriers and lower the contestability of the market is assessed. Recent studies and policy initiatives have stressed the importance of lowering economic, institutional, and locational entry barriers in seaports. Concession procedures have an effect on market entry. Tenders may lower entry barriers, by ensuring transparency, restricting discrimination and exclusivity, and limiting concessions to certain periods. However, tender procedures may also introduce entry barriers in a number of ways, including the requirement of capabilities and track records to win a tender. The paper examines relevant empirical material of concessions in major container European ports to evaluate these issues.

Introduction

This paper addresses the entry of private firms to markets in seaports through concessions.[1] The port industry is characterized by substantial government involvement. Even though private terminal operators provide container terminal services in most international seaports, governments usually retain the planning initiative (cf. Baird's (2002) study of privatization trends in the world's top-100 container ports; ESPO's (2011) factual report; Farrell 2012). The UK

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is an exception, with predominantly private port-development initiatives[2]. Because governments mostly take the initiative for port development through a public Port Authority (PA), the dominant entry mode for private firms is through acquiring a concession to provide terminal services.

The focus of the study is concession procedures for port container terminals and the capabilities and strategies required for a successful tender. The paper explores the relevant theoretical issues and discusses the empirical regularities of concession procedures in certain ports. The purpose is to ascertain whether these procedures can create entry barriers and lower the contestability of the market.

In the following two sections, we review the importance of concessions in seaports and discuss some key theoretical issues with regard to entry in seaports. We then report our analysis of the procedures to grant concessions. Special attention is paid to the capabilities required to acquire concessions. Some important features of concessions of (a) the container terminals on the Maasvlakte 2 expansion of the Port of Rotterdam; (b) the tendering of the Muelle Prat Wharf container terminal in the Port of Barcelona; (c) the Deurganck Dock in the Port of Antwerp; and (d) the concessioning of the Container Terminal (SEMPO) of the Port of Piraeus, are discussed in some detail. Other examples of concessions in North Africa and Latin America are briefly described. We then address the question whether the capabilities required for winning a concession favour consortia of established firms. The study concludes with a discussion of the role of the port authority with regard to concessions.

Given the relevance of concessions for port development, it is surprising that the study of concessions in ports has only emerged recently: The additional references of the current updated version of the paper compared to the 2008 original version that was published in the journal of *Maritime Economics and Logistics* illustrates that this field has developed significantly since this paper first appeared. Nevertheless, many of the research challenges in this paper and the follow-up work on concessions continue to require rigorous research that can directly inform port authorities, (port) regulators and the port industry.

The need to evaluate the dominant mode of entry in seaports

Concessions are a trend that has been accelerated by the advent of containerization and the development of container terminals (Olivier *et al*, 2007; Farrell 2012)[3]. In many countries around the world, governments and public port authorities have retreated from port operations in the belief that enterprise-based port services and operations would allow for greater flexibility and efficiency in the market (through more competition) and a better response to consumers' demands.

In this new environment, the awarding of port terminals to private operators through concessions. has become common practice. The World Bank Private Participation in Infrastructure (PPI) Database (World Bank, 2014) in low- and middle-income countries reported 388 port projects involving private participation for the period 1990–2012. This number includes 181 direct concessions, 160 greenfield projects (several of which involved land concessions), 26 management and lease, and 21 divestiture projects. Of the 59 seaport projects reported in 2006, 40 were concessions. Concession contracts transferring rights to provide port services are the dominant modes of private business entry in US seaport operations (Talley 2009; Wang and Pallis 2014). By comparison, in Europe, a study of 116 European ports that awarded container terminals concessions found that approximately 40% of awarded ports completed in the period 2003–2010 (Notteboom et al 2012).

In most cases, concessions are granted for specific terminals. Public port authorities (or occasionally other public agencies) generally develop a port master plan (detailing the layout of port development, such as breakwaters and terminal areas) and invest in general port infrastructure (port land, access roads and rail tracks). These port authorities grant private terminal operating companies concessions to operate a terminal and receive a concession fee from these companies. The responsibility for investment differs between concessions: in some cases, the public PA invests in quays and terminal area, while in other cases the private terminal operator has to make these investments. In such cases, the government usually still determines the main terminal characteristics such as size, location, and waterside and landside access.

This overview shows that entry to the terminal industry is strongly regulated and the prevailing entry mode is through acquiring a concession. Given these characteristics of the port industry, academics paid surprisingly limited attention to concession procedures until the mid-2000s when the first relevant port studies appeared (Defillipi, 2004; Olivier 2005; Van Niekerk 2005; on the way that the phenomenon was treated in port studies: Pallis et al 2011) Since then, the search for a research agenda (Theys et al 2010) has led to theoretical insights with empirical case studies aiming at deepening and broadening the academic discussion on the award of terminals to private terminal operators (see the special issue of the scholarly journal Maritime Policy and Management: Notteboom et al 2012).

Paying attention to entry barriers is particularly worthwhile given the ongoing consolidation and market concentration. According to Drewry Maritime Research, the top ten terminal operators control an increasing share of the world's total container handlings exceeds 65% in terms of total throughput handled in 2012 compared to 41% in 2001. Focusing on throughput by the equity TEU measure (Table 9.1), whereby throughput is adjusted to reflect the share of individual terminal operating companies, in 2001 the market share of the top four global operators (PSA, APM Terminals, Hutchison Port Holdings, and DP World) was below 30% of worldwide container traffic. In 2006 these companies handled 38.1% while in 2012 they collectively accounted for 26.5% of world container port throughput, the latter being lower than in previous years only due to the emergence of other large players (i.e. China Shipping Terminal Development; Terminal Investment Limited).

According to the same report, local container terminal operators are often just as efficient as their global rivals; a well-run local terminal operator can frequently perform at the same level as a global operator located in the same region[4].

In Europe, the non-carrier-based global container-terminal operators have expanded business considerably (cf. Slack and Frémont, 2005). Following an expansion wave between 2005–2007 (Notteboom and Rodrigue, 2012), the top five leading operators (HPH, PSA, APM Terminals, Eurogate and DP World) handled an estimated 75% of the total European container throughput in 2008 compared to less than 50% in 1998, illustrating the mature and consolidated nature of this market. The consolidation trend in Europe – which is further increasing as big players progress the planning and operation of new massive terminals (i.e the DP World in the London Gateway terminal along the Thames; PSA in Zeebrugge, Eurogate in Wilhelmshaven and HPH in the UK and the Baltic – rises the relevance of the issue of the contestability of the market (Notteboom, 2002).[5]

A relevant question is to what extent consolidation arises because of the entry conditions in the terminal industry. Do the global container-terminal operators have an edge in the bidding procedure related to concession agreements? Do concessions contribute to the unprecedented and extraordinary level of mergers and acquisitions (M&A) in the container terminal industry? The relevance of these questions accounts for the recent investigations of concessions by the European Commission (2007).

Table 9.1 Top 10 global container terminal operators' throughput (equity based; 2006, 2012)

	2006			2012			
Ranking	**Operator**	**Equity TEU throughput (in million)**	**% share of world throughput total**		**Operator**	**Equity TEU throughput (in million)**	**% share of world throughput total**
1	PSA International	41.2	9.3	1	PSA International	50.9	8.2%
2	DP World	26.2	5.9	2	Hutchison PH	44.8	7.2%
3	APM Terminals	32.4	7.4	3	DP World	33.7	5.4%
4	SPIG			4	APM Terminals	33.4	5.4%
5	Evergreen	8.1	1.8	5	COSCO Group	17.0	2.7%
6	Cosco Group	7.9	1.8	6	Terminal Investment Limited	13.5	2.2%
7	Eurogate	6.6	1.5	7	China Shipping Terminal Development	8.6	1.4%
8	HHLA	6.0	1.4	8	Hanjin	7.8	1.3%
9	OOC	4.8	1.1	9	Evergreen	7.5	1.2%
10	APL	4.6	1.0	10	Eurogate	6.5	1.0%
Top-10 global operators		**168.6**	**38.2**			**223.7**	**36.0%**

Note: Figures include all terminals in which 10% plus shareholdings were held. Figures do not include operations at common-user terminals.
Source: Drewry (2007; 2013), Annual Review of Global Container Terminal Operators.

Entry Barriers in Seaports

Barriers to entry have long been studied in industrial organization. The Harvard structuralist school (Bain, 1956) defines a barrier to entry as anything that allows incumbent firms to earn surpranormal profits without the threat of entry. The Chicago school of efficiency (Stigler, 1968) identifies an entry barrier when the potential entrants face costs greater than a currently incumbent firm has had to bear. In contrast, the normative school (Von Weizsäcker, 1980) defines an entry barrier as an impediment to the flow of resources into the industry arising as a result of socially-excessive protection of incumbent firms. According to this account, a barrier is an undefined object whose presence is to be judged only in terms of its undesirable consequences for social welfare. These three major definitions of an entry barrier represent three distinct schools (Geroski *et al*, 1990), and have led to the broad and inclusive definition of a barrier to entry as *anything that prevents an entrepreneur from instantaneously creating a new firm in a market, while a long run barrier to entry is a cost that must be incurred by a new entrant that incumbents do not (or have not had to) bear* (Carlton and Perloff, 1994: 110).

Based on this broad understanding of barriers to entry, de Langen and Pallis (2007) identified a number of different entry barriers in seaports and summarized them in three categories. The first category is *economic entry barriers* that make entry unprofitable, and include structural cost advantages of incumbents; high switching costs; and the required investments (capital time and knowledge) of *de novo* firms to develop spatial and functional networks. The second category is *legal and institutional entry barriers*, such as entry permissions (that is, restricted entrance for historical, ideological or commercial reasons) and the conditions of exclusive concessions. Finally, there are *locational entry barriers,* for example the unavailability of land for entrants.

All three types of entry barrier can be substantial. The European Sea Ports Organisation (ESPO, 2004) conducted a survey that reported some factual information of European seaports of international importance (with a total annual traffic volume of not less than 1.5 million tonnes of freight or 200,000 passengers). This study showed the limited presence of intra-port competition (see: de Langen and Pallis, 2006). Access to the market of terminal services as well as such services as pilotage and other techno-navigational services is also often regulated. In addition, incumbents frequently have cost advantages, because new entrants would have to bear costs the incumbents have not had to meet. These characteristics make entry difficult. This situation may account for the relatively high profits in the terminal industry (Olivier, 2005). These characteristics might also explain why, in a situation of severe shortage of terminal capacity, as on the US west coast, the value of firms holding terminal concessions has risen substantially, while private investments in developing additional capacity have been relatively limited.

Given the fact that acquiring concessions is in many cases the only mode of entry to the terminal industry, the characteristics and the details of concessions, together with the procedures for awarding these concessions, stand to the fore in the analysis of entry in seaports.

Procedures and characteristics of concessions

The relevant issues concerning concessions in seaports include: the process of granting concessions; the criteria used to grant concessions; the duration of concessions; and the capabilities required to acquire concessions[6].

The process of granting concessions

Terminal concession agreements may be awarded by several methods, including direct negotiation, selection from a qualified pool, competitive bidding, and a tender procedure. The difference between competitive bidding and a tender is that, in competitive bidding, a preferred candidate is selected and negotiations are held with this candidate, while in a tender all contractual agreements are detailed in advance. Empirical evidence (Textbox 9.1) suggests that governments, port authorities or other relevant policymakers may prefer competitive bidding since in this case the terms of a concession do not have to be

Textbox 9.1 The awarding of concessions: some examples

Port of Antwerp: The concessioning with respect to the Deurganckdock in Antwerp followed a competitive bidding procedure. However, it was clear from the start that the Antwerp Port Authority (APA) was eager (a) to grant the two terminals (east and west side of the dock) to different operators to enhance intra-port competition and (b) to give two incumbent firms (P&O Ports and PSA Hesse Noordnatie) the opportunity to further develop their business in Antwerp. This latter objective resulted in an unusual arrangement in the initial concession agreement: should one contender, Maersk Line meet certain volume growth conditions, then Maersk (through APM Terminals) would be granted an exclusive terminal in 2007, with the site 'to be defined' at the Deurganck Dock. This arrangement did not materialize, partly owing to the development of APM Terminals in the outer port of Zeebrugge, a Belgian coastal port.

Port of Rotterdam: In the case of the two Maasvlakte 2 container terminals, the Port of Rotterdam Authority used two methods. One terminal was awarded to APM Terminals, following direct negotiations between the PA and AMP terminals. A second terminal was awarded via competitive bidding, in which interested firms had to submit bids. In the last phase of this procedure two candidates remained: a combination of MSC and PSA and a consortium of DP World, CMA CGM and the New World Alliance. The latter eventually won the concession and is expected to start operations at its Rotterdam World Gateway in 2014.

Port of Barcelona: In the case of the Muelle Prat Wharf container terminal, the call for tenders was open to all, and the Barcelona Port Authority (BPA) proceeded to a contract with the 'winner' of the tender procedure.

Port of Piraeus: In 2006, the Greek government (as the major shareholder) held direct talks with several terminal operating companies (COSCO, HPH, DP World, APM Terminals, MSC, and ZIM) and governments (China, Korea) that were interested in investing in the Greek port. Reportedly, following intergovernmental talks between the Greek and the Chinese governments, COSCO was regarded as a likely partner for terminal investments in Greece's largest container termninal (Piraeus), the aim being to develop Piraeus as a transhipment hub in East Mediterranean. Following objections by the European Commission, as regards the concessioning of seaport terminals on the basis of intergovernmental decisions – rather than following a competitive bidding – the process was abandoned. In December 2007, the government returned with a call for tender that was open to all. The process completed in 2008, with COSCO being the company that was awarded the right to operate the terminal for 35+5 years, based on a minimum throughput and a certain level of investments (for details: Psaraftis and Pallis, 2012).

specified in advance. Furthermore, policymakers can assess the interest of terminal operators or other companies for the concession in advance (Juan *et al*, 2004).

The EU legislation limits the scope for direct negotiations with only one candidate, as recently highlighted in the case of port reform in Greece. The concessioning process has been postponed twice owing to repeated industrial action by militant port labour (Pallis, 2007a). The initial intention of the Greek government to have direct negotiations with COSCO and the Chinese government had to be abandoned, because the European Commission ruled that such preferential treatment would breach the EU competition rules. Following this review, an *international tender* was the adopted approach (for details: Psaraftis and Pallis 2012).

The Barcelona and Rotterdam cases show that PAs can start with the process of granting concessions in advance of the construction of the site to be concessioned. The Barcelona Port Authority decided to award the concession two years before the site became available. In 2005, the Port of Rotterdam Authority started the competitive bidding process procedure for operating the first Maasvlakte 2 container terminal to be operational in 2014.

National and supranational legislation, port privatization schemes, and legal disputes with regard to irregularities in concession policy have made competitive bidding the most common current procedure in concession granting. Typically, a competitive bidding procedure for berths and terminals consists of two stages: qualification and selection. In both stages, potential candidates are evaluated against certain criteria.

Criteria used to evaluate competing bids for a concession

Candidates that want to compete for a concession first need to qualify for the bidding process. Qualification is typically based on proven business experience, technical solvency, and financial strength. The first stage in the bidding procedure reduces the number of candidates, and thus competition. At the same time, the risks of non-compliance by unreliable bidders is also reduced.

The experience of the candidate, for instance, can be demonstrated by their management of similar terminals in the same or other ports (Textbox 9.2). Candidates have to provide evidence of their experience in terminal operations.

In the selection stage, firms have to submit a bid for the concession. These bids are evaluated according to several criteria (see examples in Textbox 9.3). Apart from the price (an upfront payment and/or a lease rental, both discussed in the following section), the quality of the technical and operational proposal and the business plan are also evaluated. This business plan must show how the candidate aims to attract volume

Textbox 9.2 Measuring 'business experience' in the tendering procedure

The tendering of the container terminal in the Port of Barcelona was only open to companies with experience in managing a terminal handling over 500,000 TEU for successive years or to joint ventures with at least one partner with such experience who agreed to take a minimum 25 percent stake in the concessionary company. Experience of handling one million TEU per year has been the threshold to be set for participating in the future concession process of the Piraeus port.[10] With regard to technical solvency, in the Barcelona case the call added 'horizontal integration' to 'loading, unloading, stevedoring, transhipment' and 'warehousing' as the required 'basic port handling services'.

According the Port of Rotterdam Authority, 'filling capability gaps in logistics, broadening the geographical markets served, and expanding terminal networks' were core criteria in the competitive bidding procedure for the Maasvlakte 2 concession.

Textbox 9.3 Criteria used to evaluate bids: some examples

The Port of Rotterdam Authority used four criteria to evaluate bids: the financial bid (40 percent), the business plan (25 percent), the sustainability of the bid (20 percent), and the terminal concept (15 percent). Aspects of sustainability included the 'modal split' (percentages of rail, inland shipping, and truck in hinterland transport), emissions from the terminal, and the overall vision of the bidders with regard to sustainable enterprise[11]. Financially, the bids were assessed in terms of volume guarantees in addition to the usual revenues from land rent and harbour dues. The business plan was evaluated specifically with regard to the position of Rotterdam in the shipping and port network of the consortia and the degree to which the terminal would attract new cargo to Rotterdam. In the technical field, the efficiency of operations and the quality of the terminal were evaluated.

As in the Rotterdam case, the concession in Barcelona's port followed evaluation of the business plan (30 percent), the technical and operational proposal (40 percent), and the financial bid (30 percent). The intentions regarding the concession of the Piraeus container terminal and the Antwerp Deurganckdock are also related to experience, capacity to invest, the business plan, and the financial bid.

to the terminal. Although some requirements differ significantly from case to case, the following criteria are generally included; implementation details, financing details, a marketing plan, operational and management details, employment impact, an environment plan, and an organizational plan.

Capacity calculations have to demonstrate that the terminal layout will have the necessary capacity to accommodate the projected throughput. The marketing plan typically includes a market study that defines the demand of services for the terminal, including projections of yearly throughput for a number of years.

Bidders frequently have to guarantee a certain minimum throughput per year. If this minimum is not met, the operator may have to pay a penalty, or a part of the terminal may even be withdrawn from the concession[7]. Throughput guarantees are especially required for the first years of a concession and are aimed at securing growth of throughput and market share. Furthermore, such guarantees can also be a criterion for awarding additional concessions to expand capacity. For example, Barcelona's tendering process stated that if the criteria of 80 percent capacity utilization in the first two years and over 50 percent transhipment were met, an additional concession to expand the terminal would be granted. Setting a high traffic guarantee limits potential bidders to the firms that operate container terminals in the port region (and can shift cargo volumes if they win the concession), carriers with sufficient container volumes or firms that have a satisfactory track record to attract liner-shipping companies.

In general, the bidding procedure also contains thresholds on the financial strength of the bidders. In the Barcelona case, financial solvency was associated with the financial track record and the capacity of the operator to maintain reserves of over 20 percent of total assets and over 30 percent of net fixed assets throughout the lifetime of the concession. Given the investments required, bidders need extensive resources. Consequently, an increasing number of terminals are awarded to consortia rather than individual terminal operators (Textbox 9.4). Global operators in some cases opt for a consortium with local partners to set up successful operations, but these global operators often aim to have a controlling stake in terminal operations[8]. Consortia between terminal operators and shipping companies are also frequently observed. Such consortia combine the terminal handling capabilities of terminal operators and the volumes generated by the shipping lines.

With regard to experience, the Port of Barcelona notes that: "*It has been shown that investing in the resources and capital needed to operate a*

Textbox 9.4 The rise of consortia in concessioning procedures: some examples

TANGERMED – Morocco: Consortia are involved in developments in some North African terminals aiming to become a major Mediterranean hub[12] and challenge European ports. The €1bn ($1.4bn) concession of two terminals of the new TangerMed port indicates that, given the size of the concessions, local players prefer to participate in consortia that guarantee financial and technical solvency, while global players also strive to develop consortia; though in the latter case this decision might extend well beyond such financial and/or technical considerations. The concession of the two new TangerMed container facilities resulted in bids by consortia combining local players with the major companies. The final round of bidding for a second terminal facility of 1.5 m. TEU capacity and 40 acres of yard space was between two consortia. The winner was the consortium of the terminal operator Eurogate/Contship, shipowners MSC, CMA-CGM and the local company Comanav; the loser was a consortium that combined the local player IMTC and Hutchinson. The final round of the first facility concession (2002), which mirrors the dimensions of the second one, was between a consortium formed by a global player (APM Terminals), in partnership with a local company (Akwa Holding) and another that included major shipping names — Evergreen, CMA-CGM and P&O Ports.

MAASVLAKTE 2 – Rotterdam: The case of the competitive bidding procedure for the Maasvlakte 2 container terminal is similar. Fourteen shipping and stevedoring companies expressed interest. The size of the terminal (a 4 million TEU, 146 hectare site, with a depth of 20m for larger vessels, a quay wall of around 2,350 m., including space for the barge and feeder handling, and a dedicated rail terminal) contributed to the formation of consortia. Six consortia, including, some firms that have major terminals in the rival port Antwerp (the combination PSA/MSC, DP World) submitted bids. Notably, the concession of the first phase of the Euromax terminal at the existing Maasvlakte site (1,500 m of quay wall, 2.3 million TEU capacity, operational in the second half of 2008) was also awarded to a consortium rather than a single firm: ECT (part of the Hutchison PH group) with 51 percent and the CKYH alliance (Cosco, K-Line, Yang Ming and Hanjin) with 49 percent.

terminal is not enough to offset the company's lack of experience in the port sector, which is shaped by specific labour laws (…) the importance of large shipowners and the special legal status of ports and the collectives involved in the maritime industry" (Port of Barcelona, 2006: 7). The port of Barcelona needs a terminal with operational excellence in terms of both service quality and productivity. BPA argues that such high standards require extensive knowledge of the sector and experience in it.

Recent M&A activity in both the container terminal operating business and liner shipping has affected (the strategies of) the contracting parties for concessions. Consequently, PAs include stipulations on M&As in the concession agreements. The Antwerp PA introduced a controversial clause in some concession agreements requiring every M&A activity involving the terminal concession to be reported to and approved by the PA (Textbox 9.5).

Textbox 9.5 Dynamics in terminal consortia: the Deurganckdock case in Antwerp

The initial plan was that the first and the second phase (west) would incorporate the building of a dedicated terminal allocated to the joint venture Hessenatie/MSC with an annual capacity of at least two million TEU. The second phase (east) was granted to Hessenatie to accommodate container flows generated by the CP Ships group (CAST, Canmar, Contship and Lykes Lines). The concession for the third phase (west) was granted to the combination of Hessenatie / Noord Natie, while the Board of the Antwerp PA awarded the concession for the third phase (east) to P&O Ports. In 2003 MSC, the largest customer of the Antwerp port (1.8 million TEU in 2003 and 3.6 million TEU in 2007) announced there would be no move of activities from the right to the left bank. The MSC shipping company opted for handling its vessels on its own "MSC Home Terminal" located at the Delwaide Dock on the Right Bank behind the locks in collaboration with PSA HNN (50–50 joint venture). In September 2003, the Board of Directors of the Antwerp PA gave the green light for the further implementation of the decisions and options in connection with the concessions to the Deurganck Dock and its reconfiguration, partly in reaction to the decision of MSC. The main candidates for the terminals were PSA HNN, Maersk, Eurogate and P&O Ports. After a competitive bidding procedure, the incumbent firms P&O Ports and PSA HNN acquired terminal concessions. The implementation of the decisions taken implied that the western side of the Deurganck Dock would become available for PSA HNN. Total capacity could reach 3.75 million TEU. The first part of the terminal became operational at the end of 2005. The eastern side of the Deurganck Dock was awarded to the P&O Ports consortium 'Antwerp Gateway' (40 years concession). Initially Antwerp Gateway was a joint venture between P&O Ports (67.5 percent), P&O Nedlloyd (25 percent) and Duisport (7.5 percent – the German inland port of Duisburg). The first phase of the new terminal commenced operations in September 2005. When fully operational, the terminal, with a total development cost estimated at €450 million, will add over 3.5 million TEU.

Since 2003, the year the concessions were granted, the market has changed quite significantly. First, the takeover of P&O Ports by DP World meant that the PA was suddenly confronted with a new operator. Second, the takeover of P&O Nedlloyd by Maersk meant that the AP Moller/Maersk group became a shareholder in Antwerp Gateway. Cosco Pacific and CMA CGM came in as partners a few years ago. In mid 2007, ZIM Port Logistics took over the 20 percent shareholding of Maersk in Antwerp Gateway, leading to a complex shareholder structure that has little in common with the initial one: DP World 42.5 percent, ZIM Port Logistics 20 percent, Cosco Pacific 20 percent, CMA CGM 10 percent, Duisport 7.5 percent (situation mid 2007). Third, PSA HNN renamed its Deurganck dock terminal 'Antwerp International Terminal' (AIT)'. PSA HNN (later renamed to PSA Antwerp) has managed to lock in three members of the CKYH alliance (with the exception of Cosco) under the terms of a joint venture making use of two berths in the Deurganck dock. All the market changes listed above meant that the evolving consortia exerted an almost constant pressure on the PA to renegotiate the concession agreements. The formation of the P3 alliance in 2014 (Maersk, CMA CGM and MSC) created new challenges for the port of Antwerp. On 12 May 2014 the Antwerp Port Authority (APA) gave the green light for the relocation and expansion of the MSC Home Terminal from the Delwaidedock to the Deurganckdock. It is one of the biggest (if not the biggest) terminal moves in European port history. The terminal at the Deurganckdock, named MSC PSA European Terminal (MPET), will have a total capacity of 9 million TEU for MSC and its P3 partners. It will be operated by a 50/50 joint venture between PSA Antwerp and TIL. When fully developed, MPET will take up the entire West side of the Deurganckdock presently in concession with PSA Antwerp, as well as 800m of the East side previously in concession with Antwerp Gateway.

The concessions of the two Turkish ports of Izmir and Mersin (Textbox 9.6) provide an example of consortia that have managed to use financial solvency and experience to limit entrance to the market in spite of the expressed intentions of policymakers in the early stages of the process to ensure that competing companies would have opportunities for market entry.

Even though the quality of the business plan is invariably an important criterion, one might question whether the ability to attract cargo to the terminal can best be assessed on the basis of a business plan or from the price the candidate is willing to pay for the concession. In principle, a candidate who can attract more cargo will place a higher bid so the need to scrutinize and score business plans can be questioned.

Concessions and pricing

The stipulations on the price bid depend on the price bidding system used (Goss, 1990). The alternatives available range from: (a) a given rent but minimal charges to (b) a maximum rent and the private operator's freedom to set charges. In the first option the port authority, or the competent government agency, aims to maximize the direct revenue. The payments are typically made on an annual basis. The second option concentrates on the interest of the port users and ensures price minimization.

Concession pricing may also consist of both an upfront payment and a cargo-handling fee, with seaport facilities awarded to the operator bidding the lowest cargo-handling fee (*Demsetz auctions,* after Demsetz, 1968). The latter fee cannot be lower than the floor the government decides. If two or more operators tie, then the operator offering the highest upfront payment wins the concession. In such Demsetz auctions, the setting of a cargo-handling fee is vital. Concessions are supposed, *inter alia*, to re-structure the market via the evaporation of the monopoly fee that the port operator extracts by fully exploiting monopoly powers. Whatever the floor cargo-handling fee is, the winning fee most probably equals it and the determining factor is commonly the upfront payment

Textbox 9.6 Consortia and market entry: the case of Izmir and Mersin

The TCDD (The State Railway Company, General Directorate of the State Railway Administration of Turkey) started a concession process in Turkey with the aim of avoiding dominant positions in the provision of container-handling services, and ensuring intra-port competition. Consequently, TCDD has developed two separate packages in both Izmir and Mersin to be operated by two different undertakings and/or associations of undertakings

When successful bidders were reported to the Competition Board, it ruled that any one of the successful bidders could acquire the right to operate the entire Mersin port. As a result, the consortium PSA and (Turkey's) Akfen Joint Venture, which offered the highest bid of $755 million (reportedly paid in advance)[13], obtained a concession to operate the port for 36 years. The Competition Board, in contrast with its initial opinion to disallow a single undertaking to obtain the right to operate Mersin port, allowed the acquisition. This was because of the existence of provisions in the contract for transfer of the right to operate the port (including: compulsory investments within the first 5 years that would increase container-handling performance by 2.25–3.2 times, performance criteria to be satisfied while compulsory investments are undertaken in order to avoid failure in services given in the port). The Competition Board advocated that these contract provisions would substitute the expected benefits of establishing intra-port competition as foreseen in its initial Opinion, arguing that the latter favoured the creation of intra-port competition only as a result of the initial strict attitude that no regulatory arrangements could be applied in ports (OECD, 2006). In fact, the Turkish state was even considering offering the Izmir port to the same consortium, again ignoring its statement regarding intra-port competition. In the end, Hong Kong's Hutchison group and its consortium partners, Turkey's Global Investment Holding and Turkish port operator EIB won the bid for operating the port of Izmir with an offer of $1.275 billion for 49-year operating rights. Turkey's Celebi Holding, the only single-entity bid, and another consortium including the Turkish port operator Alsancak and the Egyptian-owned cement firm Baticim Bati were ignored.[14] Looking to the future, independent actors (that is, the Turkerler Group) are seeking global partnerships in order to run another Turkish port (Derince) even though in that case they have submitted the highest bid in a tender for the operating rights.

(Engel *et al,* 2004). This principle is particularly popular in developing countries where regulatory institutions are relatively weak (Flor & Defillipi, 2003). An illustrative example of a Demsetz auction has been the new Callao Peru terminal concession (completed in 2006 – Textbox 9.7).

The economic rationale in all the pricing processes described above is that a concession is granted to those bidders willing to pay the highest access charges. The case described in Textbox 9.7 is one of those in which the government took advantage of conditions of trade booming and lack of container terminals concessions to be won and operated in the particular region, and set the floor fee at remarkably low levels (note: this floor can even be set below the ports average cost). Still, global operators jockeyed to match this floor-fee.

But as it has been assessed elsewhere (Engel *et al*, 2004) in the case of a Demsetz auction the *ex-post* market structures will be determined by the floor fee. In particular, concessions like the preceded one might create barriers for those not having developed networks of business organizations and resources to advance a vertically-integrated market. As potential bidders pursue aggressive company strategies – because they seek more (container) terminals to operate but face a short supply

Textbox 9.7 Demsetz auction at the Callao Peru terminal concession

Apart from the upfront payment, the government dictated the terminal handling charges capable of being levied in conjunction with the concession, setting a $69 to $90 per TEU range for a full cycle move from hold to gate and vice-versa. Bidders had to fix a charge in this range in the initial part of the bid process; to stand any chance of winning the concession, the 69 level was seen as the tariff that had to be offered. Indeed, the three first-ranked bidders (P&O/DP Word, ICTSI and Dragados/CSAV) adopted this low tariff. Other bidders (SSA, HHLA, APM Terminals) decided to withdraw the $69 offered. The only bidder to be eliminated in the first round was Hutchison, with a proposed per TEU tariff of $75.13. Further detailing this concession example, the winner of the concession (DP World) offered 144m for it, compared with some 95.5m from the second bidder (ICTI) and over 100m in excess of the third one. This result led various parties to question whether there was an 'economic rationale' and conclude that the 'winner is not a winner'.[15]

of availability and concessioning of such terminals – it is logical to expect the winner of concessions to be one that has:

(a) *ex-ante* established vertical-integration type relationships with the relevant downstream shipping market, or
(b) explored the potential of developing ex-post such vertical integration, or
(c) a major other (than pure economic) reason to be present in the specific port (that is, prestige).

Besides, as Engel et al (2004) assert, setting a low floor fee diminishes the operator's potential profit margin. To overcome this, the company gaining the concession may opt for arrangements that integrate vertically into shipping and may become involved in sabotage as a means of driving competitors out of business. Sabotage might involve the slowing down of loading or unloading processes and the manipulation of the procedure for awarding slots in the port to arriving ships in a way that increases the capital and operational costs for the non-integrated shipper, so that companies would be obliged to send cargo using a specific integrated operator, logistics, and shipping companies. Entry barriers remain high, since non-integrated bidders competing for access in the port market cannot follow in offering abnormal upfront payments to win the concession and enter the specific market. Notably, the regulatory framework might determine whether vertical integration practices are allowed to develop or not.

On the other hand, the floor fee might be high enough for the winner to choose to avoid the inefficiencies of vertical integration and extract monopolistic rents. In this case, the competition in the port services market remains low; despite the concession process, incumbent firms continue to earn supra-normal profits without the threat of entry.

There is, however, a threshold fee such that the operator prefers separation if the floor is set higher or chooses vertical integration if it is set lower. To achieve this optimum level, which stands as second price (because the user of the port will not pay the lowest possible handling fees) the regulatory framework needs to be adjusted accordingly. Banning or controlling vertical integration-related practices lowers this threshold fee (not least because of the probability of paying relevant punishment costs should underhand agreements be detected and therefore prosperity increases (since port users pay lower fees; and entry barriers are lower).

Duration of concessions

A third issue is the appropriate duration of a concession. Terminal operators are in favour of long concessions (FEPORT, 2005). Clearly, the length of a concession varies with the need for immovable investments. To give an example: in the (twice proposed but rejected) proposal for an EU directive on market access in European ports, the European Commission suggested a maximum duration of 8 years when there are no investments, 12 years in the case of significant investments in movable assets, and 30 years in the case of significant investments in immovable assets. Port authorities and operators argued for a 10/15/45 clause and shipowners for 8/15/36 (Pallis, 2007b). A number of PAs have worked out a system that helps them determine the concession term based on the initial investments of the concessionaire (see example in **Table 9.2**).

Port authorities have three reasons for aiming at relatively short concessions. First, especially in unstable economic and political countries, the risk valuation of private companies will be high. Consequently, the price firms are willing to pay for a concession will only increase marginally when the concession period is lengthened. From a revenue-maximizing point of view, relatively short concessions are more attractive for port authorities than longer ones. Second, long concession periods reduce the opportunities for effective port redevelopment, because concession holders will seek high compensation should their terminal operations be affected by port-redevelopment projects. Third, short concession periods reduce entry barriers since opportunities to enter the market are more frequently available.

Table 9.2 System for the calculation of the concession term as used by the Antwerp Port Authority

Investment level	Term
Investment >= 375 EUR/m^2 of arable land	40 years
225 EUR <= investment < 375 EUR/m^2 of arable land	35 years
175 EUR <= investment < 225 EUR/m^2 of arable land	30 years
150 EUR <=investment < 175 EUR/m^2 of arable land	25 years
125 EUR <= investment < 150 EUR/m^2 of arable land	20 years
100 EUR <= investment < 125 EUR/m^2 of arable land	15 years
25 EUR/m^2 <= investment < 100 EUR/m^2 of arable land	10 years
0 EUR/m^2 <= investment < 25 EUR/m^2 of arable land	Quarterly

Note: The total arable land is typically much smaller than the concessioned land as there are severe building restrictions on large parts of concessioned land.
Source: Antwerp PA.

The conditions for the renewal of a concession are a key issue. On the one hand, if the concession agreement does not stipulate the conditions for renewal, the concessionaire will typically cease all investments in the last years of the concession. Lower terminal efficiency and a sub-optimal use of the land can ensue. On the other hand, clauses regarding *renewable* concessions result in a bidding procedure that offers a comparative advantage to the existing concessionaire *vis-à-vis* potential entrants. This existing concessionaire is likely to have an advantage deriving from experience, market knowledge, and an established customer base. Therefore, PAs have to make a trade-off between securing market entry and binding efficient terminal operators.

Do concession procedures favour global terminal operators?

As a response to the concentration in container shipping, a number of terminal operators have expanded internationally. Through such growth strategies, today's global operators have progressed from local/regional players to the global market. The ability to enter new markets is a key issue in such a strategy. The preceding analysis shows global terminal operators (mostly in consortia) are well positioned in the competition for terminal concessions.

First, the move towards transparent and open concession procedures reduces the protection of local terminal operators. The protection policy of local PAs gave local firms an incontestable advantage. Local players who used to rely on the protection of local authorities now face competition from experienced global players who seek to secure capacity all over the world. In the best-case scenario, the local players could engage in a joint venture to operate the concession. In other cases, local players are taken over by global players or forced to focus on niche markets.

Secondly, port liberalization has facilitated the expansion of well-funded global players with specific expertise. The scale of operations of the global operators has created substantial surplus resources that allow them to outperform rival companies financially in the bidding procedures for new terminal operations. The sound financial status facilitates the movement of resources to wherever they generate the highest yields. Since these operators often manage more than one terminal in the same port region, they are to some extent able to redistribute cargo flows among their terminals to comply with the minimum throughput guarantees as stipulated in the respective concession agreements[9].

Third, in the current market situation, the global players seem to be best placed to meet the high capital requirements and required capabilities in the competition for concessions. For example, PSA first built a stronghold in Singapore, its home base, before taking the step towards global scale and coverage. The critical mass and its focused strategy at Singapore enabled PSA to develop exceptional competencies in terminal handling. Once the company had established itself as an international benchmark, the company's ambitions went global through a mixed strategy of organic growth (new terminals) and acquisitions (for example, HesseNoordNatie in Belgium in 2002) backed by a sound financial position. This development was accelerated by increased competition at its Singapore terminals, not least from newcomer Tanjung Pelepas in Malaysia.

Conclusions and policy discussion

This combination of empirical data and conceptual analysis makes it clear that, even though concessions may improve market access, many concession processes demand capabilities that limit considerably the pool of potential candidates for entry.

The criteria commonly used in evaluating competing bids for a concession, as well as issues related to the pricing and the terms of a concession (that is, required cargo guarantees, duration, terms of exit and renewal), create barriers to entry. In the competition for concessions, specific terminal capabilities, control over container flows, and a solid financial position are crucial. In practice, these requirements advance the presence of (consortia of) established firms. Thus, unintentionally concession practices often discourage entry from newcomers to the industry.

Concession agreements are probably the most important tool available to landlord port authorities in dealing with the terminal-operator industry. The design of the concession agreement is crucial (Notteboom, 2007; Notteboom et al, 2012). Port authorities can retain some control of the organization and structure of the supply-side of the port market, while optimizing the use of scarce resources such as land through the design of a concession agreement, its regulatory regime, the tariff regime and the way the concession is awarded.

First, through specifications in concession agreements, port authorities can shape the structure of the terminal handling business in the port area. To widen the private sector's participation and provide competition, the PA can stipulate that an operator may not participate in more than one contract at the same port. In smaller ports, a concession agreement could state that no other stevedore may handle containers over berths in the same port. Port authorities can partially design the intra-port market configuration they prefer through the bidding procedures and concession agreements used. A port authority may have good reason to opt for a market configuration of only one or two container terminal operators within a specific port area – for example, to provide a better answer to carrier power and carriers' demands and to guarantee a larger financial base for investments in expensive terminal infrastructure.

Secondly, port authorities can set the term of a concession. In general, the duration of a concession varies with the amount of the initial investment required, compliance with the development policy of the port and land lease, and other easement rights. The duration of the agreement is of crucial importance to both terminal operators and port authorities. In general, long-term agreements allow private port operators to benefit from learning-by-doing processes and to achieve a reasonable ROI. Port authorities try to find a balance between a reasonable payback period for the investments made by terminal operators on the one hand and a maximum entry to potential newcomers on the other. Since long-term agreements limit market entry, intra-port competition will only take place among the existing local port operators. However, even when concession periods are long, new players can still enter the market through a merger or the acquisition of a local operator or when a long-term concession or lease of a new terminal expansion is allocated to them.

Thirdly, the landlord PA can indicate upfront a minimum throughput to be guaranteed by the concessionaire (especially in the case of existing berths/terminals). Throughput guarantees should secure a reasonable level of land productivity. There is also a potential impact on the terminal market structure within the port. Hence, stringent demands regarding the use of space by the concessionaires can lower the entry barriers to newcomers. The PA could withdraw underutilized parts of the terminal from the concession. These kinds of stipulation in concession agreements contribute to improved contestability in the container-handling industry (Notteboom, 2002).

Finally, there is the issue of concession fees. High fees, royalty payments, and revenue-sharing stipulations are detrimental to the terminal operator's ROI and could decrease the investment potential of the incumbent terminal operator and discourage future investors. Low payments could negatively affect the revenue base of the PA.

With the emergence of global terminal-operator groups and shipping lines, and not least the increased presence of financial institutions such as banks, hedge funds, private equity groups and investors entered in the terminal business (Rodrigue et al, 2011) port authorities are confronted with powerful and footloose players. Uneasiness concerning traffic losses might make port authorities less vigilant and strict with regard to the interpretation and enforcement of the rules in the concession agreement. Global terminal operators typically possess a market-based edge in the bidding procedure for concessions and their market share in terminal throughput is therefore likely to increase in the future. The market-based strengths of global terminal operators relate to their financial strength and their proven record in terms of terminal development and expertise. These two elements play a crucial part in the bidding procedure.

Concession agreements increasingly take the form of performance-based contracts to create incentives for the terminal operator to act in the PA's interest. The dynamics in the port environment induce port authorities to evaluate continuously the effectiveness of their concession policies in the light of market trends and advances in the legal framework.

Since concession procedures and the associated capability requirements create entry barriers for newcomers, policies aiming to lower these barriers may be relevant. Relevant initiatives should address such issues as optimum duration, prices, and processes. Clear definition of inter- and intra- port competition rules, the downplay of 'strategic factors' for winning a concession, and not least the currently neglected issues of incumbent firms' practices during the last years of the concession period and the details of market exit also deserve attention. The same applies to rent-seeking practices of 'local partners' and the stability of consortia involved in tendering. These factors all represent avenues for further research, Given the fact that granting concessions is one of the most influential port-development characteristics, the relevance and the necessity of such research is evident.

Notes

1. An earlier version of the paper won the Palgrave Macmillan-Maritime Economics & Logistics Best Paper Award, 2008, at the International Association of Maritime Economists (IAME) 2008 Conference, 2–4 April 2008, Dalian China.
2. However, even in the British case, where both the regulatory and port-ownership role of the public sector have been minimized, government influence is significant at various levels (national, regional or local) in port development (Gilman, 2004). Recent examples are the UK government decisions to grant approval for the London Gateway development and to reject the proposal for the expansion of the port of Southampton.
3. Liquid bulk cargo ports often do not require large infrastructure investments and may simply consist of infrastructure to connect a ship at anchor through pipelines with storage facilities on shore. Containers require specialized gantry cranes and further maritime and hinterland infrastructures.

4. This conclusion is irrespective of the way in which their performance was measured – throughput per quay metre, TEU per ship-to-shore gantry or TEU per hectare.
5. The concentration of terminal operators may be considered as an effective means to counterbalance the power of liner shipping companies and alliances. On the other hand, the concentration is sufficiently large to question whether terminal operators have market power. EU competition regulations have affected Hutchison's expansion in North Europe, and it is likely that the regulatory authorities will also scrutinize future expansions by the major players carefully.
6. See the general literature on concessions in infrastructure and the related (re) negotiation processes between public actors and private interests: Kerf *et al*, 1998; Guasch, 2004; Guasch *et al*, 2006.
7. In several cases a minimum percentage of transhipment containers is also agreed in the concession contract.
8. The nature of the container-handling business (notably the high fixed costs and lack of service differentiation, except in terms of location) in theory creates significant opportunities to improve service through co-operation. However, forms of operational co-operation in the market do not come about easily and they usually end up in mergers or acquisitions (Notteboom, 2002, Musso et al, 2001, Slack and Frémont, 2005).
9. Terminal operators that operate more than one terminal in the same port area (each terminal with different concession stipulations regarding throughput guarantees) are very creative in redistributing volumes over the different terminals in order to meet minimum throughput guarantees and optimize terminal operations.
10. Naftemporiki. *Open Process targets 550 million euros investments*. 8 November 2006.
11. With H. Smits (Port of Rotterdam Authority CEO) stating that: "*The new port area will therefore be truly sustainable. Without an assessment procedure in which consortia know that they are competing with each other for a highly coveted terminal, it is much more difficult to agree on both a good price and sustainable operations*." In: PRA press release. *Container terminal on Maasvlakte 2 goes to broad consortium*, 11 July 2007.
12. See: Lloyd's List. *Morocco as a transhipment hub*, 26 October 2005. Notably, Contship Italia, also runs transhipment facilities in Cagliari and Gioia Tauro as well as other Italian terminals in Livorno, La Spezia and Ravena, so shifting cargoes stands as a potential.
13. Portworld. *PSA and Hutchison vying for Turkish port*. 3 May 2007
14. Portworld. *Hutchison wins bid for Turkish port*. 4 May 2007.
15. See: Port Strategy, August 2006.

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10

Competition, Excess Capacity and the Pricing of Port Infrastructure

Hercules E. Haralambides

Intensified inter-port competition, combined with automated labour-saving cargo handling systems, reduces the local economic impacts of port investments, as well as the value-added of port activities. In such a situation, the beneficial impacts of low port prices are not localized, but are instead dissipated from the country in question to the foreign consignor/consignee. This issue causes considerable concern to governments contemplating the continuation of their public investment programmes, as it deprives them of the basic rationale *of doing so, namely, that the port provides a public service to the benefit of the whole nation. Such concerns have become noticeably "vociferous" nowadays when governments have to reduce in size, cut down on spending and taxes, and allow for more private sector participation in some 'strategic' sectors that, until recently, were jealously guarded as government prerogatives.*

Revised from *International Journal of Maritime Economics* 4, 323–347, 10 December 2002, 10.1057/palgrave.ijme.9100053, 'Competition, Excess Capacity, and the Pricing of Port Infrastructure', by H E Haralambides. With kind permission from Palgrave Macmillan Ltd.

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However, the pricing strategy of a port depends on the way the port is financed and, ultimately, on the ownership status of the port: should, thus, a publicly owned and financed port be allowed to compete on price, for the same custom, with a privately owned port that has to charge higher prices in an effort to recover its investments? What if these ports are in the same, economically interdependent, geographic area? What if the effects of strategic pricing of different ports are, at the end of the day, felt by the same consumers or taxpayers? Should ports primarily engaged in commercial operations, such as container terminals, be publicly financed or should the port user pay in full for the port services he enjoys? Do ports need to recover infrastructure costs through pricing? And what happens if some do and others don't while all have to compete for the same hinterland? Is there such a thing as 'efficient port pricing' and is there scope for policy intervention to ensure a level playing field? Should ports, regions and countries compete or cooperate when it comes to infrastructure? In principle, cooperation among producers (ports) is not to the benefit of the consumer but, on the other hand, does the latter benefit when he pays taxes to develop 'competing' infrastructure while knowing that he is due for reprisals in a never-ending vicious circle of public spending? Shouldn't such public spending be also liable to the same international anti-dumping laws as other goods and services? In terms of trade policy, is there a difference between a subsidised shipyard and a subsidised port? If not, why do we shout about the former but turn a blind eye to the latter?

The European Union continues to remain neutral on the public or private ownership status of a port and it does not dispute in any way the fact that public investments are the prerogative of Member States. It nevertheless attempts to have a saying on whether a certain investment, that in theory *is open to all, but in practice is meant for a few, could, in the spirit of its Treaties, be considered as 'public investment'. For example, a road that connects a container terminal to the national motorway system is in principle open to all citizens and as such the road is a public good. In practice, however, the road is only used by the operator who exploits the terminal. The access channel to a port is dredged down to 15 metres. In principle, every floating craft can go through the channel but, surely, the channel wasn't dredged to that depth with the fisherman in mind. Should such investments be public or private? And should their costs be paid for by the taxpayer or those who directly benefit from them? These are some of the pertinent questions in port pricing that this paper aims to address with special emphasis on container ports.*

The paper shows how Marginal Cost Pricing of port infrastructure can be a powerful 'pricing discipline' towards achieving cost recovery and fair competition among ports. To succeed in this, the paper advocates for stronger *policy intervention in order to ensure greater transparency of port accounting systems, better and more harmonised port statistics, a meaningful set of state aid guidelines, and stricter application of Competition Law in port infrastructure investments.*

Introduction

In ports, as in many other industries, prices -port dues and cargo-handling charges as they are often called- can 'make' or 'break' a port. The right prices can lead a port to prosperity and growth; the wrong ones can guide it to extinction or to the proliferation of subsidies and inefficiency. High prices would normally deprive a port of part of its patronage (vessels and cargo owners) and thus reduce demand for port services. Since, once a port is built, it has few alternative uses if any, i.e. its investments are largely sunk[1], excess capacity will ensue as a result, and resources and infrastructure will become underutilised. Even when ports have some degree of monopoly power over their customers, and thus demand for port services is not reduced much, high port prices would still hurt the very trade the port is supposed to serve.

Low port prices, on the other hand, may bring clientele to the port but congestion could ensue, investment costs may not be recovered in the long-run, and the port's competitors may grudge about unfair competition, particularly when low prices are the result of subsidies.

In competitive industries, a producer has no influence on the price he sells his product or service; he either adjusts his costs to the externally determined prices or he vanishes. A port, however, operates in a market of imperfect competition[2] where pricing often becomes 'strategic pricing', i.e. the ability of the producer to influence, or set, prices in order to achieve certain objectives. Such objectives, many of which simultaneously pursued albeit often in conflict, include profit maximization through price discrimination; throughput maximization; generation of employment and economic activity; regional development; minimisation of ship times in port; and, last but not least, the promotion of trade.

However, the pricing strategy of a port depends on the way the port is financed and, ultimately, on the ownership status of the port: should, thus, a publicly owned and financed port be allowed to compete on price, for the same custom, with a privately owned port that has to charge higher prices in an effort to recover its investments? What if these ports are in the same, economically interdependent[3], geographic area? What if the effects of strategic pricing of different ports are, at the end of the day, felt by the same consumers or taxpayers? Should ports primarily engaged in commercial operations, such as container terminals, be publicly financed or should the port user pay in full for the port services he enjoys? Do ports need to recover infrastructure costs through pricing? And what happens if some do and others don't while all have to compete for the same hinterland? Is there such a thing as 'efficient port pricing' and is there scope for policy intervention to ensure a level playing field? These are some of the pertinent questions in port pricing that this paper aims to address with special emphasis on container ports[4].

The production of the port service

There is no such thing that could be adequately described by the mere word 'port' and no two ports are alike. A port could be anything from a small sheltered patch of sea that protects fishermen from the roughness of the sea, allowing them to moor their boats and trade their wares in safety somewhere in the south pacific, to the huge industrial complex of the city-port of Rotterdam, embracing in its expanse hundreds of companies, roads, railway lines, distribution centres, refineries and other industrial and manufacturing activity.

Regardless of how a port is developed and organised, however, its main function is to enable, hopefully in a safe and cost effective manner, the transfer of goods from sea to shore and *vice versa*. As such, a port is an interface between sea and land; a node in a transport chain; a point where goods change mode of transport. Cargo-handling is thus a port's core business. In order to do this, a port has to organise a large array of other services, all equally important in the facilitation of cargo transfers: it has to provide (dredge) sea channels and turning basins of adequate depth (draft) to enable the approach and manoeuvres of vessels; navigational aids, breakwaters, pilots, tugs and linesmen to allow vessels to moor and unload safely; equipment to handle goods in port and move them around; warehouses to store them until they are picked up by their owners; electricity; water; security; customs; administrative offices and much more.

The paramount good a port has to provide however, in order to facilitate all this, is *land*. A port is a land-intensive industry. Here is the first issue where *port pricing* encounters its major stumbling block: what is the value of land? What is its opportunity cost? Under what terms should port land be made available to private port operators, stevedoring companies and others?

In many parts of the world, land, particularly land close to the sea, is a scarce good with high opportunity cost and many potential claimants. Cities can use it for residential and office space[5]; offshore industries have to be located in its proximity; tourism and recreation industries would naturally consider it as prime location; fishermen would also value it highly, while nature lovers would tend to preserve it, and its ecosystem, at all costs. This is why port management, and the supervision of port activities, is often entrusted to municipal authorities and other port stakeholders, who strive to steer a balanced course and reconcile the various interests at stake.

More important than the land itself, however, is how, and by whom, land is developed to become ready to provide the port service. Often, land has to be reclaimed from the sea; it has to be paved; reinforced; roads and rail trucks have to be constructed on it; while to extend a port, even by just a few hundred metres of quayside, would require massive investments. The way these investments are financed, i.e. publicly or privately, bears the most upon the way port services are priced. Simply, a publicly funded container terminal may not have to recover – through prices- investment costs and thus its prices (cargo-handling tariffs or concession fees) could be set quite low, *vis à vis* a privately developed and financed terminal, which must recover investment costs and, other things being equal, would thus be at a competitive disadvantage.

Port competition

In the past, particularly after WWII, the development and provision of infrastructure was largely in the hands of the State. Often, infrastructure was considered as a public good, serving the collective interest of the nation by increasing social cohesion, as well as by expanding markets for inputs and output, i.e. bringing people to work, raw materials to industry, and goods to consumers. Infrastructure and mobility allows for large-scale production of goods, consequently low unit costs, and thus international competitiveness[6].

With the exception of some developing countries, infrastructure was thus invariably developed ahead of existing demand -on the part of industry, agriculture and commerce- in the hope that the latter activities would expand in the wake of the former (infrastructure) (Rosenstein-Rodan, 1943). A notable example of this was the case of the North

American railways, particularly those of Canada. Furthermore, large capital indivisibilities in infrastructure development, coupled with substantial financial requirements and long gestation periods until demand picked up, had made infrastructure development the prerogative of the public sector.

With regard to ports in particular, in the past, general cargo traffic was less containerisable, regional port competition was less of an issue, and ports comprised a lot of labour intensive activities, generating considerable value-added and a multitude of direct and indirect impacts on the national economy, including of course the facilitation of international trade. They were thus seen by governments as *growth-poles* of regional and national development and, as a matter of fact, they were often used as instruments of regional planning. Around the world, countries have done so by steering public investment, through regional policies, towards ports, in order to encourage national development. Thus, investment costs did not have to be recovered, being financed by the taxpayer through the general government budget or similar regional or municipal sources.

Ports, in addition, were fairly insulated from competitive forces, each serving its own, more or less captive, hinterland. This was due to trade barriers, national borders and inadequate land transport infrastructure. No matter how inefficient the port, the ship would still have to go there. Most ports were badly run, disorganised, bureaucratic, inefficient and expensive; a shipowner's nightmare and worst enemy!

Nowadays, however, the picture is considerably different. Trade liberalisation, helped by the remarkable developments in transport, logistics and communication technologies, has drastically weakened the link between manufacturing and the location of factors of production and has stimulated a most noticeable shift in manufacturing activities towards countries with a comparative advantage.

Developments in international transport have been instrumental in shaping these processes. Containerisation and multimodal integrated transport have revolutionised trading arrangements of value-added goods and have given traders and global managers more control and choice over their 'production-transport-distribution' chain. Furthermore, transport efficiency is necessitated by the very same nature of value-added goods whose increasing sophistication requires fast transit times from origin to destination, in order to increase traders' turnover and minimise high inventory costs. Today, these costs have been brought down significantly through the use of logistical concepts and methods, and also by the increased reliability and accuracy of international transport that allow manufacturing industries to adopt flexible *Just-in-Time* and *Make-to-Order* production technologies. *Inter alia*, such technologies enable companies to cope with the vagaries and unpredictability of the seasonal, business and trade cycles and plan business development in a more cost effective way.

Trade liberalisation, land infrastructure development, and new logistical concepts in the organisation of international transport of containers have had an equally profound effect on the port industry. Port hinterlands have ceased to be captive and have extended beyond national boundaries[7]. Governments are increasingly realising that, from mere interface points between land and sea, ports have become the most dynamic link in international transport networks and, as a result, inefficient ports can easily wither gains from trade liberalisation and export performance. Convinced about this, governments have often taken drastic steps to improve the performance of their ports: new capacity and labour-saving cargo-handling equipment have replaced outdated facilities; port worker training has intensified; customs procedures simplified; information technology widely adopted; and management structures commercialised.

Moreover, the port industry has moved noticeably from one in which predominantly public funds were used to provide common user facilities, to one where capital -public and private- is being used to provide terminals which are designed to serve the logistical requirements of a more narrowly defined group of users. Indeed, they may be designed to serve the needs of a few or even one firm (Dedicated Container Terminals).

At the same time, economies of scale in liner shipping and the sophistication and capital-intensity of modern containerships have limited the number of ports of call to only a selected few transhipment hubs or load centres. These very important ports (such as Rotterdam, Hong Kong and Singapore) have become the *foci* of international trade, and goods are moved by land (road and rail) and water (barge) from inland centres and feeder ports to these global hubs. The hub-and-spoke system that has ensued in this way has made transhipment traffic a lucrative business to be had at all costs.

The ‘mobility’ and ‘footloose’ character of the transhipment container, however, together with intertwined land transport networks and extended hinterlands, have intensified competition among container ports immensely. Today, it makes little difference if a Hong Kong container destined for Paris will pass through the port of Rotterdam, Antwerp or Hamburg. This container has little ‘loyalty’ to any given port and it switches between ports with relative ease. The price elasticity of demand for container handling services has thus become quite high[8] (Table 10.1). Transhipment may thus be profitable for some ports (with considerable domestic cargo, such as Rotterdam) but it could also be quite risky for others (pure transhipment), even if they are as strategically positioned as the port of Singapore.

In this way, each port's development, financing and pricing decisions can have marked effects on its neighbours, nationally and -most importantly- internationally. Often, this raises strong voices for 'market driven' investments; a more harmonised approach in the financing of port infrastructure; as well as pricing policies that will have to allow for full cost recovery.

These are most complex and often political issues that, as a result, have not allowed much progress to be made in terms of port policy formulation in economically interdependent areas. In all my discussions with port managers over the years, no one would ever question the importance of 'market driven' investments and pricing for cost recovery. However, in all such discussions, there has always been an implicit 'from now on' assumption and no port would seriously consider that pricing for cost recovery should reflect the costs of past (public) investments.

However, in the past, investments were not always market driven. Massive amounts of public monies have in the past been funnelled into port development, enabling many ports to consolidate such a strong market position that makes it rather easy for them, now, to advocate for the need for market driven investments. This should be kept in mind and the market-driven investments argument should not become a 'limit pricing' strategy of large and powerful ports, deterring market entry of smaller and peripheral ports who also aspire to develop and serve *themselves* their rapidly growing regions.

Table 10.1 Price elasticities in selected north European container ports

Port	**Elasticity**
Hamburg	3.1
Bremen Ports	4.4
Rotterdam	1.5
Antwerp	4.1
Le Havre	1.1

Source: *ATENCO.*

Cost recovery and limit pricing

In industrial economics, *limit pricing* refers to a strategic behaviour whereby incumbent firms raise competitors' costs, through a multitude of ways, to a level that makes new entry unprofitable (Martin, 1993). The above strategy can be explained by the simplified example of Figure 10.1. Port A (incumbent) of country X has a dominant market position. This has been established over many years of public expenditure both in the port itself and its related infrastructure (roads, maritime access, etc.). As such, the port is able to meet a substantial part of the trade of country Y through transhipment. Port A is a strong proponent of cost recovery policies in port development in general but, at the same time, it is allowed to consider 'bygones as bygones' and thus its prices, current and future, do not have to include the recovery of its past investments. The demand for its services is given by DD´.

Port B (entrant) in country Y is much smaller. Although in a favourable geographic position, the port has never developed its own container facilities, as a result of both lack of funds *and* because it was adequately served (feedered) by port A. The trade of country Y, however, is rapidly increasing and port B feels that it is now time to develop its own facilities and 'claim back' its traffic –and all that comes with it- from port

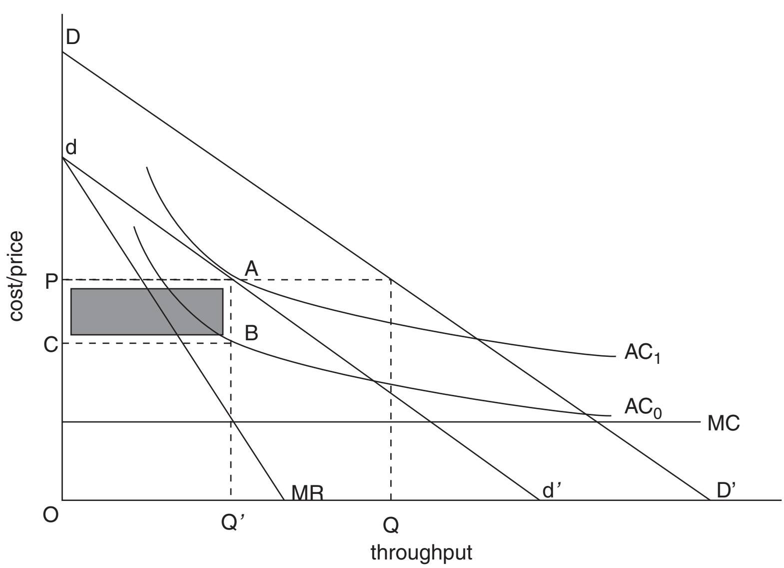

Figure 10.1 Cost recovery and limit pricing

A. The government of Y sees the importance of such an action and is prepared to fund the required investments.

Once developed, the demand for port B services is expected to be dd´; dMR gives its marginal revenue line. Its average cost (without recovery of infrastructure costs) and marginal cost curves are given by AC_0 and MC, respectively. The port maximises economic surplus (ABCP) by serving OQ´ level of throughput at a price of OP. Only Q´Q of total traffic is now left to port A.

Naturally, port A is rather unhappy with these plans. Its port policy department mounts a very strong campaign, together with other ports in the same predicament, lobbying regulatory authorities on unfair competition from a to-be-subsidised port that, if it materialises, it would deprive port A of much of its traffic. Port A claims that, by not charging for infrastructure costs, port B will be producing at prices below costs and thus antidumping and competition laws should be applicable.

Were port A to succeed in demanding full cost recovery pricing, port B's average cost curve would shift upwards to a new position AC_1 or even further. At this level, there is no single price that would enable port B to break-even, let alone realise a positive surplus. In such a situation, port B wouldn't even consider expanding, leaving the whole market to port A. By insisting on, and achieving a policy of full cost recovery, port A has been successful in maintaining its dominant market position.

The pricing of port infrastructure

As it was mentioned above, strategic pricing can pursue a multitude of objectives and it can take various forms such as marginal cost pricing (MCP), average cost pricing (ACP), Ramsey Pricing (Ramsey, 1927) and two-way tariffs. Whatever the pricing method, or combination thereof, it is becoming more and more obvious among competing ports, and those who fund them, that prices should be cost-related and, in the long-run, they should allow for cost recovery, including infrastructure development costs.

There are cases however of ports that face, or pose, little competition. These serve local industries and communities and may be important centres of territorial development. Often, the port is the only major economic activity and employer in the territory. Such peripheral ports could still be considered as 'public goods', without a need to recover the costs of infrastructure development. In this case, the government should assess, through *economic impact analysis* and *social cost-benefit analysis*, the relative merits from regional development impacts *vis à vis* the (opportunity) costs of the public resources required to develop and maintain the port. If the former exceed the latter, prices could be set below costs in order to promote regional development. Ensuing deficits could then be seen as the 'social cost of regional development'.

In all other cases, particularly in the case of container ports amidst intense regional competition, the setting of prices below costs, in order to attract traffic from competitors, is not an acceptable strategy.

First, this would lead to a misallocation of resources (and taxpayer money). Intensified inter-port competition, combined with automated labour-saving cargo handling systems, reduces the *local* economic impacts of port investments and the value-added of port activities. In such a situation, the beneficial impacts of low port prices are not localized, but are instead dissipated from the country in question to the foreign consignor/consignee. This issue causes considerable concern to governments contemplating the continuation of their public investment programmes, as it deprives them of the basic *rationale* of doing so, namely, that the port provides a public service to the benefit of the whole nation[9]. Such concerns have become noticeably "vociferous" nowadays when governments have to reduce in size, cut down on spending and taxes, and allow for more private sector participation in some 'strategic' sectors that, until recently, were jealously guarded as *government prerogatives*.

Second, in economically interdependent regions, such as for instance the EU, below-cost pricing would lead to complaints for unfair competition and competition law would in principle be applicable, particularly as deficits would have to be covered from public funds, often seen as *state aid* rather than public investment.

However, cost-relatedness of prices and full cost recovery are things easier said than done. A port is a multi-product firm and prices for many of its services, e.g. those described as *services of general economic interest*, are often bundled in port dues. Cross-subsidisation is also common. For instance, in order to attract transhipment cargo, a port may cross-subsidize feedering operations, or penalize, through higher prices, domestic cargo which is fairly captive. The *joint cost allocation* problem in economics is therefore present here too, together with the difficulty, if not impossibility, to allocate such costs to different port services.

The difficulty of this problem is often exacerbated by our inability to accurately measure port costs, especially marginal costs. Reliable and comparable port statistics do not exist; port accounting systems diverge; and, finally, the financial flows between the port and its institutional 'owner' (municipality, region, State) are not always known or transparent.

Many of the above difficulties, however, are often exaggerated. What follows is an attempt to demonstrate how the consistent application of *marginal cost pricing* (MCP) in ports could eventually eliminate deficits and the need for public funding, lead to an efficient allocation of scarce resources, and achieve a level playing field among competing ports.

The issue of excess capacity

As a result of inherent excess capacity, container ports are declining cost industries or, in economic terms, industries of *increasing returns to scale*[10]. In such industries, short-run marginal cost pricing (SRMC) results in deficits, for marginal costs –the level at which prices are set under competition- are always below average total costs.

Excess capacity in competing container ports has a number of causes. As a matter of fact it could be shown (Haralambides *et al*, 2002[a]) that the higher the competition among ports, the higher the need for excess capacity.

First, as already mentioned above, ports are often seen as pivots of regional development and, thus, infrastructure is built far ahead of demand in order to promote economic development. Second, managerial 'ego-boosting' is often not innocent of its responsibilities for the creation of excess capacity. However, the real economic culprits of excess capacity ought to be found in capital indivisibilities (lumpiness of investments), economies of scale in port construction, and over-optimistic demand forecasts.

In competing container terminals, furthermore, excess capacity is also an 'operational necessity', being the only way to provide quick turnaround times to ships and thus maintain or increase patronage. It can be easily shown through a simple single-channel-multiserver queuing model (Haralambides *et al*, 2002[a]) that once a port reaches 75% capacity utilization, congestion sets in; and waiting is unacceptable in today's liner shipping industry. With this in mind, 'operational' excess capacity ought to be seen as another unavoidable cost, rather than an indication of inefficiency and wastage of resources. However, in their appeals to public funding agencies, port managers have not been very convincing in bringing this point across and, as a result, governments have been reluctant to see excess capacity in this light.

The problem of 'operational' excess capacity is exacerbated with the increasing deployment of ever larger containerships. As has been shown earlier (Cariou and Haralambides, 1999; Cariou, 2000[a]), in general, the cost per TEU of ship-time in port is an increasing function of ship size (Figure 10.2). In other words, one TEU, arriving on a larger ship, costs more to handle and store. This has to do mainly with the limited availability of cargo-handling equipment (cranes) that can be put to work on a ship, and the problem of course intensifies at higher levels of terminal capacity utilisation. Still, four and sometimes five crane operations are standard today in many major ports for post-Panamax ships. One cannot envision however eight or ten cranes working concurrently in sustained operations on a 10,000 TEU vessel in Hong Kong, Singapore, Rotterdam or Los Angeles any time in the near future. (Haralambides *et al*, 2002[b]).

Figure 10.2 deserves some further discussion. If you ask a carrier how large a port should be, the answer you will invariably get is 'as large as possible'. The carrier's objective is to have ample port capacity, if and when he calls, so as to minimize his turnaround time. To the same question, a port manager will answer 'as small as possible, even if carriers

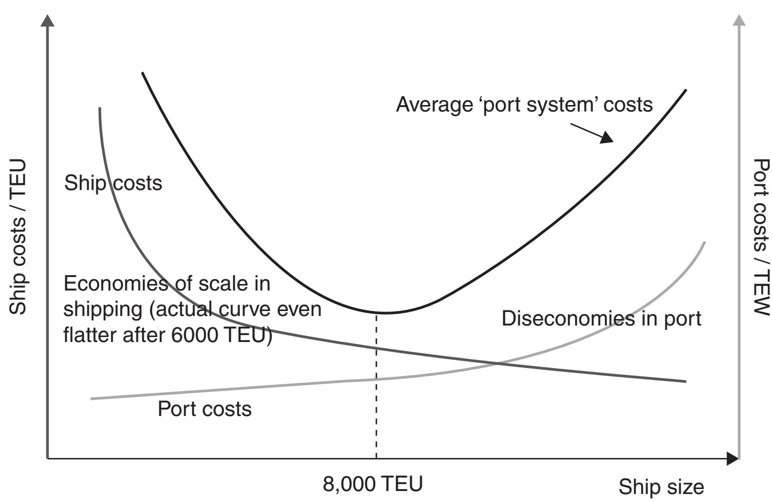

Figure 10.2 The need for joint optimization: Economies of scale in shipping, diseconomies in ports

would have to queue for a berth'. Here, the port's objective is obviously the maximization of the utilization of its infrastructure. A middle road, a compromise in other words, needs to be taken and this is what Figure 10.2 shows.

Figure 10.2 two presents the declining average costs of shipping (economies of scale), and the increasing average port costs (diseconomies of scale), as functions of ship size. The 'compromise' consists in the minimization of *average 'port system' costs* (u-shaped line), derived by adding up the two average cost lines. In doing so, the optimum ship size is also derived at the lowest point of that line. Ships larger that this increase port costs, while those smaller increase shipping costs by not enjoying economies of scale.

Thus, other things being equal, the handling of larger vessels requires more excess capacity in ports. There is one more reason for this. A daily demand of 15,000 TEU, at a certain 900-meters quay-wall container terminal, could be served either by 3 panamaxes (280 meters length) or 2 post-panamaxes (350 meters length). In the latter case, the berth is underutilized by 33%.

Figure 10.3 tells the same story for a 600 m quay terminal, serving an annual demand of 720,000 TEU[11]. The example presents four scenarios in which the above annual traffic is served by ships of different sizes, ranging from panamaxes (4000 TEU) to the 18,000 TEU Malacca-max. In the latter case, and assuming constant berth service time, berth productivity needs to quintuple, while berth utilization is cut to a third.

Finally, the creation of excess capacity can also be seen as a form of *limit pricing* (see above) and this often explains the reluctance of both governments and regulatory authorities (e.g. the European Commission) to sanction and finance ambitious port development plans that go beyond what would normally be regarded as 'realistic' demand forecasts. Here, hub-port strategies and port investments that encourage the construction of larger and larger containerships[12] increase the sunk costs of new entrants, thus consolidating the incumbent ports' market power on the one hand, and making new entry unprofitable on the other.

Competition and excess capacity mix an 'explosive cocktail'. Competition pushes prices down to marginal costs, not allowing full cost recovery (and, often, survival). In liner shipping, an industry with similar structure to that of ports, this problem has been solved -at least so far- through self-regulation and the organisation of carriers in conferences and global shipping alliances. The objective of the former (conferences) is to cover long run average costs through price-fixing, while the objective of the latter (alliances) is to achieve the same result albeit by

VESSEL INCREASE AT EQUAL VOLUMES				
Parameter	**Set-up 1**	**Set-up 2**	**Set-up 3**	**Set-up 4**
Volume (TEU) per m quay length	1,200	1,200	1,200	1,200
Berth length (m)	600m	600m	600m	500m
Yearly berth volumn (TEU)	720,000 TEU	720.000 TEU	720,000 TEU	720,000 TEU
Average vessel length (TEU)	4.000 TEU	9.000 TEU	12,500 TEU	18.000 TEU
Average vessel length (m)	270m	350m	400m	400m
Average call size (containers)	1,000	2.250	3,125	4.500
ASSUMED AND REQUIRED PRODUCTIVITY LEVELS AND CRANE DENSFTY				
Parameter	**Set-up 1**	**Set-up 2**	**Set-up 3**	**Set-up 4**
Gross birth time (= net + 2 hrs.)	24	24	24	24
Resulting vessel service time	22	22	22	22
Requited berth productivity (moves per hour)	45	102	142	205
Operational quay crane productivity (moves per hour)	28	30	32	30
Resulting crane dertsity	1.6	3.4	4.4	6.3
Required number of quay cranes per ship	2.0	4.0	5.0	7.0
NUMBER OF CALLS AND NUMBER OF CRANES				
Parameter	**Set-up 1**	**Set-up 2**	**Set-up 3**	**Set-up 4**
Yearly number of calls in order to handle yearly volume	450	200	144	100
Realised berth utilisation with yearly volume (C)	55 %	32%	26%	18%
Crane hours per year to handle yearly volume (C)	16,071	15,000	14,063	15,000
Required number of quay eranes	4	4	5	7
Crane utilbation (100% = 8760 hts/y)	46%	43%	32%	24%

Figure 10.3 Impact of large ships on berth utilization
Source: TBA.

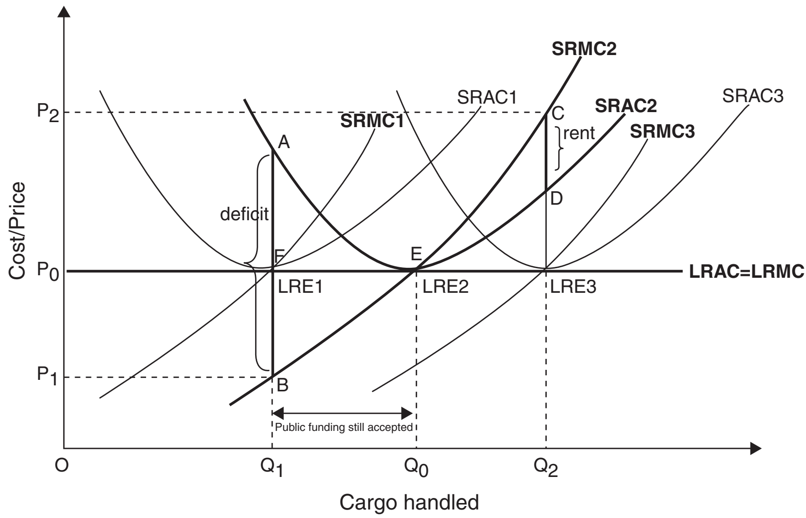

Figure 10.4 Marginal cost pricing in ports

better capacity utilization, through mutual slot charters; vessel swaps; and, in general, joint planning and scheduling.

Short- and Long-run Marginal Costs

Let us try to see the above context through the use of a simple graph (Figure 10.4) that will also be our vehicle for showing how *long-run marginal cost pricing* (LRMCP) can have the positive effects mentioned above. In order to do this, a brief elaboration on the concepts of short- and long-run marginal costs is necessary; particularly of the latter which is a most crucial, albeit misunderstood, concept in maritime economics.

In the short-run, the size of a port must be considered as fixed. The costs of fixed capital assets, such as quays, yards and rest of infrastructure, are invariant to output, and variable costs mainly relate to those of cargo-handling and nautical services (e.g. pilotage). In the short-run, marginal costs (SRMC) consist of the increment in variable costs required to produce and extra unit of port service, e.g. the handling of an extra container, when all other costs are kept constant.

In the long-run, all costs are considered variable. The concept of long-run marginal cost (LRMC) is similar to before with the difference that, now, LRMC is the increment in *total* costs required to produce an extra unit of port service. By considering total costs, i.e. by including infrastructure costs as variable ones, LRMC becomes a *planning* concept. In other words, it gives us the *long-run equilibrium* (LRE) port size, able to satisfy a given level of demand at minimum average total cost, without incurring deficits or realising *economic rent* (i.e. supernormal or monopoly profit). In the absence of rapid technological change, we often assume that LRMC=LRAC=Constant (Figure 10.4).

Increasing returns to scale

The above could be better grasped by looking at Figure 10.4. Assume that the size, organisational structure and 'operational' excess capacity of our port can be adequately described by its short-run average total cost curve SRAC2. The port faces intense regional competition from neighbouring ports, its investments are publicly funded and, at present, the level of demand it has to satisfy is Q_1. Increasing returns to scale are thus present.

As a result of competition and the lack of a need to recover (publicly funded) infrastructure development costs, our port will be tempted -if not forced- to set prices equal to marginal costs, i.e. P_1. (SRMC2 is our port's short-run marginal cost curve). Such costs regard technical-nautical services; regular maintenance; security; and other services of general economic interest. A deficit of the order of AB is thus created and MCP does not allow the port to recover its infrastructure costs. Apparently, our port is too large for that level of throughput (Q_1).

Unless demand picks up considerably far beyond Q_1, such a situation is not sustainable in the long-run without continuing public support. Taxpayers, however, will become increasingly sceptical and competitors abundantly vociferous, in whichever way they can, on unfair competition. In long-run equilibrium (LRE), that level of throughput (Q_1) ought really to be produced by a much smaller port (LRE1 / SRAC1) whereby SRMC pricing would allow the recovery of full costs. At that size, the port would exhibit *constant returns to scale* and it would be able to produce its services at minimum average cost.

Diminishing returns to scale

Let us now see what would happen if our port was faced with a situation where demand for its services was substantially higher, say Q_2. Here, the port exhibits *diminishing returns to scale* (diseconomies of scale) and although State coffers cannot complain in terms of revenues, congestion is a chronic problem and ship waiting times unacceptably long. Port capacity is over-utilised, accidents in cargo-handling very likely, and carriers impose surcharges on shippers. Demurrages are claimed. Such a situation, common in many ports during the pre-containerisation era, can still be found in many general cargo ports around the world.

Here, MCP is not only appropriate but strongly recommended as a pricing strategy that rationalises demand and allocates scarce port capacity according to carriers' and shippers' willingness to pay. Apparently, *balking* (carriers refusing to call at the port) and *reneging* (existing carriers leaving the port) are at this point the least of our port's concerns.

Setting price equal to marginal cost in this case means that our port charges a price of P_2 for the last ton of cargo it handles and this price is over and above (line CD) what on average it costs the port to handle a ton of cargo when the total amount of cargo handled in a certain period of time is Q_2 tons. Now, the port realises *economic rent*, or supernormal profit, i.e. an economic surplus after all factors of production have been paid for, including entrepreneurship, as well as a normal return on capital. Total economic rent accrued to the port beyond the minimum cost production level Q_0 is thus equal to the area ECD.

Here too, the situation is not sustainable in the long-run. Clearly, the port is too small for that level of throughput. Eventually it will have to expand to its long-run equilibrium position LRE3 / SRAC3 where it will only earn normal profit, producing and charging at minimum average cost. The port will be helped in this by its competitors who will also invest and expand in an effort to capture part of its economic rent.

Constant returns to scale

However, port development and contraction are dynamic processes and rarely, or by accident, would a port be found on its LRE position. As said earlier, lumpiness of investments, economies of scale in port construction and wrong demand forecasts would see to it. This is why we stressed above that LRMC is a planning, i.e. normative, concept; a snapshot of a dynamic process. At any point in time, a port could diverge markedly from the idealised situation of LRE.

Having said that, however, if all competing ports within a certain economically interdependent geographical region were to be taken together, it would be reasonable to assume that the industry as a whole demonstrates constant returns to scale and, therefore, LRMC pricing, if ever achievable, would lead to efficient resource allocation, maximisation of social welfare and a level playing field among competing ports. This was the spirit and philosophy of the European Commission's White Paper on *fair payment for infrastructure use* which ascertained that *'…the entire infrastructure complex of the EU as a whole may not exhibit economies of scale…'*. This means that, at least at an aggregate level, it should be possible to recover total costs.

Cost recovery through MCP

But let us, for the time being, return to our example of Figure 10.4 and the case where our port faces the limited demand of Q_1. The port management remains optimistic that their plans and forecasts will eventually materialise and demand will pick up to the level of $Q_{0,}$ if not further. However, costs have now to be recovered through port charges. If at the level of Q_1 the port charges a price of P_1, equal to its long-run average and marginal cost, there would still be a deficit but now reduced from AB to AF.

In so doing, i.e. by consistently charging at LRMC=LRAC, and as demand picks up, the port will eventually reach its LRE level of throughput where costs will be fully recovered. In the range of output Q_1 to Q_0, public funds are gradually and increasingly recovered until the deficit is phased out completely at point E.

Such public funding is and should be allowed given its digressiveness (temporary and declining) and the private sector's frequent reluctance to finance chunky investments of long gestation periods. The understanding now however is that these funds will have to be eventually recovered, irrespective of whether they are ploughed back to the public sector or used for further development by the port itself. In an era of reduced public spending, such an understanding may also help in enticing private funds to the port sector, as well as in giving an answer to the important question as to whether the pricing of port expansions should also reflect the cost of past (public) investments.

Despite the elegance and desirability of MCP, a lot of questions still remain open. Could this be done in practice? Could a port voluntarily and single-handedly charge prices higher than its competitors? Is there scope for policy intervention in pricing matters? Can we measure LRMC? Is MCP economically efficient when applied by some ports only, while the rest of the infrastructure connected to these ports (e.g. roads and railways) does not follow suit? Let us take these questions in turn.

Measuring marginal costs

With a given level of technology and organisation -fairly standard aspects in modern ports today-, the measurement of long-run average or marginal costs simply boils down to forecasting future demand for port services (Figure 10.4). Once this is established, the LRE size of the port can be established too and the only cost element required for the measurement of LRMC is the construction cost of an additional metre of quayside and all that comes with it (aprons, yards and possibly organisational costs as a result of bigger size). Port engineers have fairly accurate data on these.

Forecasting port throughput

But can demand for port services be forecasted with any degree of confidence? This is one of the trickiest and most complex questions in maritime economics and one that can only be treated rudimentarily in a paper such as this.

In a closed economy, forecasting port demand is straightforward: observe population, agglomeration, consumption, personal incomes, and consequent international trade volumes and translate them -mostly through regression analysis- into required port capacity; a popular exercise for students of maritime economics.

In an open and economically interdependent economy, however, things are different. As a result of intertwined and extended (common) hinterlands; abundant land infrastructure; short-sea feedering networks; continuously evolving liner shipping networks; and the infamous 'mobility' of a 'footloose' container, port demand is very volatile and unpredictable today: from deterministic in the past, port demand has now become stochastic. Port market shares are thus unstable, and investments in one region or country have an impact on another. For example, a dedicated railroad line connecting Rotterdam with the Ruhr area in Germany will impact north sea German ports; new container capacity in Antwerp will take away traffic from Rotterdam; the port of Tanjung Pelepas in Malaysia has stolen Maersk from Singapore; and Korea invests tremendously in order to compete, as a hub, with both Japan and China.

In such a 'fluid' environment, how could one forecast port demand with any degree of credibility? Should ports, regions and countries compete or cooperate when it comes to infrastructure? In principle, cooperation among producers is not to the benefit of the consumer but, on the other hand, does the latter benefit when he pays taxes to develop 'competing' infrastructure while knowing that he is due for reprisals in a never-ending vicious circle of public spending? Shouldn't such public spending be also liable to the same international anti-dumping laws as other goods and services? In terms of trade policy, is there a difference between a subsidised shipyard and a subsidised port? If not, why do we shout about the former but turn a blind eye to the latter?

Answers to such questions belong to the realm of public- rather than maritime economics. One could however start fathoming the answers by looking at the role of *public investment*; a concept that, surely, globalization, and regulatory authorities, will redefine before too long. Here are two examples of such *public investment.* A road that connects a container terminal to the national motorway system is in principle open to all citizens and as such the road is a public good. In practice, however, the road is only used by the operator who exploits the terminal. The access channel to a port is dredged down to 15 metres. In principle, every floating craft can go through the channel but, surely, the channel wasn't dredged to that depth with the fisherman in mind. Should such investments be public or private? And should their costs be paid for by the taxpayer or those who directly benefit from them? I firmly believe it should be the latter.

The kinked demand for port services

Another question we posed above was whether a port would, voluntarily and single-handedly, charge a price higher than that of its competitors. The answer here is '*no, unless it has to'*, i.e. unless it has to recover costs. As we mentioned above, ports operate in an oligopolistic market and individual upward price moves tend not to be matched by competitors who will most likely maintain their own prices low in an effort to benefit by capturing a larger market share. A port's demand curve is thus a *kinked* demand curve such as dD´, depicted in Figure 10.5.

Assume that, originally, the demand for the services of our port is given by DD´. The port is at equilibrium, charging a price of P per ton of cargo for a total throughput of Q. The port, believing that its competitors will follow suit, plans to raise prices to P_1. Knowing its price elasticity of demand, the port calculates that the increase in revenue as a result of higher prices ($ABPP_1$) will more than compensate the loss in revenue due to lower (Q_1) throughput ($BCQQ_1$); that is $ABPP_1 - BCQQ_1 > 0$.

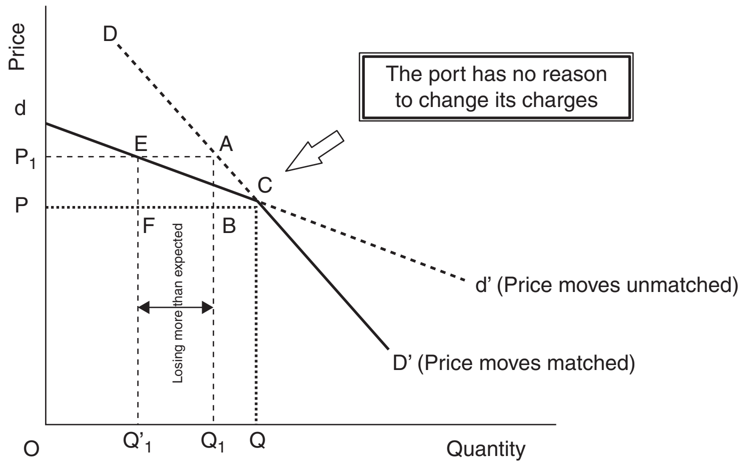

Figure 10.5 The kinked demand for port services

To its bad luck, however, the competitors of our port maintain prices at the same level hoping to capture a greater market share. This does of course happen and our port's demand curve flattens to dd´. At the higher price of P_1, our port is only able to serve a Q'_1 level of throughput. It loses revenue much more than what it was expecting ($FBQ_1Q'_1$ more), while its extra revenue due to the price increase is only $EFPP_1$, less by ABFE from what the port was originally anticipating. Had our port known, as it should, that its competitors would not follow suit in raising their prices, it would have no good reason to raise its own price single-handedly, as this would make it worse-off in the end. This is the more so when ports and governments are aware that LRMC pricing can lead to allocative efficiency only as long as other markets are also efficient (Pareto optimality). If the latter condition is not satisfied because of institutional restrictions, then, according to the *Theory of Second Best* (Lipsey and Lancaster, 1956) *'…it is in general neither necessary nor sufficient to satisfy the remaining conditions…'*; i.e. to endorse MCP in ports when roads, railways and the rest of the infrastructure do not do the same.

In the context of the European Union, a voice is often loudly raised, by both the Commission and the port industry, arguing that MCP in ports will only make port services 'unilaterally' more expensive thus penalising the Union's efforts to check road traffic and promote short sea shipping; a most valid argument indeed. In this light, efficient port pricing cannot be seen in isolation but only through a general equilibrium approach where the rest of the port related infrastructure and its pricing are also being considered simultaneously.

Policy intervention

If ports are not, naturally, individually prepared to disadvantage themselves by charging higher prices, in order to recover costs, is there scope for *policy intervention*? Could a 'pricing discipline' be imposed on competing ports in economically interdependent regions that could alleviate their own misgivings about unfair competition?

In the European Union, this was the objective of the Commission's *Green paper on ports and maritime infrastructure*[13]. The Paper set out the broader context of Community port policy, with a focus on the issue of state aids and infrastructure charging. The main question was whether, and how, an efficient pricing system, leading to cost recovery, could be implemented in practice in the port sector, taking into account a variety of relevant objectives and constraints including higher market based efficiency; increased cohesion; distributive goals; the development of short sea shipping; the improvement of safety and environmental protection, etc.[14]

The *Green Paper* attracted growing industry attention on the desirability and scope of a more harmonised European seaport financing and pricing strategy. A large scale, pan-European research study for the European Commission (DG Transport and Energy), known under the acronym "ATENCO" (***A***nalysis of the main ***T***rans-***E***uropean ***N***etwork ports' ***CO***st structures), was subsequently carried out[15], with the main goal to provide input for an in-depth reflection at European level on (a) the design of a strategy to achieve efficient pricing and (b) the possible impacts of a cost recovery approach on the functioning of ports.

The study came up with a number of conclusions, the most important of which were: (a) The high sensitivity of demand for port services to changes in prices (Table 10.1). As an example, the study calculated that if the port of Hamburg were to recover the dredging costs of river Elbe from user charges, this would add Euro10 (or roughly 5%) to its terminal handling charges per TEU. According to Table 10.1, such a price increase would lead to a 15.3% (roughly half a million TEU) reduction in container traffic[16]. (b) No policy intervention on pricing matters would ever be acceptable by the industry, who strongly felt that pricing policies are solely for the ports themselves to decide. The argument here was that even when full cost recovery is sought as an overall objective, ports apply a variety of pricing principles simultaneously in order to achieve managerial effectiveness at the micro-level. (c) However, it was unanimously agreed, by every port management team interviewed, that *cost recovery* -regardless of how this was to be achieved by each individual port- should be pursued and, for that purpose, better port statistics, accounting systems and transparency of port accounts are required[17].

Following the ATENCO results, the Commission came up with what has come to be known as its 'port package' (European Commission, 2001[a] and 2001[b]). In this, the EC, convinced now about the desirability of cost recovery in ports, has taken a fresh look at two most important issues: (a) the need for greater transparency in the efficient allocation (leases/concessions) of port land to service providers on an equal opportunity basis and in a way by which leases reflect better the opportunity cost of port investments; (b) the no longer indiscriminate treatment of port infrastructure investments as 'public investment'. Particularly with regard to the latter, although the Commission continues to remain neutral on the public or private ownership status of a port, and it does not dispute in any way the fact that public investments are the prerogative of Member States, it nevertheless attempts to have a say in whether a certain investment, that in theory is open to all, but in practice is meant for the few, could, in the spirit of the Treaty, be considered as 'public investment'.

Conclusions

Cost recovery and the pricing of port services are complex and controversial issues, both technically and conceptually. This is so because they deal with the development and provision of infrastructure; economic development; public investment; fiscal policy and the role of the State in economic activity. Before too long, economic analysis of this type takes one into the realm of *moral philosophy*. Indeed, the type of *economics* we accept as valid reflects nothing more than our philosophical inclinations as regards the evolution of society, the desirability of equity, and the importance of production.

The issue of port pricing in maritime economics has not arisen only out of academic interest but as a response to the need felt in the port industry itself for a self-discipline mechanism that, if consistently applied, would eventually lead to the recovery of port investment costs and to future investments that are largely *demand driven*. This requirement has been the result of the recognition that, in the intensified regional port competition of today and the increasingly tightened fiscal constraints, it is no longer acceptable to indiscriminately and without a formal economic *rationale*, spend taxpayer money on port investments, often aimed at increasing market share at the expense of other ports, particularly within the same economically interdependent area.

Naturally, pricing for cost recovery looks at the 'user' rather than the 'taxpayer'. This is just as well, given that ports (at least container terminals) are being transformed from public to private enterprises. The allocative and income distribution effects of such a switch in direction are obvious: investments are recovered, and port revenues generated, from the user of a (private) facility, who will have to somehow pass these costs on to the final consumer. The latter will in all likelihood have to pay higher prices for the goods he consumes but, at least in efficient markets, he is compensated by correspondingly paying less taxes (for infrastructure investments). Obviously, such issues are highly complex and have yet to be researched.

In principle, pricing for cost recovery should mean that depreciation of port infrastructure is included as a cost in the port's pricing system. Something like this would undoubtedly raise the level of port prices, but the overall effect of this on consumer prices and traffic diversion may not be as large as some might at first sight expect. This effect depends on the percentage of port costs in final consumer prices; the import and export elasticities of traded goods; the level of competition in transport markets (especially liner shipping) as well as all other markets along the door-to-door chain (i.e. distribution, wholesaling, etc.). It could well be argued that higher port prices are not necessarily passed on to consumers but are instead absorbed by transport operators and other market intermediaries.

But even if higher port prices are, to some extent, passed on to consumers, the overall effect on society could be ascertained by comparing the loss in consumer surplus, as a result of higher port prices, to the welfare gains had the public funds in question been invested in other sectors of the economy or led to lower taxes in general.

This paper has argued in favour of pricing for cost recovery among competing commercial ports and it has shown how long-run marginal cost pricing can be a powerful pricing discipline that can eliminate subsidies and establish a level playing field among ports.

However, a 'pricing discipline' imposed on ports through policy intervention would be unacceptable. The objectives often pursued by ports are so divergent that any uniform approach to pricing becomes meaningless and politically unfeasible. Pricing matters on the other hand, at least in a liberal economic environment, ought to be, ideally, left to the producers (ports) themselves.

The ATENCO study has demonstrated that, however controversial the issue of port pricing itself may be, there is general consensus on the importance of cost recovery. And this was an important development and step forward. Indeed, as long as this objective is respected, the specific pricing policy of the individual port becomes of secondary importance and only in so far as crowding out effects and efficient allocation of resources are concerned.

Once cost recovery is generally accepted as a guiding principle in port investment and pricing, the way forward is much simpler. It involves the compilation of better and more harmonised statistics on port costs; adoption of standardised port accounting systems; greater transparency of port accounts and of financial flows between the port and its institutional master; and, perhaps, a common glossary of terms. Last but by no means least, the institution of an *Independent Regulatory Authority*, or in any case the existence of efficient *supervisory control*, would be a sine qua non. And these are objectives not so difficult to achieve.

In conclusion, therefore, port policy is reorienting its attention from the idea of adopting uniform cost based pricing principles, towards: (a) more indirect incentives promoting cost based thinking in ports (e.g. by defining more clearly what constitutes acceptable public support in port infrastructure); and (b) rethinking how conventional competition rules (related, *inter alia*, to market access; abuse of dominant position; collusive behaviour, etc.) should be applied to the port sector.

Notes

1. Often there is some confusion between the concepts of 'sunk' and 'fixed' costs. The former are costs that cannot be recovered once the firm decides to leave the market; a breakwater could be a good point in case here. Fixed costs, naturally, are those that do not vary with output. A sunk cost could thus well be variable, e.g. marketing and advertising expenses, while a fixed cost, such as that of a gantry crane, does not necessarily have to be sunk, as the asset could be sold to another port.
2. Despite the degree of competition, a port will always have a *captive* market, at least on cargoes in its immediate hinterland. This fact alone suffices to describe ports as an imperfectly competitive market where the producer, i.e. the port, may have considerable power over its prices. (Chamberlin, 1933; Robinson, 1969).
3. The concept of an economically interdependent geographic area or region, as I use it here, has both a spatial and an economic dimension. It refers to a spatially delineated geographic area in which 'binding' arrangements (laws) of direct economic impact –such as for instance competition, labor and fiscal laws- are 'jointly and institutionally' put in place with the aim of maximizing collective welfare. Apart from an individual country (with its regions, provinces, etc.) that would obviously qualify under such a definition, a good example of such an area is the European Union, as well as other regional blocs, depending on the strength of their institutional ties over and above trade policy.

4. I vividly recall a rather heated discussion on such issues, over lunch, among the members of Kinnock's 'wise men' group. In the middle of the discussion and quite unexpectedly, Kinnock walked in and, before greeting us, he said : "…so you decided to spend your time on port pricing; I can promise you one thing: you will retire discussing the same subject…".
5. Sometime in the 90s, I was involved in a World Bank project on the modernization of the Indian port sector. It was the time when the WB was building, in Mumbai, one of the most modern ports in the region, the new port of Nhava Sheva (or the Jawaharlal Nehru Port). At a high level meeting, I recall myself saying, in the form of a witticism, that "…now, with a new modern seaport, JNP, Mumbai should totally scrap the old city port and develop that area into residential and office space, given the scarcity of the latter and the incredibly high real estate prices of the city…". Difficult for one to imagine how *cold* the meeting room became immediately, in spite of us being in the middle of the monsoon period… I often make the same joke to my Antwerp friends. "…I cannot understand", I keep telling them, "why Antwerp – a river port with locks and dredging requirements- is necessary, when just around the corner there is Rotterdam…".
6. After the canals of the Great Lakes were constructed, an Ohio farmer would receive 10 times the price for his corn, which could now be sold at a much higher price in New York rather than in Cleveland.
7. Often, I ask my students to tell me which is Germany's largest port, but rarely I get the correct answer; i.e. that this is the port of Rotterdam!
8. Whether the absolute level of the elasticities in Table 10.1 is correct is a much less important issue than the observation of a very substantial divergence of elasticities among the various ports. Hence, variation in prices, as a result of the adoption of alternative pricing systems, would, at least in the case of containers, lead to fundamentally different impacts on individual ports, even when engaging in similar price increases.
9. This was in broad terms the position of various Dutch governments on the issue of the new Maasvlakte II terminals in Rotterdam.
10. Liner shipping is another good example of such an industry, familiar to the student of maritime economics.
11. The example of Figure 10.3 was prepared by my good friend and colleague Yvo Saanen of TBA whom I thank for allowing me to reproduce it here.
12. e.g. by dredging approach channels; turning basins; and quay walls at unreasonable drafts.
13. The author had the privilege of being member of the then EU Transport Commissioner, Neil Kinnock's group of experts that drafted the Paper. The Commissioner opened the first meeting of the group with a statement that took everyone aback: *'…if countries want to spend public money to develop their ports, so be it and there is nothing we can do about it…'*. A lot has changed since then though.
14. Other, more recent, policy documents at European level have also addressed this issue; cf. *Final Report* by the high level group on transport infrastructure and charging, concerning options for charging users directly for transport infrastructure operating costs.
15. The author was involved in this exercise as Chairman of the Academic Experts Group.

16. Such estimates have to be viewed with utmost caution and full understanding of the assumptions underlying them. For instance, this impressive percentage assumes that other ports in the region would be able to absorb smoothly the extra traffic or additional costs. It is also assumed that no changes take place in the pricing of the rest of the infrastructure (roads, etc.).
17. Surprisingly, most port authorities expected that the adoption of full cost recovery pricing would have little impact on pricing levels. It is believed here that, although in private ports, such as those of the UK, this may well be the case, this is far from truth in all other ports and this conviction of many port managers can only be explained by their inability to grasp in full the notion and implications of long-run marginal costs.

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11

The Efficiency of European Container Terminals and Implications for Supply Chain Management

Tengfei Wang and Kevin Cullinane

This paper investigates the efficiency of container terminals within the context of global supply chain management. The efficiency and scale properties of 104 of Europe's container terminals with annual throughput of over 10,000 TEUs[1] *in 2003, distributed across 29 European countries, are derived using Data Envelopment Analysis (DEA). The main findings are that significant inefficiency pervades most of the terminals under study and that large scale production tends to be associated with higher efficiency. Terminals in the British Isles and Western Europe were found to be the most efficient, compared to their counterparts with the lowest efficiency in Scandinavian and Eastern European countries.*

1 Introduction

The critical importance of the world's container ports to global supply chains has been analysed in numerous sources (UNCTAD, 1992; UNCTAD, 1999; Notteboom and Winkelmans, 2001; Paixão and Marlow, 2003; Marlow and Paixão, 2004; Robinson, 2002; Robinson, 2003; Bichou and Gray, 2004; Beresford *et al*, 2004; Robinson, 2005; Weston and Robinson, 2005). It could be argued that a container port is simply one element or player, amongst a number of players, in the import or export supply chain linking producer with consumer. Over decades of development, however, many container ports have gradually

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evolved to become pivotal nodes in international logistics networks and product supply chains (or grids). So much so, that Robinson (2002) poses an intriguing question about the end result of this process of evolution: 'What is the role of ports in this new, logistics-restructured environment?'

The role of the container port industry within the global supply chain network is largely a function of the demands of, and influence exerted by, the other players involved in the system and their relative bargaining power. As highlighted by Cullinane (2002, 2005), the major changes in the container shipping industry over the last two decades have been: (a) the globalization of service coverage, achieved mainly though mergers and acquisitions (i.e. horizontal integration) within the liner shipping industry and the cooperation of companies within worldwide strategic alliances and; (b) the provision of extended logistics services in an international context, so that the core business of the liner shipping industry can no longer be construed as simply providing an ocean shipping service, but is actually more concerned with being a key provider in the market for door-to-door and added value logistics; this is an aspect that has largely been made possible by the vertical integration of traditional liner shipping companies, ports and inland haulage companies.

Enhancements to the provision of freight transport infrastructure in and around the world's major origins and destinations of containerised cargo flows, the deployment of increasingly large container vessels on mainline and feeder services (Cullinane and Khanna, 1999, 2000) and the application of hub-and-spoke operations have all led to, and reinforced, an expansion in port hinterlands. This, in turn, has led to enhanced competition between container ports as a result of the greater likelihood that the hinterland of an individual container port will overlap with that of another. Hence, even container ports that specialise in handling gateway traffic, rather than the more footloose transhipment business, are facing new competitive pressures.

In consequence, it is fair to say that shipping lines possess a relatively strong bargaining position compared to that of the suppliers of container handling services in ports. This is because these shipping companies normally have more than one port to choose from; certainly for transhipment traffic, but increasingly also for gateway business. Therefore, liner shipping companies are in a strong position to require ports to provide an efficient and cost-effective service, while container ports need to invest heavily to meet the evermore stringent demands for greater service speed and quality. As a result, the port industry is constantly at the mercy of the shipping lines and frequently risks the loss of important customers when shipping lines adjust their shipping route and port choice (Slack, 1993, Notteboom and Winkelmans, 2001).

In order to survive and prosper in such a competitive and challenging environment, the port industry needs to look both externally and internally. From an external perspective, the port industry needs to understand and adapt itself to meet the frequently changing demands of its customers (Notteboom and Winkelmans, 2001). In this respect Cahoon and Hecker (2005) argue that contemporary ports need to attach greater importance to the marketing of their facilities and services. Robinson (2002, 2003 and 2005) goes further by arguing that container terminals in particular should embed themselves into a whole supply chain and attach greater importance to the provision of value-added service for the benefit of the whole system.

In the short term, a port can obviously attract customers by lowering the price charged to its customers. However, in the long term, the port industry needs to ensure its own sustainable development and recover its costs, particularly those associated with investment. As such, all these costs are eventually passed on to port customers. In consequence, ports need to be productively efficient. Adopting an internal perspective, Marlow and Paixão (2004) have asserted that in a competitive environment, ports should efficiently utilise their existing facilities in serving their customers. Heaver (2001), Notteboom and Winkelmans (2001) and Robinson (2002) have argued that it is imperative for container ports and individual terminals to be efficient in order to survive in today's competitive environment. The corollary of this logic is that ports should ensure that existing infrastructure and equipment is utilised to maximum economic and technical efficiency in order to optimize the container port production process. In so doing, actual and perceived service quality is enhanced by reducing the time that vessels need to stay in port and this translates into indirect, but very real, cost savings to the main customers of container ports; the shipping lines.

From a geographical point of view, container terminals in Europe play a particularly important role in the region's economic, supply chain and logistical development (for example, see Winkelmans, 2004; Martine Zarzoso *et al*, 2004). Because of the advanced nature of the inland transportation systems in Europe and the relative proximity of competitor ports, container terminals in this area face fiercer competition than in the rest of the world (Wang and Cullinane, 2004; Notteboom, 1997).

This paper focuses on measuring the efficiency of container terminals in Europe. It is important to note that in this paper, the container terminal, rather than container port, is treated as the production unit under study. This is in line with the argument that comparable data can only be attained at the level of the container terminal, rather than the port (Goss, 1990; Heaver, 1995; Alderton, 1999; Heaver *et al*, 2000; Heaver, Meersman and van de Voorde, 2001). As a basis for enhancing the literature in this sphere, this paper serves to supplement existing studies by deriving estimates of relative efficiency for a sample comprising 104 of Europe's container terminals with throughput of over 10,000 TEUs per annum distributed across 29 European countries. The scale properties of container terminal production are also considered as part of the study, as is the relationship of efficiency to geographical influence.

The next section outlines the methodology adopted for undertaking the analysis. Section 3 justifies and describes the variables for which data must be collected and the process by which this is achieved. Results from the empirical analysis are presented in section 4 and a summary provided and conclusions drawn in section 5.

2 Methodology

Two approaches to efficiency measurement have been widely applied to measure port efficiency. These are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). Applications of DEA to the port sector include Roll and Hayuth (1993), Martinez-Budria *et al* (1999); Tongzon (2001), Valentine and Gray (2001), Barros and Athanassiou (2004), Turner, Windle and Dresner (2004), Cullinane, Song and Wang (2005), Cullinane, Song, Ji and Wang (2004), Cullinane, Ji and Wang (2005) and Wang, Cullinane and Song (2005). Example applications of SFA to port data include Liu (1995), Notteboom, Coeck and van den Broeck (2000), Coto-Millan, Banos-Pino and Rodriguez-Alvarez (2000), Cullinane, Song and Gray (2002), Cullinane and Song (2003), Tongzon and Heng (2005) and Wang, Cullinane and Song (2005).

Although there are conflicting claims made with respect to which of the two techniques is 'best' (see Cooper, Seiford and Tone, 2000; Aigner, Lovell and Schmidt, 1977), evidence suggests that the results derived and conclusions drawn from the application of each approach to port data are very highly correlated (see Cullinane *et al*, 2005). For the purposes of this study, DEA has been chosen as the preferred method to be applied. DEA can be roughly defined as a nonparametric method of measuring the efficiency of a Decision Making Unit (DMU) with multiple inputs and/or multiple outputs. This is achieved by constructing a single 'virtual' output to a single 'virtual' input without pre-defining a production function. The term DEA and the CCR model were first coined in Charnes, Cooper and Rhodes (1978), whose work was followed by a phenomenal expansion of DEA in terms of its theory, methodology and application over the last few decades. This is reflected in the 3,183 applications of DEA methodologies between 1978 and 2001 that are reported by Tavares (2002).

Among other models in the context of DEA, the two most widely used DEA models, named DEA CCR (due to Charnes, Cooper and Rhodes, 1978) and BCC models (due to Banker, Charnes and Cooper, 1984), deserve greater attention, especially since they are utilised later in this paper. The DEA-CCR model assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. The DEA-BCC model, on the other hand, allows for variable returns to scale and is graphically represented by a piecewise linear convex frontier.

Formally, let inputs be $x_k = (x_{1k}, x_{2k} \cdots x_{Mk}) \in R_+^M$ to produce outputs $y_k = (y_{1k}, y_{2k} \cdots y_{Nk}) \in R_+^N$. The row vectors x_k and y_k form the kth rows of the data matrices X and Y, respectively. Let $\lambda = (\lambda_1, \lambda_2 \cdots \lambda_K) \in R_+^K$ be a non-negative vector, which forms the linear combinations of the K firms. Finally, let $e = (1, 1, \ldots, 1)$ be a suitably dimensioned vector of unity values.

The output-oriented DEA model seeks to maximize the proportional increase in output while remaining within the production possibility set. An output–oriented efficiency measurement problem can be written as a series of K linear programming envelopment problems, with the constraints differentiating between the DEA-CCR and DEA-BCC models, as shown in (1) through (5).

$$\max_{U,\lambda} \quad U \tag{1}$$

Subject to

$$U y_k' - Y' \lambda \leq 0 \tag{2}$$

$$X' \lambda - x_k' \leq 0 \tag{3}$$

$$\lambda \geq 0 \text{ (DEA-CCR)} \tag{4}$$

$$\mathrm{e}\lambda' = 1 \text{ (DEA-BCC)} \tag{5}$$

The combination of Equations from (1) through (4) and (1) through (5), respectively, form the DEA-CCR and DEA-BCC models. The output-oriented measure of technical efficiency of the *k*-th DMU, denoted by TE_k, can be computed by equation (6).

$$TE_k = 1/U_k \tag{6}$$

The technical efficiency derived from DEA-CCR and DEA-BCC models are frequently used to obtain a measure of scale efficiency, as shown in equation (7) (Cooper, Seiford and Tone, 2000).

$$SE_k = U_{CCR\_k}/U_{BCC\_k} \tag{7}$$

…where SE_k, indicates the scale efficiency of the *k*-th DMU, while U_{CCR_k} and U_{BCC_k} are the technical efficiency measures for DMU *k* derived from applying the DEA-CCR and DEA-BCC models respectively. $SE_k = 1$ indicates scale efficiency and $SE_k < 1$ indicates scale inefficiency.

Scale inefficiency is due to either increasing or decreasing returns to scale which can be determined by inspecting the sum of weights, $e\lambda'$, under the specification of the CCR model. If this sum is equal to one, the law of constant returns to scale prevails, whereas increasing returns to scale and decreasing returns to scale prevail when the sum is, respectively, less than, or greater than, unity.

3 Definition of variables and data

The scientific definitions of input and output variables are crucial for the application of DEA. This is because specifying erroneous or ill-defined variables for collection and analysis will inevitably lead to the wrong conclusions emerging, however elaborate the models employed may be. In line with the recommendations of Norman and Stoker (1991), a thorough discussion of variable definition is provided in Wang, Cullinane and Song (2005), but can be summarised as follows. The input and output variables should reflect the actual objectives and process of container port production as accurately as possible. As far as the former is concerned, the observed performance of a port might be closely related to its objective. For instance, a port is more likely to utilise state-of-the-art, expensive equipment to improve its productivity if its objective is simply to maximise cargo throughput. On the other hand, a port may be more willing to use cheaper equipment if its objective is simply to maximise profits.

The objectives of a port, therefore, are crucial for the definition of variables for efficiency measurement. For instance, if the objective of a port is to maximise its profits, then employment or any information on labour should be counted as an input variable. However, if the objective of a port is to increase employment, employment should be accounted for as an output variable.

In this paper, the main objective of a port is assumed to be the minimisation of the use of input(s) such as port infrastructure, equipment and labour assuming a given level of cargo that is handled annually. This assumed objective may not be entirely consistent with the more orthodox corporate objective of profit maximization. However, it can be justified not only by its analytical tractability but also by, *inter alia*, the facts that:

(i) As an important element in the global supply chain, the ability of ports to efficiently utilise their infrastructure and facilities will ultimately benefit most port users in terms of a reduction in their costs. Container ports compete on both their direct costs (in that, where possible, these are passed onto customers) and their indirect costs related to productivity levels. Given a standard unit cost, price competitiveness is undermined by the failure to minimize the use of inputs. In the light of the fierce and ever-increasing competition faced by each container port, to achieve this objective is likely to be more urgent than any other.
(ii) Contemporary container ports rely heavily upon sophisticated equipment and information technology rather than being labour-intensive. In applying the empirical analysis contained herein to determine how well the assumed objective has been attained, the level of utilisation of state-of-the-art assets and, therefore, the overall quality of the management can be inferred. This has obvious implications for, and likely a high correlation with, the achievement of more orthodox corporate objectives such as profit maximization;

As far as the output variable of container terminal production is concerned, container throughput is unquestionably the most important and widely accepted indicator of container port or terminal output. Almost all previous studies treat it as an output variable, because it closely relates to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Most importantly, it also forms the basis for the revenue generation of a container port or terminal. Another final, but extremely pragmatic, consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a port. The proportion of transhipment containers/lifts accounted for in the throughput of each of the container ports in the sample may be considered to be a potentially confounding problem. However, in the vast majority of cases, the amount of 'work' associated with the handling of a transhipment container within a terminal does, in fact, equate very closely to that associated with a direct import or export container. Although collecting data on this proportion across the whole sample under analysis would be difficult, especially given the potential political or commercial sensitivities involved. This too provides an interesting avenue for further investigation within the context of container terminal efficiency estimation.

According to orthodox economics, inputs to any form of production process can normally be classified as capital, labour and/or land (Perloff, 2004). This is also the case for the particular circumstances governing the production of a container terminal. A container terminal depends crucially on the efficient use of labour, land and equipment. In the study reported herein, the total quay length, the terminal area and the aggregate annualised expenditure associated with terminal equipment (as a proxy for the capital input) have all been deemed to be the most suitable factors to be incorporated into the models as input variables. The latter item includes annualised capital expenditure on equipment such as quay gantry cranes, yard gantry cranes, mobile cranes, straddle carriers, reachstackers, yard gantries (driverless), rail mounted stacking cranes, rubber tyred gantry (RTG) cranes, terminal tractors, multi trailer trains, automated guided vehicles, automated stacking cranes, container lift trucks, container chassis, forklifts, empty container handlers, prime movers, rolltrailers, sideloaders and toplifters.

Other input factors that might possibly exert an influence over the efficiency estimates that may be derived from this analysis include aspects such as: berth occupancy, berth accessibility, proximity to major trade lanes, terminal/port connectivity (as proxied by the number and frequency of liner services that service the terminal or port), crane operating hours, different handling speeds of yard and ship-to-shore cranes, equipment age and maintenance, the total capital invested in a terminal and associated equipment, average container interchange per ship and quayside water depth. However, the practical problem of obtaining data on each of these variables across the whole sample is likely to prove virtually insurmountable. In addition, with the vast number of potential input variables that may be hypothesised as influencing container port efficiency, the issue of multicollinearity becomes rather salient.

While the potential criticisms that can be levelled at the input variables incorporated within the models estimated herein are indeed obvious, they serve merely to instil the requirement for care in the interpretation of the results that are forthcoming from the analysis. They also point the way to the further development of this avenue of research, with the next obvious stage being the incorporation of more wide-ranging asset values and maintenance expenditures covering the full scope of terminal operation beyond those associated merely with container quay and yard equipment, for which data collection is comparatively more straightforward than for other alternative potential input variables.

A reliable source of labour data was not available. However, efforts were made to obtain precise data on the labour input through a survey of the sample. In common with previous research of this type (Valentine and Gray, 2001) many of the responses were found to be inconsistent, illogical and perhaps even indicative of policy response bias. As such, their use would have undermined the objectivity of the analysis and the validity of the efficiency estimates derived from it. In the light of the unavailability or unreliability of direct data, therefore, information on labour inputs is derived from a pre-determined relationship to terminal facilities (De Neufville and Tsunokawa, 1981; Notteboom, Coeck and van den Broeck, 2000). It is very important to note, however, that this pre-determined relationship is not applicable to all types of ports with different characteristics of production. It should also be recognised that it is risky to apply this relationship to container ports of different production scale (throughput) because of the different equipment and labour arrangements employed.

This paper initially aimed to derive estimates of relative efficiency for a sample comprising all of Europe's container terminals with annual throughput of over 10,000 TEUs. However, given the data availability, 104 of Europe's container terminals distributed across 29 countries with annual throughput of over 10,000 TEUs were finally included in the analysis. The required secondary data for a cross-sectional analysis for the year 2003 are mainly taken from various issues of both the *Containerisation International Yearbook* and *Lloyd's Ports of the World*. As these trade publications collect information directly from the ports under study on an annual basis, and the data compiled for this analysis is based on their surveys, it is regarded as the most reliable and comprehensive available. To solve the problem of data unavailability for some

Table 11.1 Summary statistics for the sample

	Output	**Input**		
	Container throughput (TEU)	**Terminal Length (m)**	**Terminal area (ha)**	**Equipment costs (Million Pounds)**
Mean	503,053	1,000	38	45
Standard Error	71,693	68	4	4
Median	246,759	800	22	34
Standard Deviation	731,129	695	42	39
Kurtosis	8	1	4	5
Skewness	3	1	2	2
Range	4,035,000	2,981	200	221
Minimum	15,000	119	1	3
Maximum	4,050,000	3,100	200	223
Sum	52,317,500	104,028	3,972	4,700
Count	104	104	104	104

terminals, a questionnaire was sent to these container terminals and the data collected in this way were also incorporated into the final sample. Important statistics relating to the sample are summarised in Table 11.1.

4 Empirical analysis

Without precise information on the returns to scale of the port production function, two types of DEA models, namely the CCR and BCC models, are applied to analyse the efficiency of the sample container terminals.

The efficiency estimates, the scale efficiency and scale properties of each container terminal are estimated in line with formulae (1) through (7) and the relationship between scale inefficiency and the sum of weights, $e\lambda'$, under the specification of the CCR model. As one would expect, the DEA-BCC model yields higher average efficiency estimates than the DEA-CCR model, with respective average values of 0.44 and 0.43 and where an index value of 1.00 equates to perfect (or maximum) efficiency. Respectively, 9 and 7 out of the 104 terminals (ports) included in the analysis are identified as efficient when the DEA-BCC and the DEA-CCR models are applied. The result that the DEA-BCC model yields more efficient container terminals is not surprising since a DEA model with an assumption of constant returns to scale provides information purely on technical and scale efficiency taken together, while a DEA model with the assumption of variable returns to scale identifies technical efficiency alone. An ANOVA of the efficiency for the DEA-BCC and DEA-CCR analyses ($F = 0.18$) indicates that the efficiency measures calculated using these two different approaches are not significantly different at the 5% level (with a critical value of 3.89). A Spearman's rank order correlation coefficient between the efficiency rankings derived from DEA-BCC and DEA-CCR analyses is 0.997. The positive and high Spearman's rank order correlation coefficient indicates that the rank of each firm derived from applying the two different models is similar. A combination of ANOVA and Spearman's rank order correlation coefficient leads to the conclusion that the efficiency estimates yielded by the two approaches are similar and follow the same pattern across firms.

Empirical results reveal that there exists substantial waste in the production of the container ports in the sample. For instance, the average efficiency of container ports derived from applying the DEA-CCR model amounts to 0.43. This indicates that, in theory, the ports under study can, on average, dramatically increase the level of their outputs to 2.3 (= 1/0.43) times as much as their current level while using the same inputs. This is dependent, however, on the appropriate approaches to production being implemented and the appropriate scale of production adopted.

As far as individual container terminals are concerned, of the 104 terminals (ports), 54 exhibit constant returns to scale, 39 exhibit increasing returns to scale, and 11 have decreasing returns to scale. Among the 15 terminals classified as being *large* in size (i.e. having annual container throughput of more than 1 million TEU), seven, three and five exhibit decreasing, increasing and constant returns to scale, respectively. Among the 58 *medium* size terminals (classified as having annual container throughput of less than 1 million TEU and more than 100,000 TEU), most of them exhibit either constant or increasing returns to scale, 35 and 19 respectively. Only 4 medium size terminals exhibit decreasing returns to scale. Finally, all 31 *small* terminals (classified as having annual container throughput of less than 100,000 TEUs) exhibit either constant or increasing returns to scale.

Figure 11.1 plots the average tendency for the relationship between efficiency scores and production scale (as measured by container throughput). It reveals that a large scale of production is more likely to be associated with high efficiency scores. Since the correlation coefficients of the mean efficiency scores against container throughput are

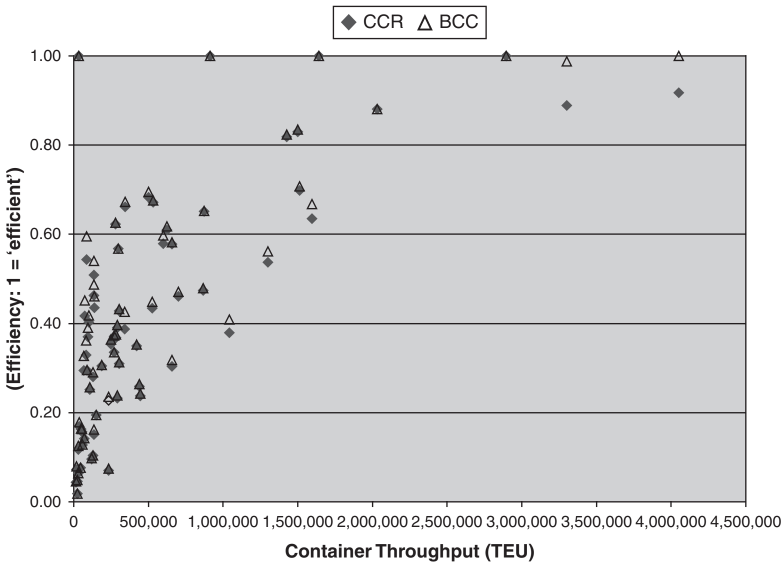

Figure 11.1 Relationship between efficiency and production scale

0.63 for both the DEA-BCC and the DEA-CCR models, it would appear that the efficiency of a terminal is significantly influenced by its production scale and that there is evidence to support the existence of economies of scale in the sector.

The relationship between efficiency scores and container throughput can be further analysed through the application of a Tobit regression model where the values of the dependent variable (relative efficiency scores) fall within the interval [0, 1] (Greene, 2003). The results of the Tobit analysis are reported in Table 11.2. The test-statistic for the Tobit model is calculated as $-2\ ln\ \lambda$, where $ln\ \lambda$ is the difference between the natural logarithm of the maximized value of the likelihood function with all independent variables equal to zero, and the natural logarithm of the maximized values of the likelihood function with the independent variables as observed in the regression. The log-likelihood ratio test has a chi-squared distribution, where the degrees of freedom denote the number of explanatory variables in the regression. The calculated values of Chi-squared statistics of 51.90 and 57.90 are higher than the critical value of 6.63 at the 1% significance level with 1 degree of freedom. This indicates that the level of port efficiency is significantly influenced by the scale of port production.

Table 11.2 Estimation results for Tobit model

Explanatory variables	**CCR Analysis**		**BCC Analysis**	
	Coefficient	***t*-stat**	**Coefficient**	***t*-stat**
Constant	0.3	11.12	0.30	10.48
Throughput	$2.6*10^{-7}$	8.05	$3.1*10^{-7}$	7.96
Chi-squared[a]	51.90		57.90	

[a] The chi-squared statistic is based on a likelihood ratio test which tests the joint significance of the independent variables. The likelihood ratio is computed as $-2\ ln\ (\lambda_0 / \lambda_1)$, where λ_1 is the value of the likelihood function for the full model as fitted and λ_0 is the maximum value if the coefficient of throughput is zero.

It should be noted that the results shown in Table 11.2 suggest that a positive relationship exists between efficiency scores and throughput. To a great extent, this validates the observation made in relation to Figure 11.1 that container terminals that are large in production scale are more likely to be associated with higher efficiency scores. This is not surprising considering the fact that large terminals are more likely to utilise more state-of-the-art equipment and sophisticated management than their smaller counterparts. This finding is consistent with that of the pioneering work conducted by De Neufville and Tsunokawa (1981), who analysed a sample of a mere 5 container ports in the United States over the time period from 1970 to 1978 and found that the production of container ports had a tendency to follow the law of increasing returns to scale.

The average efficiency of container terminals located in different regions of Europe is found to differ from each other to a large or small extent. Figure 11.2 shows the average efficiency of container ports in different regions and reveals that the average efficiency of ports in the British Isles and west Europe are higher than that of the other regions, while container terminals in Scandinavian and Eastern European countries have the lowest average efficiency. This result should be viewed with great caution, bearing in mind that some important container terminals were not included in the sample due to data unavailability and that these missing terminals are likely to exert either a positive or negative influence on the efficiency estimates of those that remain in the sample. Nevertheless, this finding is interesting in that such a difference might indicate that more complicated factors exert a significant influence over the efficiency of a region's ports. Such region-specific influences might include: the level of general economic development

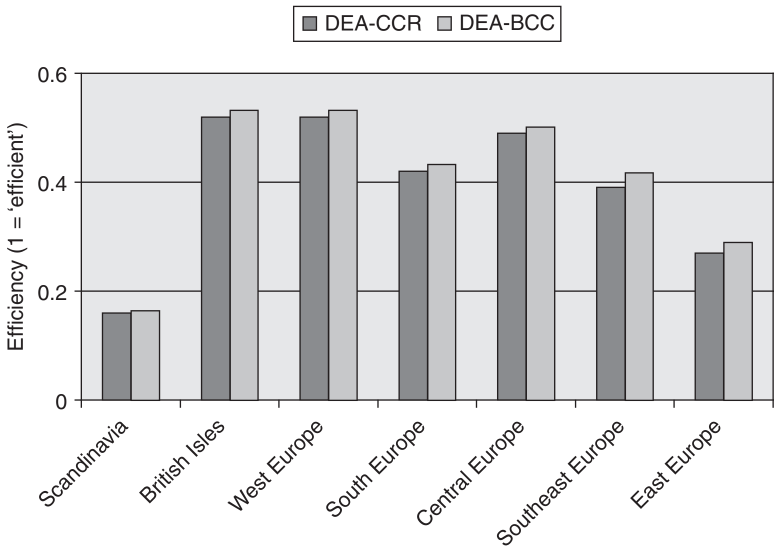

Figure 11.2 Efficiency of container ports in different regions in Europe[a]

[a] Note that the countries where the ports under study are located are roughly divided into seven regions. They are Scandinavia (Denmark, Finland and Sweden), the British Isles (Ireland and the UK), West Europe (Belgium, France, Netherlands), South Europe (Cyprus, Malta, Portugal, Spain, Canary Isles and Italy), Central Europe (Germany, Hungary, Poland and Slovak Republic), Southeast Europe (Bulgaria, Croatia, Greece, Romania, Slovenia and Turkey) and East Europe (Estonia, Latvia, Lithuania, Ukraine and Russia).

(Miyashita, 2005), the comparative competence of management, organisational style/culture, accessibility to/from major trade lanes (Tongzon, 2005) or simply the level of competition or geographical proximity between ports within a particular region (Cullinane, 2000; Cullinane, Wang and Cullinane, 2004).

5 Summary and Conclusions

This paper investigates the enormous challenge of ensuring maximum efficiency in the container port industry in an era where supply chain management has emerged as a core business competence. It is asserted that contemporary container ports face much fiercer competition than before and that to survive in this competitive environment, modern container ports need to look at all the factors influencing port performance, both externally and internally. Externally, a port needs to understand the changing demands of its customers and to recognise, and attach greater importance to, the role of marketing and the position of ports within the context of a grid of global supply chains in which they participate. Internally, container ports need to reduce any slack in production in order to ensure sustainable development and competitiveness. Because port costs are increasingly passed onto customers, in the long run, reducing slacks in port production to a minimum will ultimately benefit the whole supply chain and most port users.

DEA has been applied to determine the relative efficiency of Europe's leading container terminals. To this end, the fundamental properties of DEA and the definitions of input and output variables with reference to the characteristics of container terminal production have been thoroughly discussed. Data for the year 2003 on 104 leading container terminals with an annual container throughput over 10,000 TEUs distributed across 29 European countries were finally collected for the estimation of individual efficiency scores for each port/terminal. The sample analysed is hitherto the most comprehensive of its kind compared with existing studies. One major benefit of large sample studies is that the efficiency estimates derived from them are likely to be more consistent and robust. Therefore, efficiency estimates are less sensitive to change (subject to maintaining a similar sample size), when the constituency of the sample is changed. The comparatively large sample analysed in this study has, it is ventured, yielded low relative efficiency scores compared with the findings of previous studies. However, as sample size increases this phenomenon is to be wholly expected. There may be other reasons that contribute to explaining this phenomenon, but this question remains subject to further investigation and provides an interesting avenue for further research.

The primary finding of this paper is the significant inefficiency that generally pervades most of the terminals under study. The average efficiency of container terminals under study amounts to 0.43 (assuming constant returns to scale) and 0.44 (assuming variable returns to scale). The latter, more realistic, figure indicates that, on average, terminals can dramatically improve the level of their output by up to 2.3 times as much as current levels, while using the same inputs. However, it is extremely important to note that although the results derived from DEA provide important information on 'theoretically' optimum production, such results should be always interpreted with a fair degree of caution in practice. This is especially true with respect to applications to the port industry. Every port has its own natural situation, cargo hinterland and inland transportation system. The optimal production achievable in one port is not necessarily achievable for another port. From this point of view, the communication of DEA results to the port industry and to their customers, the liner shipping industry, is an important area for the extension of this body of research. Undertaking an assessment of the perceptions of these groups of the levels of relative efficiency which prevail in the port sector is also an important avenue for further research. Ultimately, however, the ambition is to develop suitable metrics and to collect data on these more ephemeral determinants of port efficiency and to include them as variables within DEA models so that they might then exert a more direct quantitative influence over the efficiency estimates derived.

Another important area deserving of further study is the analysis of the relationship between DEA efficiency estimates and more widely used industry data and indicators. As previously mentioned, DEA has been widely applied by academics in the analysis of the overall productive efficiency of container terminals or ports. However, in practice, such methods have been applied a lot less widely by the port industry. A comparison between an approach based on DEA and the approaches routinely adopted within the port industry will not only justify the usefulness of DEA and lead to its further enhancement as a tool which the industry may utilise for improving its performance, but also will offer deeper insights into the choice of performance measurement approaches that are currently employed within the port industry.

For the purposes of this study, the scale properties of container terminal production have also been analyzed. Most of the container terminals that are large in production scale are more likely to already be associated with higher efficiency scores. These findings are particularly informative for policy makers and corporate decision makers. For example, these findings provide some theoretical support for the increasing tendency towards the construction of large-scale container ports (mega-ports) that is progressing worldwide. These findings, however, also suggest that not every individual container terminal (even ones that are currently small) follows the law of increasing returns to scale. Decision makers, both commercial and political, will need to carefully study, therefore, their own particular set of circumstances and general situation.

This paper has also found that the average efficiency of container terminals located in different regions differs from each other, either to a large or small extent. The container terminals in the British Isles and Western Europe were found to be the most efficient, compared with their counterparts with the lowest efficiency in Scandinavian and Eastern European countries. A further investigation into the reasons behind the relative (in)efficiency of these terminals will be both interesting and complicated. On the one hand, to find the reasons behind (in)efficiency is a prerequisite for obtaining any further efficiency improvement. On the other hand, the possible reasons behind (in)efficiency (such as the level of economic growth within the region under study, the port governance structure, extent of port competition and private sector participation etc) can be so wide-ranging, difficult to quantify and interdependent that an investigation along this line might prove to be extremely challenging. From this point of view, the derivation of the efficiency estimates for the sample of container terminals analysed in this paper constitutes merely a beginning, rather than an end in itself.

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Note

1. Twenty-foot Equivalent Unit; a standard size of container, typically used for denoting the output or capacity of container ports or terminals or for defining the container carrying capacity or loading of ships.

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12

An Alternative Approach to Efficiency Measurement of Seaports

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A whole series of changes in world economic order in the last decade such as globalisation of production and consumption, and structural changes in inter-port relations, port-hinterland relationships and logistics have strengthened the role of ports as nodes in the global transport system. In such an environment, port production economics plays an important role in port management considerations. This paper reviews approaches to performance measurement and provides an examination of the applicability of alternative (four-stage) Data Envelopment Analysis to seaport efficiency measurement. The study finds that alternative DEA is a potentially powerful approach to the evaluation of the overall efficiency of seaports.

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Introduction

Port being a sub-system of the total transport network and a meeting place of other modes of transport is essentially an economic infrastructure that serves to handle domestic and overseas cargoes. An efficient port raises the productivity of prime factors of production (labour and capital) and profitability of the producing units thereby

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permitting higher levels of output, income, and employment (Walter, 1975; Bennathan and Walters, 1979; Talley, 1988; Dowd and Leschine, 1990; Ghosh and De, 2000; Lee, 2001).[1]

The rate of growth in world trade has been strong and since the mid-1980s, it has consistently exceeded that of world output. Rising trade is linked to the increasing integration of national economies across the globe, the deepening of the international division of labour, and the concomitant emergence of increasingly internationalised production patterns. These developments have greatly increased the difficulties of monitoring a port's performance.

On the other hand, the continuous changes in international transport management, from a segmented modal approach to a much more integrated transport concept tailored to better meet the pressing needs of customer industries are resulting in an increasing pressure on ports to reorient their roles and functions to this more demanding operational environment (Cullinane and Song, 1998). Port managers are often under great pressure to improve the performance of their ports. To improve performance, port managers need to evaluate constantly operations or processes related to providing, marketing, and selling of services to the users. This entails the rethinking of port development strategies as well as far-reaching reforms in the legislative, regulatory, and managerial environment. Naturally therefore, the efficiency of ports has become a critical factor for a country's competitiveness and its trade prospects (Cullinane, 2002; Wilson *et al*, 2002).

Improving the performance of a port system improves the country's international market access and leads directly to increased trade and, through this, to higher income. Better monitoring of seaport performance, in a fast changing world, is very crucial in measuring its level of efficiency and thereby competitiveness. Hence, it is felt necessary that in each port a complementary performance monitoring approach to address the changing environment of global trade is very much required to gain sustainable improvement in competitiveness. Thus, the requisite policy agenda extends broadly to stimulating the evolution of port services, promulgating new performance standards, and encouraging their implementation. In view of the above, this paper introduces an alternative approach to measuring seaport efficiency, with the use of Korean port traffic data.

The application of traditional production function methodology to spatial production units like airports and seaports, in order to find out the nature and strength of the explanatory variables, is not new, particularly when the sole independent variables used are labour and capital. But beyond the conventional wisdom in production economics, ports unlike other manufacturing decision-making units (DMU), represent a spatial production system that cannot be fully understood simply by the quantity of labour and capital alone even under equal demand conditions. One must probe deeper into the many more internal and external factors affecting a port. The adversity or favourability of the inherent locational features of a port ultimately dictate the desired amount of capital expenditures that significantly affect the efficiency of operation at various layers of management, not necessarily all in the port complex. Hence, port efficiency is expected to be highly contingent upon factors, which are not merely labour and capital. Thus, the mere amount of capital is not sufficient to measure the efficiency of a port. What is important is how this capital is allocated and utilised in order to enhance port performance. Ideally, $Y = f(L, K)$. But in the case of a spatial DMU like a port, the optimal combination of geo-navigational and strategic factors, along with current labour, are ultimately responsible for port efficiency rather than the mere amount of capital. There is reasonable consensus among economists that the mobility of goods, services, and labour across regions depends largely on the quality and quantity of various integrated facilities available, and not directly and solely on the amount of investment or capital stock. Naturally therefore, the use of the Data Envelopment Analysis (DEA) is likely to better reflect the input-output relationship relative to capital in such a context. The point is not that capital is unimportant. Had there been adequate information on capital accumulation – and some quantitative idea on public corruption at various layers of fund disbursement and execution across each region – it would have been justified to work with capital stock pertaining to the relevant infrastructures for measuring the efficiency of ports.

Performance evaluation and benchmarking are a widely used method to identify and adopt best practices as a means to improve the performance and increase productivity, and are particularly valuable when no objective or engineered standard is available to define efficient and effective performance. Consider port operations, for example. The inputs include labourers, equipment, hydrographical attributes, information and communication technology, and others, and outputs include volume of traffic handled, number of port personnel trained, and others. As a matter of fact, evaluation of performance of a port under such a complex environment is difficult. Complexities are getting wider day by day due to the emergence of numerous unknown environmental factors. Over and above, environmental

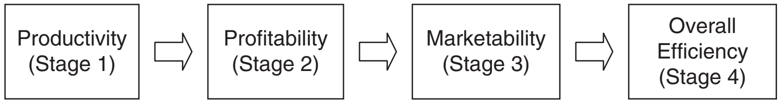

Figure 12.1 Alternative (four-stage) DEA model

heterogeneity strongly prevails and differs across the globe. Therefore, benchmarking is often used in managing service operations, because service standards (benchmarks) are more difficult to define than manufacturing standards. Difficulties are further enhanced when the relationships between the inputs and the outputs are complex and involve many unknown tradeoffs. DEA is a tool that can evaluate performance and benchmarking of port services in the context of multiple inputs and outputs.

The purpose of this paper is to introduce a new and alternative approach to measure the performance and efficiency of ports because efficiency ratings are likely to be a powerful tool for port authorities in assessing the comparative performance of their ports. This paper considers, as an extension of general DEA, a four-stage DEA, to overcome the limitations of basic DEA models. Figure 12.1 portrays the measurement and classification of port efficiency in the context of the alternative (four-stage) DEA.

The paper is organised as follows. The following section outlines the concept and measurement of DEA. The one thereafter concentrates on the basic concept of four-stage DEA and its application in the port industry. Finally, conclusions and policy implications are drawn.

Brief survey of studies on application of DEA in seaports

DEA is one of the most important approaches to measure efficiency. Since its advent in 1978 (Charnes *et al*, 1978), the method has been widely utilised to analyse relative efficiency, and has covered a wide area of applications and theoretical extensions (Allen *et al*, 1997). There are some studies that have tried to measure the productivity and efficiency of container ports using DEA (Wang *et al*, 2002; Tongzon, 2001; Valantine and Gray, 2001; Martinez-Budria *et al*, 1999; Roll and Hayuth, 1993). However, except Wang *et al* (2002) and Valantine and Gray (2001), all of them have concentrated on the CCR (Charnes *et al*, 1978) model. The major difference between the CCR and BCC (Banker *et al*, 1984) models is that while the CCR model normally measures efficiency under CRS (constant returns to scale), the BCC model does this under VRS (variable returns to scale). Some of the pioneering studies that have dealt with productivity and efficiency of seaports in the last 15 years are De Monie (1987); Dowd and Leschine (1990); Liu (1995); Fleming (1997); Roll and Hayuth (1993); Banos *et al* (1999); Coto *et al* (2000); Tongzon (2001); Estache *et al* (2001); Valantine and Gray (2001); Han (2002); De and Ghosh (2002); and Cullinane *et al* (2002). While Roll and Hayuth (1993), Tongzon (2001) and Valantine and Gray (2001) used the DEA method, the rest of the studies concentrated on production function models. A summary of some important studies is presented in Table 12.1.

Four-stage DEA for measuring productivity, profitability, and marketability

DEA is widely acclaimed as a useful technique for measuring efficiency, including production possibilities, deemed to be one of the common interests of Operations Research and Management Science (Charnes *et al*, 1994).[2] DEA is defined as a non-parametric method of measuring the efficiency of a DMU with multiple inputs and/or multiple outputs. This is achieved by constructing a single 'virtual' output to a single 'virtual' input without pre-defining a production function.[3] The sum of weighted outputs over the sum of weighted inputs is taken into consideration in measuring port efficiency (Valantine and Gray, 2001). Naturally, port productivity is influenced by physical and/or institutional factors. We, going beyond the conventional methods, have attempted to measure the general productive efficiency emphasising market-ability, which is one of the important factors in measuring competitiveness of a port and its profitability. There are some basic differences between general DEA and our proposed alternative DEA. First, conventional DEA methods usually measure the overall efficiency by using specific input and output variables. Our paper has divided the overall efficiency into several stages by transforming the inputs and outputs in each stage. Therefore, our paper derives the several efficiencies according to the production process. Second, our four-stage DEA method also shows the role of the inputs and outputs according to the stages differently. Third, policy planners can analyse a situation correctly, and suggest a solution for enhancing the efficiency of each DMU. In nutshell, the four-stage DEA method is introduced here to measure the productivity, efficiency and marketability of a port.

Table 12.1 A survey of the literature on efficiency measures in seaports

Author	**Data**	**Model**[1]	**Functional form**
Liu (1995)	Panel 28 UK ports 1983–1990	SPF	Translog Neutral and non-neutral Technological change
Coto *et al* (2000)	Panel 27 Spanish ports 1985–1989	SCF	Translog Non-neutral Technological change
Banos *et al* (1999)	Panel 27 Spanish ports 1985–1997	SCF DF	Translog Neutral Technological change
De and Ghosh (2002)	Cross Section 12 Indian ports 1985–2001	TVPF	Cobb-Douglas Neutral Technological Change
Roll and Hayuth (1993)	Cross Section 20 hypothetical ports 1993	DEA (CCR)	Not applicable
Martinez-Budria *et al* (199	9) Panel 26 Spanish ports 1991–1997	DEA (BCC)	Not applicable
Tongzon (2001)	Panel 16 world ports 1996	DEA (CCR) Additive DEA	Not applicable Tests both CRS and VRS
Valantine and Gray (2001)	Panel 31 world ports 1998	DEA (CCR)	Not applicable
Estache *et al* (2001)	Panel 14 Mexican ports 1996–1999	SPF	Translog, Cobb-Douglas Neutral and non-neutral Technological change
Cullinane *et al* (2002)	Panel 15 world ports 1989–1998	SPF	Cobb–Douglas Neutral
Han (2002)	Panel 25 world ports 1993–1999	PF	Cobb-Douglas Neutral and non-neutral

[1] SPF: stochastic production function; SCF: stochastic cost function; DF: distance function; TVPF: time varying production function; PF: production function; DEA: Data Envelopment Analysis.

Basic DEA models (CCR and BCC)

DEA, as developed by Charnes *et al* (1978), is basically a linear programming application to measure relative efficiency among similar DMUs entailing multiple inputs and outputs. Suppose we have a set of n peer DMUs, which produce multiple output vector $\mathbf{Y}$, by utilising observed multiple input vector $\mathbf{X}$, respectively. Then, the production possibility set $\mathbf{F}$ is defined as follows:

$$\mathbf{F} = \{(\mathbf{Y}, \mathbf{X}) \mid \mathbf{X} \text{ can produce } \mathbf{Y}\} \tag{1}$$

An efficient frontier (or production technology) can be represented by a set of DMUs that satisfy Pareto efficiency conditions. This efficient frontier requires the following two basic assumptions (Shephard, 1970).

First, the efficient frontier should satisfy the convexity assumption of the production possibility set **F**. This means that, for a DMU with a single input A and single output B, if

$$(y^A, x^A) \in \mathbf{F} \text{ and } (y^B, x^B) \in \mathbf{F}, \text{ then } \{\lambda y^A + (1-\lambda)y^B, \lambda x^A + (1-\lambda)x^B, 0 \le \lambda \le 1\} \in \mathbf{F}$$

where λ is a variable concerning linear combination of DMUs.

Second, the efficient frontier should satisfy the 'free disposability' assumption of inputs and outputs. This means that, for inputs, if $(y^A, x^A) \in \mathbf{F}$ and $x^B \ge x^A$, then $(y^A, x^B) \in \mathbf{F}$, and for outputs, if $(y^A, x^A) \in \mathbf{F}$ and $y^B \le y^A$, then $(y^B, x^A) \in \mathbf{F}$. Shephard (1970) provided another functional representation of production technology through the definition of a distance function:

$$D(\mathbf{Y}, \mathbf{X}) = \min\{\theta \mid (\mathbf{X}, \mathbf{Y}/\theta) \in \mathbf{F}\} \tag{2}$$

where θ is a variable representing the efficiency index and $D(\mathbf{Y}, \mathbf{X})$ is an output-oriented distance function.[4] To estimate such a distance function, Aigner and Chu (1968) used linear programming, which later helped Charnes *et al* (1978) in framing the DEA methodology shown in equation (3). Interestingly, this optimal solution can be viewed as reciprocal of Farrell's (1957) technical efficiency estimates.

$$\begin{aligned} &\mathbf{Min}\ \theta - \varepsilon\sum_{r=1}^{s} s_r^+ - \varepsilon\sum_{i=1}^{m} s_i^- \\ &s.t. \quad x_{ij0}\theta - \sum_{j=1}^{n} x_{ij}\lambda_j - s_i^- = 0, i = 1,2,\ldots,m \\ &\qquad \sum_{j=1}^{n} y_{rj}\lambda_j - y_{rj0} - s_r^+ = 0, r = 1,2,\ldots,s, \\ &\qquad \lambda_j, s_i^-, s_r^+ \ge 0, \quad \forall j,r,i. \end{aligned} \tag{3}$$

where we assume n units, each using m inputs to produce s outputs. We denote by y_{rj} the level of the rth output ($r = 1, 2, \ldots, s$) from unit j ($j = 1, 2, \ldots, n$) and by X_{ij} the level of the jth input ($j = 1, 2, \ldots, m$) to the jth DMU.

ε is a very small positive number that prevents the weights from vanishing (formally, should be seen as a non-Archimedean constant), s_i^-, s_r^+

represent the slack variables and λ_j are variables whose optimal values will define an efficient production possibility minimising inputs DMU_0 without detriment to its output levels. As a result, the optimal solution of θ represents the estimated efficiency of DMU_0.

Equation (3) represents a CCR model, which considers the constant returns to scale condition of efficient frontier to retain the above two basic assumptions, whereas the constant returns to scale condition means, for $k > 0$, if $(\mathbf{Y}, \mathbf{X}) \in \mathbf{F}$, then $(k\mathbf{Y}, k\mathbf{X}) \in \mathbf{F}$.

By adding the convexity constraint $\sum\lambda_j = 1$ to the traditional CCR model, the BCC model (1984) estimates pure technical efficiency and scale efficiency, on the assumption that variable returns to scale in production technology exist.

Empirical analysis and explanation

The first step towards conducting a relative efficiency analysis is to define the characteristics that best describe port performance (Roll and Hayuth, 1993). We Fisheries have focused on the measurement of productivity, profitability, and market-ability of seaports by using the congestion and factor-specific efficiency with the four-stage DEA method. The raw data for the four-stage DEA model, collected from the *Statistical Yearbook of Maritime Affairs and Fisheries*, (2001) published by the Korean Ministry of Maritime Affairs and Fisheries, are reported in Table 12.2. To introduce the four-stage DEA model, (i) berthing capacity; (ii) cargo handling capacity have been chosen as inputs; (iii) cargo

Table 12.2 Input and output variables of selected Korean ports for 1999

Ports	Berthing capacity (no. of ship)	Cargo handling capacity (million ton)	Cargo throughputs (ton)	No. of ship calls	Revenue (billion won)	Customer satisfaction (score)
Busan	108	84.764	107.757	69429	47.41	51.00
Incheon	71	56.590	108.227	40639	40.66	48.70
Yeosu	8	3.018	6.752	6385	1.58	55.60
Masan	26	14.233	11.321	13199	6.16	51.80
Ulsan	81	24.776	151.117	45464	32.18	55.20
Donghae	15	23.035	17.072	4370	3.00	66.90
Gusan	24	7.596	11.503	8954	5.70	62.50
Mogpo	13	6.271	6.253	17899	1.54	58.10
Pohang	44	44.542	49.120	13871	10.85	54.90
Jeju	17	3.589	2.386	6332	0.63	51.80
Daesan	14	4.987	49.546	7293	8.10	58.20

Source: Statistical Yearbook of Maritime Affairs and Fisheries, 2001, Ministry of Maritime Affairs and Fisheries.

throughput; (iv) number of ship calls; (v) revenue; (vi) customer satisfaction as outputs. With the exception of (i) and (ii), the role of each variable is changed from input to output and *vice versa* in each stage. The four-stage DEA is measured as follows. First, efficiency is analysed using the CCR and BCC models. Second, congestion in stages 1 and 4, in terms of input amounts, is shown. Third, factor-specific efficiency in stages 1, 2, and 3, in terms of inputs and outputs, is given.

Explanation

As explained above, the following steps are followed in the four-stage DEA method to measure multi-stage efficiency of seaports.

- Stage 1. Productivity: input (berthing capacity, cargo handling capacity) and output (cargo throughput, number of ship calls);
- Stage 2. Profitability: input (cargo throughput, number of ship calls) and output (revenue);
- Stage 3. Marketability: input (revenue) and output (customer satisfaction); and
- Stage 4. Overall efficiency: input (berthing capacity, cargo handling capacity) and output (customer satisfaction).

Efficiency results using CCR model

Table 12.3 shows the efficiency results of the CCR model for 11 Korean ports. The ranking order of the efficiency level of Korean seaports is productivity, profitability, marketability, and overall efficiency. A few observations can be made.

Table 12.3 Efficiency results of CCR model

Ports	**Productivity (Stage 1)**	**Profitability (Stage 2)**	**Marketability (Stage 3)**	**Overall efficiency (Stage 4)**
Busan	0.72693	0.96604	0.01315	0.06795
Incheon	0.74295	1.00000	0.01465	0.09869
Yeosu	0.90470	0.45217	0.43125	1.00000
Masan	0.52100	1.00000	0.10280	0.28666
Ulsan	0.97043	0.69525	0.02098	0.12094
Donghae	0.43267	0.66333	0.27306	0.64173
Gusan	0.51603	1.00000	0.13416	0.44662
Mogpo	1.00000	0.45362	0.46021	0.64305
Pohang	0.45085	0.76437	0.06185	0.17953
Jeju	0.70081	0.48787	1.00000	0.78343
Daesan	1.00000	1.00000	0.08788	0.63347

First, the efficiency of a port in terms of each stage is: productivity (Mogpo, Daesan), profitability (Incheon, Masan, Gunsan, and Daesan), marketability (Jeju), and overall (Yeasu). Second, the ports of Yeosu, Ulsan, Mogpo, and Jeju have shown a high level of efficiency in terms of productivity. Third, except for Mogpo and Jeju, profitability of all seaports has improved in the second stage. Fourth, apart from Yeosu, Donghae, Mogpo, and Jeju, the efficiency level of marketability is low. Fifth, with the exception of Busan and Incheon, the overall efficiency in the fourth stage is low compared to productivity and profitability.

Efficiency results using BCC model

Table 12.4 shows the efficiency results of the BCC model for 11 Korean ports. Some of the findings of the BCC model are as follows.

First, the efficient ports, in each stage, are: productivity (Busan, Yeosu, Ulsan, Mogpo, and Daesan), profitability (Busan, Incheon, Masan, Gunsan, Jeju, and Daesan), marketability (Donghae, Mogpo, and Jeju), and overall (Yeosu, Donghae, and Gunsan). Second, the efficiency levels reported in the BCC model are higher than those of CCR, although the ranking of efficiency level is the same as that of the CCR model.

Efficiency results with RTS

Table 12.5 shows the efficiency results of RTS.[5] The RTS efficiency is calculated as the ratio of a CCR efficiency score to a BCC efficiency score. If the ratio is equal to one, a seaport is considered to be efficient. Decreasing returns to scale (DRS) describes the diseconomies of scale that should be improved to enhance the efficiency level. CCR-efficient

Table 12.4 Efficiency results of BCC model

Ports	Productivity (Stage 1)	Profitability (Stage 2)	Marketability (Stage 3)	Overall efficiency (Stage 4)
Busan	1.00000	1.00000	0.01336	0.07407
Incheon	0.94129	1.00000	0.01558	0.11268
Yeosu	1.00000	0.95510	0.75007	1.00000
Masan	0.53565	1.00000	0.10280	0.30769
Ulsan	1.00000	0.70288	0.03495	0.12181
Donghae	0.62979	1.00000	1.00000	1.00000
Gusan	0.54149	1.00000	0.39844	1.00000
Mogpo	1.00000	0.61683	1.00000	0.92713
Pohang	0.49161	0.82804	0.09962	0.18182
Jeju	0.84090	1.00000	1.00000	0.84090
Daesan	1.00000	1.00000	0.19267	0.98405

Table 12.5 Efficiency and Returns-to-Scale (RTS)

Ports	Productivity (Stage 1)			Profitability (Stage 2)			Marketability (Stage 3)			Overall efficiency (Stage 4)		
	CRS-1	**VRS-1**	**RTS**	**CRS-2**	**VRS-2**	**RTS**	**CRS-3**	**VRS-3**	**RTS**	**CRS-4**	**VRS-4**	**RTS**
Busan	0.7269	1.0000	DRS	0.9660	1.0000	DRS	0.0131	0.0133	IRS	0.0679	0.0740	IRS
Incheon	0.7429	0.9412	DRS	1.0000	1.0000	Constant	0.0146	0.0156	IRS	0.0986	0.1126	IRS
Yeosu	0.9047	1.0000	IRS	0.4521	0.9551	IRS	0.4312	0.7500	DRS	1.0000	1.0000	Constant
Masan	0.5210	0.5356	IRS	1.0000	1.0000	Constant	0.1028	0.1028	Constant	0.2866	0.3076	IRS
Ulsan	0.9704	1.0000	DRS	0.6952	0.7028	DRS	0.0209	0.0349	DRS	0.1209	0.1218	IRS
Donghae	0.4326	0.6297	IRS	0.6633	1.0000	IRS	0.2730	1.0000	DRS	0.6417	1.0000	DRS
Gusan	0.5160	0.5414	IRS	1.0000	1.0000	Constant	0.1341	0.3984	DRS	0.4466	1.0000	DRS
Mogpo	1.0000	1.0000	Constant	0.4536	0.6168	IRS	0.4602	1.0000	DRS	0.6430	0.9271	DRS
Pohang	0.4508	0.4916	DRS	0.7643	0.8280	IRS	0.0618	0.0996	DRS	0.1795	0.1818	IRS
Jeju	0.7008	0.8409	IRS	0.4878	1.0000	IRS	1.0000	1.0000	Constant	0.7834	0.8409	IRS
Daesan	1.0000	1.0000	Constant	1.0000	1.0000	Constant	0.0878	0.1926	DRS	0.6334	0.9840	DRS

seaports must show constant returns to scale (CRS). The following findings of this analysis are worth noting.

First, in stage 1, CCR-inefficient seaports show DRS or IRS. BCC-inefficient seaports show DRS or IRS. The number of DRS, IRS, and CRS seaports are 4, 5, and 2, respectively. Second, in stage 2, CCR-inefficient seaports show DRS or IRS. BCC-inefficient seaports show DRS or IRS. The number of DRS, IRS, and CRS seaports are 2, 5, and 4, respectively. Third, in stage 3, CCR-inefficient seaports show DRS or IRS. BCC-inefficient seaports show DRS or IRS. There are seven DRS seaports, two IRS seaports, and two CRS seaports. Fourth, in stage 4, CCR-seaports show DRS or IRS. BCC-inefficient seaports show DRS or IRS. There are four DRS seaports, six IRS seaports, and one CRS seaport. Fifth, in terms of DRS, efficiency levels of Korean seaports are ranked by profitability, overall efficiency, productivity, and marketability. Therefore, it is recommended that improvement of marketability of Korean seaports should be given priority.

Measurement of congestion

According to Zhu (2003), evidence of congestion is present when reductions in one or more inputs can be associated with increases in one or more outputs, or when increases in one or more inputs can be associated with decreases in one or more outputs without worsening any other input or output.[6]

Therefore, input congestion (Brockett *et al*, 1998; Cooper *et al*, 1999) can give information about the effect of efficiency on output improvement by reducing the input amount. Table 12.6 shows the input congestion in Stages 1 and 4 as an example. The input slack for each seaport will decide the input congestion. In this paper, we measure the congestion of berthing capacity and cargo handling capacity, which are reported in Table 12.6. The port of Ulsan, which was ranked 2 in terms of the biggest berthing capacity, had an input congestion of berthing capacity whereas the ports of Busan and Incheon, which are ranked 1 and 2, respectively, in terms of cargo handling capacity, had an input congestion of cargo handling capacity. Furthermore, in Stage 1 of the port of Ulsan, the amount of berthing capacity congestion was around 18% of the current berthing capacity input level, and in the case of ports like Busan and Incheon, the amounts of cargo handling capacity congestion were around 36% and 38%, respectively, of the current cargo handling capacity input levels.

In Stage 1, four out of 11 seaports had an input congestion of berthing capacity and five seaports had a serious input congestion of cargo-handling capacity. In Stage 4, six seaports had an input congestion of

Table 12.6 Congestion in efficient ports

	Stage 1		Stage 4	
	Amount for congestion		Amount for congestion	
Ports	Berthing capacity	Cargo handling capacity	Berthing capacity	Cargo handling capacity
Busan	0.00000	30394.78373	0.00000	2991.03517
Incheon	0.00000	21751.04030	0.00000	2941.56586
Yeosu	0.49284	0.00000	0.00000	0.00000
Masan	0.00000	1888.86752	0.00000	1268.34034
Ulsan	15.07143	0.00000	1.85330	0.00000
Donghae	0.00000	7541.76560	0.00000	11150.80216
Gusan	2.62016	0.00000	1.72611	0.00000
Mogpo	0.00000	0.00000	0.00000	878.89513
Pohang	0.00000	12611.70600	0.00000	5016.58175
Jeju	5.87375	0.00000	5.86509	0.00000
Daesan	0.00000	0.00000	0.49452	0.00000

cargo handling capacity with improvement of amount for congestion compared to those of Stage 1. Hence, from the preceding analysis, it may be concluded that the input-congestion seaports should optimise input uses for enhancement of their port efficiency.

Measurement of factor-specific efficiency

A factor-specific measure can give priority to a specific input or output, which needs to be emphasised, subject to consideration of all factors.[7] This factor-specific measure can show the maximum potential decrease (input) and increase (output), when other inputs and outputs are kept at current levels.

Table 12.7 indicates the factor-specific efficiency of each stage of the 11 Korean ports in the following manner. First, in Stage 1, except Mogpo and Daesan, all ports should decrease the input and increase the output amount to become efficient. Second, in Stage 2, the ports of Incheon, Masan, Gusan, and Dasesan are efficient ports. Third, in Stage 3, the port of Jeju is efficient. Thus, we recommend that, except for these efficient ports, all other ports should reduce their inputs and enhance outputs to increase efficiency.

Benchmarking models

Benchmarking models are used for making comparisons among the relative positions of the efficient DMUs in the reference groups. Table 12.8

Table 12.7 Factor-specific efficiency for the efficient ports

	Productivity (Stage 1)				Profitability (Stage 2)			Marketability (Stage 3)	
Ports	**Berthing capacity**	**Cargo handling capacity**	**Cargo throughputs**	**No of ship calls**	**Cargo throughputs**	**No of ship calls**	**Revenue**	**Revenue**	**Customer satisfaction**
Busan	0.72693	0.36835	2.81847	1.47344	0.94147	0.91913	1.03515	0.01315	76.02378
Incheon	0.74295	0.35859	2.12048	1.50055	1.00000	1.00000	1.00000	0.01465	68.27168
Yeosu	0.84309	0.90470	1.95389	1.11842	0.42904	0.23535	2.21154	0.43125	2.31884
Masan	0.52100	0.38829	8.12792	2.05168	1.00000	1.00000	1.00000	0.10280	9.72716
Ulsan	0.78436	0.97043	1.10856	1.04236	0.46796	0.66624	1.43834	0.02098	47.67196
Donghae	0.43267	0.10526	3.10957	3.17050	0.37665	0.62567	1.50755	0.27306	3.66222
Gusan	0.40686	0.51603	6.56074	20.79300	1.00000	1.00000	1.00000	0.13416	7.45399
Mogpo	1.00000	1.00000	1.00000	1.00000	0.45362	0.08278	2.20449	0.46021	2.17292
Pohang	0.45085	0.16771	3.17016	2.94154	0.51918	0.74048	1.30827	0.06185	16.16941
Jeju	0.35530	0.70081	11.07870	1.43132	0.48787	0.09683	2.04974	1.00000	1.00000
Daesan	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.08788	11.37864

Table 12.8 Results of benchmarking analysis

Ports	Stage 1 Input-oriented CRS Benchmarking score		Stage 1 Input-oriented CRS Benchmarking core	
	Benchmark score	**Benchmarks (port of Mogpo)**	**Benchmark score**	**Benchmarks (port of Daesan)**
Busan	2.7126	17.2330	1.2341	9.5200
Incheon	4.1442	17.3080	1.0988	5.5720
Yeosu	2.5359	1.0800	1.5321	0.8750
Masan	1.1838	1.8100	0.9745	1.8100
Ulsan	6.9138	24.1670	1.2548	6.2340
Donghae	3.0942	2.7300	0.5593	0.5990
Gusan	1.7165	1.8400	0.8061	1.2280
Pohang	3.0350	7.8550	0.6052	1.9020
Jeju	0.7534	0.3820	1.2064	0.8680

shows the input-oriented CRS variable-benchmark model.[8] We have found Mogpo and Daesan as 'peer' ports. The port of Mogpo has affected the benchmarking scores of the ports of Ulsan, Incheon, and Busan, and that was higher than Daesan as a peer DMU. Based on the benchmarking scores, or shadow prices of benchmarks, one could find out how the peer seaports have influenced other inefficient seaports.

Conclusions and policy implications

This paper has explored the four-stage DEA method in measuring seaport efficiency as an alternative approach to the original DEA method. Previous studies on DEA methods have usually measured the overall efficiency by using specific input and output variables. In sharp contrast, this paper has divided the overall efficiency into several stages by transforming the inputs and outputs in each stage, which ultimately show us the efficiencies according to the production process and stage-wise role of inputs and outputs. Therefore, we have seen that the four-stage DEA method could be a useful tool in measuring seaport efficiency in terms of productivity, profitability, and marketability. Considering Korean ports as an example, this paper has also introduced the congestion, factor-specific efficiency, and benchmarking methods for analysing the four-stage DEA model. The major findings of the study are as follows.

First, the four-stage CCR efficient ports are Mogpo, Daesan (productivity), Incheon, Masan, Gunsan, Daesan (profitability), Jeju (marketability), and Yeasu (overall efficiency). We have found that most of the seaports have improved their profitability level in the second stage. Second, the four-stage BCC efficient ports are Busan, Yeosu, Ulsan, Mogpo, Daesan (productivity), Busan, Incheon, Masan, Gunsan, Jeju, Daesan (profitability), Donghae, Mogpo, Jeju (market-ability), and Yeosu, Donghae, Gunsan (overall efficiency). Third, the RTS ranking order of the efficiency level of Korean seaports is profitability, productivity, overall efficiency, and marketability. It is recommended that improvement of marketability of Korean seaports should be the utmost priority of the port authorities. Fourth, in Stage 1, four out of 11 seaports had an input congestion of berthing capacity and five seaports had an input congestion of cargo handling capacity. In Stage 4, six seaports have a serious input congestion of cargo-handling capacity and relative large amounts (or ratio) of congestion size of cargo-handling capacity. Fifth, in terms of factor-specific efficiency in Stage 1, it is suggested that except for Mogpo and Daesan, all ports should decrease their input amount and increase output amount to become more efficient. In Stage 2, the ports of Incheon, Masan, Gusan, and Dasesan are efficient ports. In Stage 3, the port of Jeju is efficient. Apart from these, every other port should reduce its inputs and enhance output amounts to become more efficient. Sixth, the port of Mogpo has influenced the benchmarking scores of the ports of Ulsan, Incheon, and Busan more than the port of Daesan, as a peer seaport.

Studying container port performance is becoming more important than ever before due to rapid change in logistics and container transportation technology and the competitive nature of the market. Accurate and appropriate measures of efficiency of seaports are becoming a challenge. Our four-stage DEA method has proposed an alternative application of the traditional DEA, showing the multi-stage efficiency according to the characteristics of inputs and outputs. The authorities of inefficient seaports may want to introduce it as one of their efficiency-measuring tools.

The limitation of this study is its short period of analysis. However, the same model can be tested with a longer period of observations. Despite this shortfall, the results obtained in this study suggest a new approach for measuring seaport efficiency, which could become an important steppingstone in setting the future direction of studies in this field by extending previous DEA studies (Roll and Hayuth, 1993; Martinez-Budria *et al*, 1999; Tongzon, 2001; Valantine and Gray, 2001).

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Notes

1. Productivity from the point of view of manufacturer/service provider can be loosely defined as the ratio of output(s) to input(s). This definition can explain single output and single input easily. However, it is more common to find production with multiple outputs and inputs, in which case productivity refers to Total Factor Productivity, which is productivity measure involving all factors of production (Coelli *et al* 1998).
2. The term DEA and the CCR model were first coined by Charnes *et al* (1978), which was later used in humanities and social science phenomenally over the last few decades.
3. This section does not intend to review the development of DEA thoroughly for obvious reasons. Since this paper mainly focuses on the application of DEA to the seaport industry, only the key issues relevant to the current research are addressed. Interested readers may refer to Seiford and Throll (1990), Siegal (1980), Seiford (1996), Sarafoglou (1998), Callen (1990), Charnes *et al* (1991), Cooper *et al* (2000), Humphrey (1993), Roll and Sachish (1981), and Forsund and Sarafoglou (2002) for application of DEA in other fields of humanities and social science.
4. As a corollary, the input-oriented distance function is defined as $\max\{\theta \mid (\mathbf{Y}, \mathbf{X}/\theta) \in \mathbf{F}\}$.
5. DRS *means* when port inputs are increased by one unit and port outputs increase by less than one unit. IRS will result in by more than one unit while CRS induces by exactly one unit. For more detailed graphical explanation of CRS, IRS, and DRS, one can refer to Zhu (2003) and Banker *et al* (2003).
6. For a more detailed explanation including congestion model, refer to Byrnes *et al* (1984), and Ray *et al* (1998).
7. For a more detailed explanation of factor-specific model, refer to Zhu (2000).
8. To know more about the analysis of benchmarking model, see Zhu (2003).

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13

Efficiency in European Seaports with DEA: Evidence from Greece and Portugal

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In this paper, we compare the seaport efficiency of two European countries, Greece and Portugal, using data envelopment analysis (DEA). The international benchmarking procedure is implemented, in which the seaports in each country are compared against each other. The broader aim of this study is to seek out those best practices that will lead to improved performance in the context of European seaport policy. We rank the seaports according to their total productivity for the period 1998–2000. Economic implications arising from the study are considered.
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Introduction

The economic integration of the European Union (EU) is based on the Union's Single Market Program (SMP), which was established in 1992 with the aim of facilitating the free movement of goods and services among member-states. Hence, the need to foster economic policies leading to greater internal monetary stability in each member-country and favouring increased growth and the expansion of a strong market block. The SMP is a vital component of the plan of convergence of EU national economies in terms of prices and costs.

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The reorientation of seaports towards the EU's vision was actually evident prior to SMP (Pallis, 2002), but was reinforced at the beginning of the transfer program established by the European Union for the new candidate-countries (Pereira, 1999). With the increased availability of funds to invest in infrastructure, the seaports of Greece and Portugal have improved their infrastructures in order to compete in the European market. This political process of market integration is likely to be reinforced if the recommendations related to the liberalisation of the seaport sector, set out in the EU directive, 'Seaports with a Common Position' (5 November 2002) are implemented. The European sector associations see this directive as a way to enforce efficiency and to create a more favourable position for seaports in the overall supply chain (Financial Times, 17 February 2003). In this context, the benchmarking of European seaports should be a priority on the research agenda since, despite the clearly non-homogeneous nature of European ports, they perform the same task and thus, may be compared for benchmarking purposes (Tongzon, 1995).

This paper aims to contribute to the above-mentioned endeavour, by evaluating the efficiency of the main seaports in two small European countries with the CCR model, Charnes *et al* (1978) and the BCC model, Banker *et al* (1984).

The paper is organised as follows: in the next section, we describe the institutional setting of the analysis; in the third section, we survey the literature on seaport efficiency; in the fourth section, the theoretical framework is presented; in the fifth section, the data and results are set out, and in the sixth section, we consider the managerial implications of this study. In the penultimate section, we discuss the limitations and possible extensions of this study and finally, in the last section, we present our conclusions.

Institutional setting

In this section, we display the characteristics of Greek and Portuguese seaports in order to establish the institutional background against which the paper is set.

Greece

Table 13.1 presents the Greek seaports ranked according to the movement of freight. The two largest general-purpose Greek seaports – Piraeus and Thessaloniki – which are used in the present study, were run as independent state entities from the mid-1930s to the year 2000. In fact, Elefsis is the largest port by volume of freight, but a large proportion of

Table 13.1 Movement of freight through the major Greek ports in 2000

Number	**Ports**	**1000 metric tons**	**%**
1	Elefsis	17,316,346	0.15
2	Pireaus	13,292,216	0.11
3	Thessaloniki	12,293,520	0.11
4	St. Theodore	11,394,254	0.10
5	Megara	8,117,091	0.07
6	Volos	6,471,416	0.06
7	Aliveri	4,449,005	0.04
8	Chalkida	3,808,395	0.03
9	Patras	2,948,429	0.03
10	Ìilos	2,497,157	0.02
11	Êavala	1,909,307	0.02
12	Igoumenitsa	1,754,822	0.02
13	Iraklion	1,735,061	0.01
14	Rio	1,630,270	0.01
15	Larimna	1,488,852	0.01
16	Ántikira	1,311,622	0.01
17	Itea	987,360	0.01
18	Rodos	957,507	0.01
19	St. Nicholas	744,540	0.01
20	Aigina	705,938	0.01
—	Total	116,392,331	1.00

this is due to fuel oil transfers. In 2000, the legal status of Piraeus and Thessaloniki was changed to that of limited liability companies, as a prelude to future privatisation through the stock market. In preparation for this transformation, an audit of all fixed capital assets was performed, in order to assess the actual worth of these companies. All the other Greek seaports were formerly run by public bodies supervised by the Ministry of Merchant Marine. Since 2000, responsibility for this supervision has passed to the local government authorities concerned. As a result, incentives for the efficiency of the latter differ from those for the two major seaports, but more importantly, accounting practices are also substantially different. Regulation of all seaport activity is the responsibility of the recently upgraded General Secretariat of Seaport Policy, which is part of the Ministry of Merchant Marine.

The sample used in this paper represents 22% of the total movement of freight in the Greek seaport market, meaning that it is representative of the Greek seaports. Since Greek seaports do not have published time series data, we were unable to increase the data set, despite our efforts. This undisclosure policy prevents the comparison of seaports at European level, beyond those undertaken from international data sets, such as the Containerisation International Yearbook, which rely on structural characteristics of the seaports, such as the terminal quay length, neglecting financial variables.

Portugal

The Portuguese seaports are run as State enterprises, regulated by a public body, the Instituto Maritimo Portuário (Maritime Port Agency), which comes under the direct control of the Ministry of Transport. These authorities manage those seaports which are situated along the Portuguese Atlantic seaboard, as well as the islands. Table 13.2 lists the main seaports and the annual total freight handled (loaded and unloaded) by each in 1990 and 2000, in geographical order from north to south.

The sample used in the analysis – Leixóes, Lisboa, Setúbal and Sines – represents approximately 85.9% of the total movement of freight through Portuguese ports in 2000, indicating that it is highly representative of the national sector.

Literature Review

Efficiency analysis of sea-ports embraces three scientific quantitative methods, namely, ratio analysis, the econometric frontier and the DEA. Song and Cullinane (2001) apply ratio analysis to Asian container sea-ports. Among the papers using DEA are Roll and Hayuth (1993), who presented a theoretical exposition and suggested the use of cross-sectional

Table 13.2 Movement of freight through Portuguese ports

	1990		2000	
Seaports	**Quantity (1,000 tons)**	**%**	**Quantity (1,000 tons)**	**%**
Viana do Castelo	264,092	0.005	942,201	0.016
Leixões	12,130,277	0.211	13,193,744	0.218
Aveiro	1,444,019	0.025	2,635,288	0.044
Figueira da Foz	662,683	0.012	773,390	0.013
Lisbon	14,274,385	0.248	11,161,204	0.185
Setubal	3,703,258	0.064	6,096,418	0.101
Sines	22,559,238	0.392	21,448,529	0.355
Algarve	421,559	0.007	354,567	0.006
Azores	1,218,074	0.021	2,204,629	0.037
Madeira	911,189	0.016	1,573,550	0.026
Total	57,588,774	1.000	6,038,3520	1.000

data from financial reports to operationalise their approach; Tongzon (2001) uses cross-section data from 1996, covering four Australian ports and 12 other ports from around the world; Martinez Budria *et al* (1999) estimate the efficiency of Spanish ports; Barros (2003a) analyses technical and allocative efficiency of Portuguese seaports; Barros (2003b) analyses the total productivity change in the Portuguese seaports with a Malmquist index.

Papers using the econometric frontier approach are Liu (1995), who compares the efficiency of public and private ownership in Britain with a translog function; Coto Millan *et al* (2000), who estimate a translog cost frontier for the Spanish ports; Estache *et al* (2001), who estimate a Cobb-Douglas and a translog production frontier for Mexican ports; Cullinane *et al* (2002) who estimated a Cobb–Douglas production function for Asian major container terminals; and Cullinane and Song (2003), who estimated a production function for Korean container terminals. In a related paper, Baños *et al* (1999) estimate the allocative efficiency of the Spanish seaports with a cost function and a distance function (Table 13.3).

Theoretical framework

Following Farrell (1957), Charnes *et al* (1978) first introduced the term DEA (Data Envelopment Analysis) to describe a mathematical programming approach for the construction of production frontiers and the measurement of their efficiency. They proposed a model that had an input orientation and assumed constant returns to scale (CRS). This model is known as the CCR model in the literature. Later studies have considered alternative sets of assumptions. Banker *et al* (1984) first introduced the assumption of variable returns to scale (VRS). This model is known in the literature as the BCC model. There are in addition four other basic DEA models, less used in the literature: the additive model of Charnes *et al* (1985); the multiplicative model of Charnes *et al* (1982); the Cone-ratio DEA model of Charnes *et al* (1990) and the Assurance Region DEA model of Thompson et al (1986, 1990). The last two models include a priori information (expert opinion, opportunity costs, rate of transformation or rate of substitution) to restrict the results to just one best DMU (Assurance region DEA model), or linking DEA with multi-criteria analysis (Cone-ratio DEA model).

Since these models are well established and extensively applied in the literature, their discussion is limited in this paper. A brief description of the model is outlined. For more details on model development, see Fare

Table 13.3 Literature review

Papers	Method	Units	Outputs	Inputs
Song and Cullinane (2001)	Ratio analysis, 1987 to 1998	Major Asian seaports	(1) Ratio gross crane productivity equal to the ratio of TEUs handled per working day divided by number of cranes times working hours per day; (2) Ratio berth utilisation equal to TEUs handled per year divided by the number of container bertys. (3) ratio of yard throughput=TEUs handled per year divided by Gross acre in square meters. (4) Ratio yard storage productivity equal to TEUs storage capacity divided by gross acre in square metres.	
Roll and Hayuth (1993)	DEA-CCR model	Hypothetical numerical example of 20 ports	Cargo throughput, level service, user's satisfaction, ship calls	Manpower, capital, cargo uniformity
Martinez Budria *et al* (1999)	DEA-BCC model	26 Spanish ports, 1993 to 1997	Total cargo moved through docks, revenue obtained from rent of port facilities	Labour expenditures, depreciation charges, other expenditures
Tongzon (2001)	DEA-CCR additive model	4 Australian and 12 other international ports for 1996	Cargo throughput; ship working rate	Number of cranes, number of container berths, number of tugs, terminal area, delay time, labour.

Valentine and Gray (2001)	DEA-CCR	31 container ports out of the world's top 100 container ports for the year 1998	Number of containers, total tons throughput	Total length of berth, container berth length
Barros (2003a)	DEA-allocative and technical efficiency	5 Portuguese seaports, 1999–2000	Outputs: Ships, movement of freight, gross tonnage, market share, break-bulk cargo, containerised cargo, Ro-Ro traffic, dry bulk, liquid bulk, net income	Number of employees, book value of assets
				Prices: Price of labour measured by salaries and benefits divided by the number of employees; price of capital measured by expenditure on equipment and premises divided by the book value of physical assets
Barros (2003b)	DEA-Malmquist	10 Portuguese seaports, 1990–2000	Ships, movement of freight, break-bulk cargo, containerised freight, solid bulk, liquid bulk	Number of employees and book value of assets
Liu (1995)	Translog production function	28 Britain port authorities, 1983 to 1990	Turnover	Labour measured by total wage payments; capital measured by the net-book value of fixed capital assets, and dummy variables to represent ownership (private, trust and municipal).

(*continued*)

Table 13.3 – Continued

Papers	Method	Units	Outputs	Inputs
Coto Millán *et al* (2000)	Translog cost model	27 Spanish Ports, 1985–1989	Aggregate port output (includes total goods moved in the port in thousand tonnes, the passenger embarked and disembarked and the number of vehicles with passengers)	price of labour measured has the ratio of total number of workers employed, the price of capital measured as the ratio of depreciation by the number of linear metres of the quays with depth greater than 4 meters, and the price of intermediate consumption measured s the ratio of consumption, external supplies and services costs and other expenses by the port activity measured in tones
Estache *et al* (2001)	Translog and Cobb–Douglas production frontier model	14 Mexican ports 1996–1999	Volume of merchandise handled	Labour measured by the number of workers; capital approximated by the surface concessioned by the government, corrected by the percentage reflecting the actual use of this capacity, and intermediate inputs measured by the expenditures on intermediate input variables.

Cullinane *et al* (2002)	Stochastic Cobb–Douglas production frontier:half normal, exponential, truncated models	15 Asian container ports observed in 10 years, 1989–1998	Annual container throughput in TEUs	Terminal quay length in meters, terminal area in hectares, number of pieces of cargo handling equipment employed.
Cullinane and Song (2003)	Stochastic Cobb–Douglas production frontier:half normal, exponential, truncated models	5 container terminals, Korean and UK, different year of observations (65 observations)	Turnover derived from the provision of container terminal services but excluding property sales	Total remuneration of directors or executives, total wages and salaries paid to employees, net book value of fixed equipment, buildings and land, net book value of mobile and cargo handling equipment including container cranes, yard tractors and fork lifts.

et al (1994); Charnes *et al* (1995); Coelli (1996); Coelli *et al* (1998); and Thanassoulis (2001).

DEA is applied to unit assessment of homogeneous units such as seaports. The unit of assessment is normally referred to as a decision-making unit (DMU). A DMU converts inputs into outputs. The identification of the inputs and outputs in an assessment is as difficult as it is crucial. The literature review, the availability of data and managers' subjective opinions all play a role in the selection of inputs and outputs. In this paper, we follow the three procedures mentioned above to select the inputs and outputs used in the study.

In the programming method, DEA 'floats' a piece-wise linear surface to rest on the top of the observation (Seiford and Thrall, 1990, p.8). The facets of the hyperplane define the efficiency frontiers, and the degree of inefficiency is quantified and partitioned by a series of metrics that measures various distances from the hyperplane and its facets.

In order to solve the linear-programming problem, the user must specify three characteristics of the model: the input–output orientation system; the returns-to-scale and the weights of the evaluation system. In relation to the first of these, the choice of input- or output-oriented DEA is based on the market conditions of the DMU. As a general rule of thumb, in competitive markets, the DMUs are output-oriented, since we assume that inputs are under the control of the DMU, which aims to maximise its output, subject to market demand, outside the control of the DMU. With exogenous inputs, the production function is the natural choice (Khumbhakar, 1987). In monopolistic markets, the DMUs are input-oriented, because output is endogenous, while input is exogenous and the cost function is the natural choice. The input-orientation system searches for a linear combination of DMUs that maximises the excess input usage of DMUi, subject to the inequality constraints presented below. With regard to returns-to-scale, they may be either constant or variable. We calculate both forms (CCR and BCC models) for comparative purposes. In relation to the weights possibly placed on inputs and outputs in the objective function, these are subject to the inequality constraints. Weights are endogenously defined by the algorithm and measure the distance between the DMU and the frontier in the CCR and BCC models.

DEA optimises at each observation for the purpose of constructing the cost frontier (Figure 13.1), which consists of a discrete curve formed solely by efficient DMUs; those that minimise cost. The inefficient DMUs are above the cost frontier, since they do not minimise total cost for the production level.

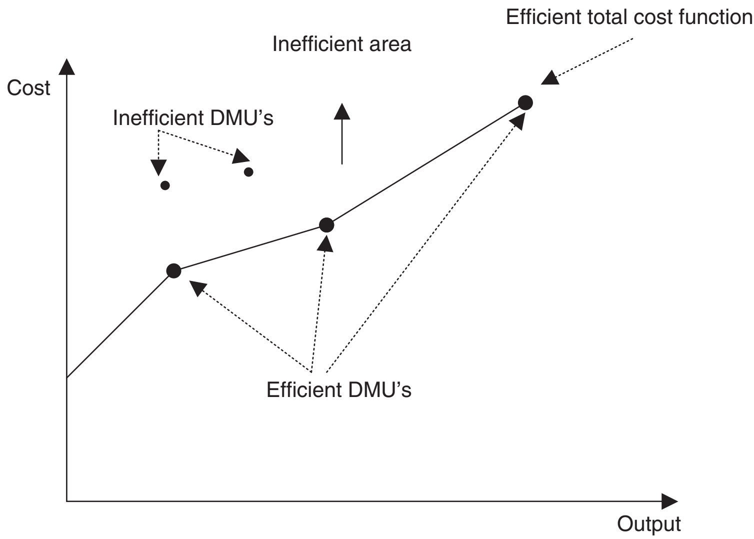

Figure 13.1 Data envelopment analysis: cost function

We define a Pareto-efficient or DEA-efficient DMU when the DMU uses $m \geq 1$ inputs to secure $s \geq 1$ outputs in either an output orientation or an input orientation.

The general-purpose DEA, developed by Charnes *et al* (1978), considers n DMUs ($j = 1,\ldots,n$), using k inputs to secure m outputs. Let us denote x_{ij}, y_{ij} the observed level of the *kth* input and *mth* output respectively, at DMU j.

An efficient score for the nth DMU can be obtained by maximising the ratio of total weighted output over total weighted input for all DMU subject to the constraint on all such ratios of the other DMUs in the sample being less than or equal to one. Mathematically, this can be written as

$$\begin{aligned} &\mathbf{max} \quad u,v\frac{uy_i}{vx_i} \\ &\mathbf{s.t.} \quad \frac{uy_j}{vxj} - \mathbf{1} \leq \mathbf{0} \end{aligned} \tag{1}$$

where u are the output weights and v are the input weights. The system of equations 1 is a fractional programming model of computing technical efficiency and can be solved with nonlinear programming techniques. To simplify computation, a transformation of the fractional programming model allows the system of equations 1 to be formulated as a linear programming problem. For the CCR model with constant returns-to-scale and strong disposability, the following linear programming problem is solved to ascertain whether DMU *i* is DEA-efficient.

$$\begin{aligned} &\min_{z,\lambda} \lambda_i \\ &\text{s.t. } \sum_{i=1}^{n} x_{ij} z_i - \lambda_i x_{ij} \le 0 \\ &\sum_{i=1}^{n} y_{ij} z_i - \lambda_i y_{ij} \ge 0 \\ &z_i \ge 0, \lambda_i \text{ free} \end{aligned} \tag{2}$$

For the BCC model with variable returns-to-scale and strong input disposability, the following linear programming problem is solved to ascertain whether DMU *i* is DEA-efficient.

$$\begin{aligned} &\min_{z,\lambda} \lambda_i \\ &\text{s.t. } \sum_{i=1}^{n} x_{ij} z_i - \lambda_i x_{ij} \le 0 \\ &\sum_{i=1}^{n} y_{ij} z_i - \lambda_i y_{ij} \le 0 \\ &\sum_{i=1}^{n} z_i - 1 = 0, \lambda_i \text{ free} \end{aligned} \tag{3}$$

where λ is a scalar variable measuring the level of efficiency. The model works as follows. For a given set of feasible λ values, the LHSs of the input- and output-related constraints specify a production point within the production possibility set. The model seeks a production possibility set point which offers at least the output levels of DMU j_0 while using as low a proportion of its input levels as possible. With the subscript * denoting optimal values, the j_0 DMU is DEA-efficient if, and only if, $\lambda_0^* = 1$. If $\lambda_0^* \le 1$ the j_0 DMU is DEA-inefficient. λ_0^* is a measurement of the radial DEA efficiency of DMU *j*0.

The model assesses efficiency in a production context. Its dual assesses efficiency in a value context. By virtue of duality, the primal and dual models yield the same efficiency ratings in respect to DMU j_0, (see Charnes *et al* (1978) for details).

Data issues

To estimate the cost frontier, we use balanced panel data on port authorities in the years 1998–2000. The ports considered in the analysis are Lisbon, Leixões, Setúbal and Sines for Portugal, accounting for 86% of the movement of freight in the Portuguese seaports; and Pireaus and Thassaloniki for Greece, accounting for 22% of the movement of freight in the Greek seaports. The data for Portugal was obtained from the annual financial reports of those authorities, but is also available in the Statistics of Transport, published by the National Statistical Institute. For Greece, the data was obtained from the National Statistical Service, 'Survey of Merchant Shipping' and the published balance sheets of the Piraeus and Thessaloniki Port Authorities.

We measured output by four indicators: ships, movement of freight, total cargo handled (dry and liquid cargo, unloaded and loaded) and containers (loaded and unloaded). The number of passengers, cars, trucks and motorcycles loaded and unloaded are available for the Greek ports, but not for Portuguese ports. Therefore, we omitted this output from the analysis.

We measured inputs by two indicators: labour, measured by the number of workers and capital, measured by the book value of assets.

All the monetary variables are in euros and were deflated by the GDP deflator and denoted at constant 1999 prices.

The combination of indicators measured ensured the DEA convention that the minimum number of DMUs is greater than three times the number of inputs plus output (18 ≥ 3(2+4) (Raab and Lichty, 2002).

By using an input orientation, one can determine whether a seaport can produce the same level of output with less input.

The characteristics of the variables for Greece are depicted in Table 13.4.

The Greek seaports analysed handle the mean number of 17,998 ships per year. The average number of employees is 1,216. The average movement of freight is 35,423,256 tons. The average amount of cargo handled (loaded and unloaded) is 12,426,811 tons. The weight of containers handled (loaded and unloaded) amounts to 584,682 tons and the average fixed capital amounts to 70,762,021 (1998 = 100) euros. These are average-size seaports in the European context.

The characteristics of the variables for Portugal are depicted in Table 13.5. The characteristics of the Portuguese seaports are the following: the average number of ships handled is 4,322; the average number of employees is 361; the average movement of freight is 53,136,290 tons; the average cargo handled (loaded and unloaded) is 11,364,205 tons;

Table 13.4 Characteristics of the variables for Greece, 1998 and 2000

	Minimum	**Maximum**	**Mean**	**Std. deviation**
Nr. of ships	4,316	33,008	17998,20	14,780,72
Movement of freight (tons)	13,303,812	59,662,395	35,423,256,83	23,559,173,55
Cargo handled (tons)	1,068,6077	13,292,216	12,426,811,34	910,632,60
Containers handled (tons)	129,927	1,161,099	584,682,17	483,020,28
Number of employees	746	1,728	1,216,17	493,990
Fixed capital in euros (1998=100)	51,050,548	92,194,013	70,762,021,33	20,167,262,52

Table 13.5 Characteristics of the variables for Portugal 1998 and 2000

	Minimum	**Maximum**	**Mean**	**Std. deviation**
Nr. of ships	1.438	7.039	4.322	2.156
Movement of freight (tons)	26.811.211	85.208.527	53.136.290	20.719.344
Cargo handled (tons)	5.910.552	21.448.529	11.364.205	5.926.629
Containers handled (tons)	311	3.141.603	1.079.689	962.044
Number of employees	207	674	361	162
Fixed capital in euros (1998=100)	13.259.051	46.089.076	24.668.663	10.729.423

the weight of containers handled (loaded and unloaded) amounts to 1,079,689 tons; and the average fixed capital amounts to 24,668,663 (1998 = 100) euros. These are categorised as small seaports by European standards.

Comparing the seaports of Greece and Portugal, we observe that the Greek ports handle a greater number of ships, but of smaller dimensions, than their Portuguese counterparts. This signifies that there is a degree of heterogeneity in the operations carried out by the seaports considered in this study.

Results

The DEA index can be calculated in several ways. In this study, we estimate an input-oriented, technically efficient (TE) DEA index, assuming the inputs to be endogenous and the outputs exogenous because of the public nature of seaports, which are required to accept traffic as offered (Khumbhakar, 1987). Moreover, as far as seaports are concerned, cost-control seems to be the natural choice, due to their significant market power in the marine cargo-transportation market.

The variable returns-to-scale (VRS) hypothesis was chosen, because 'scale' is paramount in seaport management. The VRS scores measure pure technical efficiency only. However, for comparative purposes, we also present the constant returns-to-scale (CRS) index, which is composed of a non-additive combination of pure technical and scale efficiencies. A ratio of the overall efficiency scores to pure technical efficiency scores provides a scale efficiency measurement.

The relative efficiency of the seaports is presented below in Table 13.6.

In Table 13.6, we present the relative efficiency of the European seaports under analysis. The rankings are ordered according to nationality. We verify that the DEA index is equal to 1 for all seaports when the overall level of efficiency is assumed (CRS scores), with the exceptions of Thessaloniki and Setúbal. However, Setúbal turns out to be efficient when VRS are assumed, signifying that the dominant source of inefficiency is due to scale economies. The average efficiency score under CRS is equal to 0.865. Including all sources of inefficiency, this finding signifies that, on average, the seaports studied in this paper could operate at

Table 13.6 DEA technically efficient scores for European Seaport, 1998–2000

Designation	**Country**	**Technically efficient, constant return-to-scale CCR model**	**Technically efficient, variable return-to- scale BCC model**	**Technically efficient scale**	**Position of the port in frontier**
Piraeus	Greece	1.000	1.000	1.000	—
Thessaloniki	Greece	0.376	0.380	0.987	Irs
Lisbon	Portugal	1.000	1.000	1.000	—
Leixões	Portugal	1.000	1.000	1.000	—
Sines	Portugal	1.000	1.000	1.000	—
Setúbal	Portugal	0.816	1.000	0.816	Irs
Mean	—	0.865	0.897	0.967	—

86.5% of their current input level while maintaining the same output value. However, efficiency scores under VRS are equal to 0.897. Given the scale of operations, a majority of seaports are efficient in managing their resources.

The input-oriented efficiency index used in this paper measures by how much input quantities can be proportionally reduced without changing the output quantities produced.

The last column of the table gives the position of the seaport in the VRS frontier. Since the frontier is convex, we verify that only two seaports (Thessaloniki and Setúbal) are positioned in the first part of the frontier when increasing returns to scale appear. The other seaports are in the constant returns-to-scale part of the frontier.

Economic implications of the study

A number of points emerge from the present study. First, the best-practice calculations indicate that almost all seaports operated at a high level of pure technical efficiency in the period. However, at least one seaport (Thessaloniki) was technically inefficient, with different slacks in different inputs and outputs. Second, all technically efficient constant-returns-to-scale ports also display technically efficient variable returns-to-scale, signifying that the dominant source of efficiency is scale. Third, although DEA identifies inefficient seaports in the sample, it does not identify the cause of the inefficiency. DEA identifies the slacks for the inefficient seaports and gives to each a reference set (peer group) which allows for specific recommendations to improve efficiency. Adjustments for the inefficient seaports can be identified for outputs and inputs in order for them to join the efficient frontier. Table 13.7 presents the adjustments needed for the seaport of Thessaloniki.

Table 13.7 DEA results for Thessaloniki seaport

Outputs and inputs	Original value	Radial movement	Slack	Projected value
Nr. of ships	4.758	0	0	4.758
Movement of freight (tons)	14.667.453	0	34.484.081	49.151.534
Bulk handled (tons)	12.293.520	0	0	12.293.520
Containers handled (tons)	162.995	0	1.360.935	1.523.930
Labour (number of employees)	746	–462	0	283
Capital (euros)	54.470.581	–33.751.959	0	20.718.621

We verify that there are slacks in the movement of freight and containers handled, with too little freight and too few containers handled. Relative to inputs, we verify that there are too many full-time workers relative to the frontier and too much capital. There is room to decrease the inputs with slacks and to increase the outputs with slacks, in order for the unit to catch up with the frontier. The peers used to benchmark this seaport were Lisbon (with a weight of 0.708), Sines (with a weight of 0.207) and Setúbal (with a weight of 0.085). These peer seaports should be used to benchmark the future efficiency of the Thessaloniki seaport.

The projected value of outputs identifies the increase which the DMU needs to achieve in order for the seaport to reach the efficient frontier.

What are the explanations for these findings? As mentioned earlier, DEA does not identify the factors causing inefficiency, and it only draws attention to the units in which inefficiency exists. Nonetheless, this is valid information because the inputs and outputs that contribute to this inefficiency are identified (Bessent and Bessent, 1980). Probably, the major reason for the observed inefficiency of the port of Thessaloniki is the effects of political instability in the Balkans. This has not only reduced the flow of goods to and from this port's hinterland, but has also reduced through-traffic destined to and from central and northern Europe.

Other reasons that can be advanced as causes of inefficiency in monopolies are the following: First, there are the factors associated with the pattern of ownership that may induce the principal–agent relationship (Jensen and Meckling, 1976). The principal–agent relationship relates to the difficulty of controlling those empowered as managers to act on behalf of the government or stockholders (ie the owners); secondly, there are structural rigidities associated with the labour market which give rise to the collective action problem (Olson, 1965), where workers can free-ride on the management's own efforts to improve performance. This situation can occur when job tenure is not linked to performance, a traditional procedure in public enterprises; thirdly, unequal access to information about activities, due to asymmetric information between different seaports, with some of them enjoying privileged access to information, which is inherent in the lack of transparency (Williamson, 1998); fourthly, time lags in acquiring new technology and the necessary commensurate skills upgrades due to inertia effects; fifthly, organisational factors associated with X- efficiency (Leibenstein, 1966); sixthly, organisational factors associated with human capital, such as a lack of incentive for the improvement of efficiency; and finally, size factors associated with scale and scope economies. Due to some or all of these factors, inefficient seaports may produce at a level below their potential, which is the maximum possible output.

Limitations and extensions of this study

This paper has two limitations. First, limitations related to the data set and second, limitations related to the DEA method.

With reference to the data set, the homogeneity of the seaports used in the analysis is questionable, since we compare seaports with different dimensions, traffic characteristics and locations, which may face different restrictions and therefore, might not be considered to be directly comparable. However, we can always claim that the units are not comparable, and therefore, a ratio analysis equally could not be carried out. Moreover, the data set is short, thus the conclusions are limited. In order for the conclusions to be generalised, we would need to have a panel data set. Reducing the number of observations in DEA variables increases the likelihood that a given observation will be judged relatively efficient (Banker, 1993).

The limitations of the DEA model are the following: the DEA does not impose any functional form on the data, neither does it make distributional assumptions for the inefficiency term, nor does it make a prior distinction between the relative importance of any combination of inputs and outputs. These limitations are precisely the most distinctive and attractive characteristics of DEA. This efficiency measurement assumes that the production function of the fully efficient seaport is known. In practice, this is not the case and the efficient isoquant must be estimated from the sample data. In these conditions, the frontier is relative to the sample considered in the analysis. The least attractive characteristic of DEA is that without statistical distribution hypotheses, the DEA does not allow for random errors in the data, assuming away measurement error and chance as factors affecting outcomes (Seiford and Thrall, 1990).

A variety of extensions to this paper can be undertaken. First, in this analysis, the DEA model allowed for complete weight flexibility. In situations in which some of the measures are likely to be more important than others, DEA allows for restricting factor weights through linear constraints. These linear constraints represent ranges for relative preferences among factors based on managerial input. Such analysis enables effective incorporation of managerial input into the DEA evaluations. Second, the input and output dimensions considered are context-specific. More comprehensive input and output measurements, namely, allowing for no discretionary factors, such as environmental, socio-economic and quality inputs and outputs, need to be taken into consideration. The influence of non-discretionary variables, excluded from the analysis, amounts to an assumption that these factors are constant across the sample. Third, non-parametric, free-disposal hull analysis or, alternatively, parametric, can be used to assess the efficiency scores. However, previous research has shown that the DEA scores are inferior in value to econometric scores, but the ranking is preserved (Bauer *et al*, 1998).

Conclusions

This paper has proposed a simple framework for the comparative evaluation of European seaports and the rationalisation of their operational activities. The analysis was based on a DEA model that allows for the incorporation of multiple inputs and outputs in determining the relative efficiencies. Bench- marks are provided for improving the operations of poorly performing seaports. Several interesting and useful managerial insights and implications arising from the study are discussed. The general conclusion is that the majority of the seaports are efficient with the sole exception of Thessaloniki. For this seaport, we identified peer groups among the efficient seaports and the slacks that they should adjust in order to achieve the efficient frontier. The result suggests that scale economies should be the principal target for adjustment in this sector. Moreover, the privatisation of these seaports will allow them to improve their productivity, because privatisation and competition has proven to be the best procedure for efficiency improvement (Jones *et al*, 1990). More research is needed in order to address the limitations referred to above.

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14

An Application of AHP on Transhipment Port Selection: A Global Perspective

Tai-Cherng Lirn, Helen A. Thanopoulou, Malcolm J. Beynon and Anthony K. C. Beresford

The research presented in this paper applies the Analytic Hierarchy Process (AHP) to reveal and analyse transhipment port selection by global carriers. Forty seven relevant service attributes were recorded from a literature review. Two rounds of Delphi surveys – followed by brainstorming sessions – were conducted among experts in industry and academia, in order to narrow their number to four main service attributes/criteria comprising 12 sub-criteria. An AHP designed questionnaire survey was distributed to 20 port users which covered the total population of global ocean container operators and to 20 transhipment service providers (port operators/authorities). The results of the AHP analysis revealed that both global container carriers and port service providers had a similar perception of the most important service attributes for transhipment port-selection. However, the AHP weight ranking of the sub-criteria involved was not identical between the two surveys providing scope for further adaptation of service providers to users' priorities. Differences in the performance ranking of six major container ports by global carriers, as revealed in the AHP survey, were then combined with the calculated weights for the 12 transhipment port selection sub-criteria to explore critical attributes where transhipment market strategy could focus.

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Introduction

Changes in the pattern of international manufacturing and production have transformed the demand side of liner shipping in recent decades (Peters, 2001). These changes were reflected on the supply side of the liner shipping industry (Heaver, 2001). The need for global coverage has put additional emphasis on optimising transport networks through transhipment. The extant literature has pointed to the "substantial operating and capital cost advantages of transhipment compared with multiport direct call services" (Baird, 2002b, p.249). In the context of global networks having grown rapidly, the share of transhipment container volumes in world container traffic has risen dramatically (Baird, 2002a; West, 2002). Transhipment port selection is proven thus to be even more of a critical decision for global container carriers with repercussions for competition among ports.

While carrier and port choice criteria have been extensively discussed and researched in the related literature, little is known on the subjective importance the various transhipment port characteristics have on carriers in the process of their decision-making on transhipment port selection. Awareness of the importance of these criteria can allow ports to define on which characteristics to compete. The use of the Analytic Hierarchy Process (AHP), introduced in Saaty (1977), can serve both as a tool to reveal the most important criteria for transhipment port selection by global carriers but also as a management aid in the transhipment port selection process. It can also, in the context of this research, reveal any discrepancies in perceptions between port users and transhipment port operators allowing the latter to re-define eventually their strategies.

The transhipment port decision is no less important for port operators as the nature of port investment and the existence of significant sunk costs (Haralambides, 2002) makes competition for transhipment cargoes extremely intense. A significant fluctuation in transhipment container volumes may prove of critical importance for port survival. The increasing transhipment volumes world-wide can prove extremely elusive and mobile as they are not directly connected with local traffic. Failure in obtaining the forecast transhipment volumes or in maintaining sufficient levels to cover fixed and variable costs is almost entirely irreversible in the short and medium term with potential critical implications for the financial survival of ports. The importance of large global container carriers for port operators today is obvious: The concentration ratio at the level of the four top liner companies has risen from below 15% in 1988 to almost 25% by 2001 (Containerisation International

Yearbook, 2003; UNCTAD, 2001). The list of the top 20 container companies includes, nowadays, exclusively companies with global networks covering at least the three major international liner routes, namely the Trans-Atlantic, the Trans-Pacific and the Far-East Europe routes (Containerisation International; UNESCAP, 2001).[1]

Either as independent operators, or as port-operating companies with commercial links to carriers (Woodbridge, 2002), port/terminal operators need to be able to assess customer criteria used in evaluating port alternatives for transhipment purposes.[2] The increase in the use of hubs in the main east-west arterial routes has turned transhipment traffic into a significant part of port throughput volume.[3] For the two leading ports in container traffic in 2001, namely Hong Kong and Singapore (Containerisation International Yearbook 2003), transhipment related traffic was estimated to be 45.6% (PSA, 2002) and 81.5% (Hong Kong Marine Department, 2003) of the total traffic respectively.

Choice of methodology

This study has adopted the AHP in order to reveal and evaluate the criteria used for transhipment port selection, building on previous attempts of a pilot study limited to Taiwan (Lirn et al., 2003). The use of the AHP for transhipment port-selection has been limited until now to this published application. However, the AHP has a successful track-record regarding applications in the wider transport area following its introduction as a multiple criteria decision making (MCDM) methodology in the late 1970s (Saaty, 1977).

The AHP methodology is a flexible tool that can be applied to any hierarchy of performance measures (Rangone, 1996). According to Zimmermann (1991), most of the MCDM approaches consist of two steps: (1) Aggregation of the judgements with respect to all goals and decision-making alternatives and (2) Ranking of the decision alternatives according to the aggregated judgements (scores). Vreeker et al. (2002) suggest that the basic rules for solving multi-level hierarchical problems involve essentially four steps: (1) Specification of choice problem, (2) Information analysis, (3) Choosing the appropriate method, and (4) Evaluation of alternatives.

The success of the AHP in research in a number of areas supports its use to solve transport problems, as for example in Vreeker et al. (2002), Lirn et al. (2003), Chang and Yeh (2001), Poh and Ang (1999), Tzeng and Wang (1994) and Frankel (1992). Lirn (2003) used the AHP to study job attractiveness in the airline industry in Taiwan. Yedla and Shrestha (2003) utilised the AHP to select environmentally friendly transport systems in India. Chou and Liang (2001) used the AHP in order to create a model capable of evaluating the performance of shipping companies.

The advantages of the AHP as a decision tool have been extensively reviewed. Saaty (2001) lists ten advantages of the AHP as a decision making tool*: Unity, Complexity, Interdependence, Hierarchy Structure, Measurement, Consistency, Synthesis, Tradeoffs, Judgement and Consensus, and Process Repetition.* As argued by Forgionne et al. (2002) the AHP methodology as a decision support system mechanism can easily accommodate model modifications and simulations through sensitivity analysis.

Geographical scope of the research

The focus of this paper is the application of the AHP methodology to reveal preferences regarding transhipment port selection. Transhipment decision-making and network design in general are of critical importance for carriers as networks are growing together with the complexity of logistics (Flynn, 2003). Liner shipping companies have to be active globally if they are to aim at a significant part of the demand from global shippers. At the same time every part of their network has to be able to contribute to revenue maximisation while minimising costs. The scope of this research is thus global, however, in the process it also takes into account the restructuring of the world container transport networks. Thus the geographical importance of Asian hubs in today's transhipment industry in the list of alternatives included in the survey. The manufacturing of globally trading products has concentrated in East Asia[4] with Japan leading the way in the 1960s, followed by Korea and Taiwan in the next decades and more recently by the P.R. of China.

"Selecting" global carriers' transhipment port selection criteria

Unlike general port selection problems, there is limited literature on transhipment port choice. The results of a pilot survey undertaken by one of the authors made use of the Delphi technique[5] to identify the most important factors for transhipment port selection. The numerous papers on general port selection, for example Frankel (2001), Baird (2000) and Brooks (2000)[6] served as the source for the initial pool of criteria on port choice (see Table 14.1). However, the expectation of using all 47 recorded criteria in an AHP questionnaire, or even in factor analysis in view of the small size of the population targeted, would be extremely unrealistic. In order to narrow down their number in a systematic way, a Delphi panel was created composed of 10 experts, five from academia and five experts from the shipping industry in Taiwan. Two rounds of Delphi survey were carried-out.

The Delphi approach has been used in the preliminary stages of criteria selection in a AHP context (Azani and Khorramshahgol, 1990). More often it has been used (for example Suh and Han, 2003) as a follow-up stage of an initial AHP survey with a view to increasing consensus on the importance of global weights of criteria (van Steenkiste et al., 2002; Sharkey and Sharples, 2001), without necessarily bringing them face-to-face (Addison, 2003).

All the criteria that have been proposed in the general port selection literature were validated by the Delphi panel as being important also in transhipment port selection. Table 14.1 reports mode quantity and value for each Delphi round, as well as standard deviations and differences for the above, between the two rounds. Further categorisation of the valid criteria was attempted (see column CAT.III in Table 14.1), eliminating duplication of aspects that could be perceived as proxies for others. For the purposes of this paper, brainstorming sessions between two of the authors and one academic port expert in the UK resulted in a further reduction of the number of sub-criteria that had been used in Lirn et al. (2003). The initial number of sub-criteria was deemed eligible for further reduction in order to improve the clarity of the questionnaire and the consistency of the responses.[7] The survey of global carriers used the same four major criteria derived from the Delphi rounds conducted for the pilot survey, but included only 12 sub-criteria instead of 16 (see Table 14.1).

The four major criteria and the corresponding 12 sub-criteria retained for the survey of global carriers were (see Figure 14.1, constructed from Table 14.1):

1. Port Physical and Technical Infrastructure: including as sub-criteria, Basic infrastructure condition, Technical infrastructure and Intermodal links
2. Port Geographical Location: including as sub-criteria, Proximity to import and export areas, Proximity to feeder ports and Proximity to main navigation routes
3. Port Management and Administration: including as sub-criteria, Management and Administration Efficiency, Vessel Turn-Around Time and Port Security/Safety.
4. Carriers' Terminal Cost: including as sub-criteria, Handling Cost of Containers, Storage Cost of Containers and Terminal Ownership/Exclusive Contracts Policy.

Some of the sub-criteria were further defined for their use in the survey questionnaire by including, next to their description, important

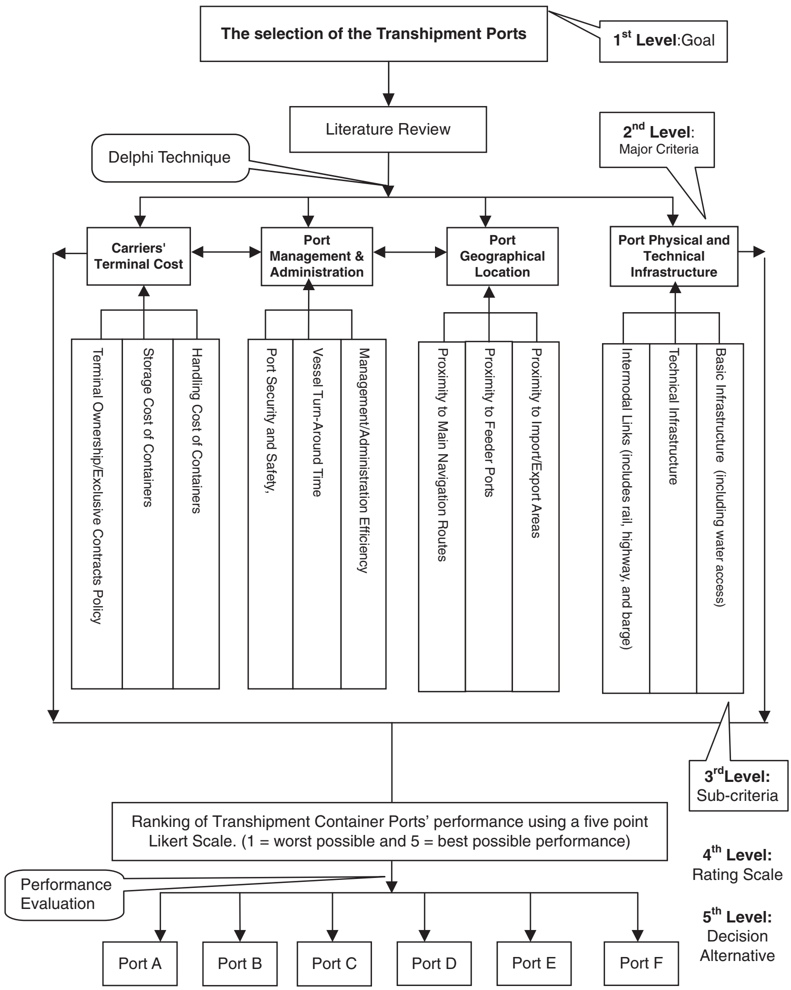

Figure 14.1 Determining optimum transhipment port for global container carriers using the AHP Model

aspects pertaining to them. Such aspects included water access for the basic infrastructure of the port; depth is one of the major constraints, which prevent the use of larger vessels to which carriers have been turning to in recent years.[8] Technical infrastructure was further defined by port facilities, size of the container terminal and the information technology status of the port. The inclusion of such definitions for the sub-criteria not only added to the clarity of the question or

Table 14.1 Deriving the major criteria through Delphi and brain-storming rounds

Categorising and Verifying Validity of Variables					1st round Delphi expert survey			1st & 2nd rounds	2nd round Delphi expert survey			1 st & 2nd rounds difference	
CAT. I	CAT. II	CAT. III	No.	CAT. IV	A1	B1	C1	D	A2	B2	C2	E	F
Port Physical and Technical Infrastructures	Basic Infrastructure Condition	Water Access	1	Depth of the port	5	4.50	0.53	5	7	4.7	0.48	2	0.04
	Technical Infrastructure	Port Infrastructure, Facilities and Equipment	2	Available number of berths	5	3.60	0.84	4	5	3.7	0.67	0	0.17
			2	Back up space on terminal	5	3.50	0.97	4	6	3.6	0.52	1	0.46
			2	Infrastructure	5	3.90	0.74	4	9	4.1	0.32	4	0.42
			2	Degree of integration (EDI)	6	4.00	0.67	4	8	4	0.47	2	0.20
			2	Port equipment	4	4.00	0.82	4	8	4.2	0.42	4	0.39
			2	Superstructure	6	3 80	0 63	4	6	3.8	0.63	0	0.00
		Size of available C.Y. & M.Y.	3	Size of port terminal capacity	6	4.20	0.63	4	8	4.2	0.42	2	0.21
	Intermodal Links	Inter-Modal Links	4	Inland freight rates	4	3.10	0.99	3	4	3.1	0.99	0	0.00
			4	Port Accessibilitv (land & sea)	5	4.10	0.74	4	6	4	0.67	1	0.07
			4	Port Service Coverage	5	3.90	0.74	4	7	4.1	0.57	2	0.17
			4	Size of hinterland	4	3.70	0.95	4	5	3.6	0.84	1	0.11
			4	Intermodal Link/Network	7	4.70	0.48	5	8	4.8	0.42	1	0.06
Port Geograhical Location	Proximity to Import/Export Areas	Closeness to the Import/Export Areas	5	Cargo volume	4	4 00	0 82	4	7	4.1	0.57	3	0.25
			5	Cargo-generating effect	5	3.90	0.74	4	6	3.8	0.63	1	0.11
			5	Containerised Cargo Proportion	3	3.50	1.08	3	4	3.6	0.97	1	0.11
			5	Geographical advantage (to Manufacturing Industry)	6	4.50	0.71	5	6	4.6	0.52	0	0.19
			5	Major Container Centre	6	3.00	0.67	3	8	3.2	0.42	2	0.25
			5	Trade Inertia	5	2.70	0.67	3	8	2.8	0.42	3	0.25

	Proximity to Feeder Ports	Proximity of Feeder Ports	6	Frequency of feeder shipping service	5	3.20	0.92	3	7	3.4	0.70	2	0.22
			6	Frequent port of call	6	3.30	0.82	3	7	3.4	0.70	1	0.12
			6	Number of sailings	5	3.40	0.70	4	5	3.5	0.53	0	0.17
			6	Service considerations	5	3.90	0.74	4	9	3.9	0.32	4	0.42
		Proximity of Competing Modes and Ports	7	Other modes' Competitiveness	4	3.40	0.97	4	5	3.4	0.70	1	0.27
			7	Proximity to alternative loading Centre	6	2.60	0.52	3	8	2.8	0.42	2	0.09
	Proximity to Main Navigation Routes	Closeness to Main Navigation Routes	8	Time on the route	6	4.60	0.52	5	7	4.7	0.48	1	0.03
			8	Transit Time	4	4.00	0.94	5	4	4.2	0.79	0	0.15
Port Management and Administration Perspective	Management/ Administration Efficiency	Port Administration and Customs Regulation	9	Labour problems	6	4.00	0.67	4	8	3.8	0.42	2	0.25
			9	Port tradition & Organisation	5	3.00	0.94	3	8	3.1	0.33	3	0.61
			9	Quality of customs handling	5	3.90	0.74	4	6	3.8	0.63	1	0.11
			9	Regulations	4	3.70	0.95	4	6	3.5	0.71	2	0.24
		Risk Management, Terminal Operation	10	Container Handling Efficiency	7	4.70	0.48	5	9	4.9	0.32	2	0.17
			10	Flexible operation process	6	4.40	0.52	4	8	4.2	0.42	2	0.09
			10	Operation	6	4.00	0.67	4	8	4	0.47	2	0.20
			10	Port Operation/Working Hours	5	4.50	0.53	5	5	4.5	0.53	0	0.00
	Vessel Turn-Around Time	Berthing Delay and Loading/ Discharging Rate	11	Congestion	5	4.30	0.67	4	7	4.3	0.48	2	0.19
			11	Loading / Discharging Rate	7	4.70	0.48	5	8	4.8	0.42	1	0.06
			11	Port Bertliing Time Length	8	4.80	0.42	5	9	4.9	0.32	1	0.11
			11	Port Productivity	6	4.60	0.52	5	8	4.8	0.42	2	0.09
	Port Security/Safety	Terminal security, Port Safety	12	Port Safety /Terminal Security	6	3.00	0.67	3	8	3	0.47	2	0.20

(*continued*)

Table 14.1 – continued

Categorising and Verifying Validity Variables					1st round Delphi expert survey			1st & 2nd rounds	2nd round Delphi expert survey			1 st & 2nd rounds difference	
CAT. I	CAT. II	CAT. III	No.	CAT. IV	A1	B1	C1	D	A2	B2	C2	E	F
Carriers Terminal Cost Perspective	Handling Cost of Containers	Government Tax/ Subsidy	13	State Aid & influence on cost	4	3.70	0.95	4	5	3.7	0.67	1	0.27
			13	Port charges/Price conditions	7	4.70	0.48	5	9	4.9	0.32	2	0.17
		Carriers'	14	Free time	5	3.20	0.92	3	7	3.4	0.70	2	0.22
	Storage Cost of Containers	Handling and Storage Cost	14	Low cost	7	4.70	0.48	5	8	4.8	0.42	1	0.06
			14	Transportation & port-user cost	8	4.80	0.42	5	9	4.9	0.32	1	0.11
	Terminal Ownership /	Ownership of Port and Terminal	15	Reiated business operation	7	4.70	0.48	5	8	4.8	0.42	1	0.06
	Exclusive Contract Policy	Privileged Terms to Carriers	16	Privilege Contract to Carrier	9	4.90	0.32	5	10	5	0.00	1	0.32

A1, A2: Mode Quantity.
B1, B2: Average Value.
C1, C2: Standard Deviation.
D: Mode Value.
E: Mode Quantity Difference between round one and round two surveys (= A1 – Ã2).
F: Standard Deviation Reduction Value (= CĨ– C2).
No.: Numbering of CAT.III Sub-criteria.
C.Y.: Container Yard.
CAT: Category (CAT.I and CAT.II = deriving from arranging the hierarchy of Delphi revealed criteria through brain-storming sessions with two UK expert academics, CAT.III = author derived from CAT.IV criteria).

sub-criterion put to the test; it also allowed the reduction of various inter-related sub-criteria into a manageable number and the reduction of the hierarchy levels.

Surveying global carriers and major world ports through AHP

Conducting the survey

The survey of the top 20 global container carriers, ranked on the basis of Containerisation International 2001 data, was carried out in late spring/early summer 2002. The definition of "global container carrier" was based on whether the carrier was covering the three major ocean container routes in the east-west direction (Trans-Pacific, Trans-Atlantic and Far East–Europe) while also having a presence at least in some of the routes of secondary importance. Of the 18 valid replies, 16 were from carriers' headquarters and two from regional offices[9] raising the response rate to 90%. In reality, if acquired companies are not counted separately from the acquiring ones, the entire population of global carriers was targeted and responded.

In parallel to the survey among global container carriers, a related questionnaire was distributed to the top 20 leading container port authorities and also to the top three leading terminal operators. The reply rate to the port questionnaire was less satisfactory than the rate for the carriers' survey, reaching just over 50%. However, it was still high enough for comparative purposes. In both cases, the introductory page of the questionnaire (see Appendix) included an explanation of the major criteria used together with a clear example of how to answer the questionnaire. This was important in order to familiarise the recipients with the pair-wise comparisons of the AHP survey and minimise inconsistent replies. When answers were found to be inconsistent, the surveying researcher followed-up respondents asking them to revise their responses, as suggested by Selly and Forman (2002).

Both carriers and port service providers were asked to proceed to pair-wise comparisons of the importance of different major criteria and sub-criteria in the transhipment decision making. The last part of the questionnaire sent to carriers also prompted respondents to evaluate the performance of the leading six container ports,[10] with respect to all 12 sub-criteria used in the survey, using a 5-point Likert scale as suggested by Min et al. (1997). Leading ports were selected according to total container throughput, as indicated by data in Containerisation International Yearbook (2002). Five Asian and one European ports were included. All five Asian ports are forecasted to lead in transhipment volumes in Asia by 2011.[11]

Analysis of the results

The results (weights expressed as percentages) of the AHP analysis of the questionnaire surveys clearly indicated the subjective importance of the cost factor for transhipment port selection by global container carriers (see Table 14.2). The result is significant from a port's perspective as well: although the difference between the weight of this major criterion and the weight of the Geographical Location criterion is not high, port costs are within the realm of management decision making. Geographical location is mostly critical from a port operator's perspective at the stage of planning or acquiring terminals. Location can only change at the start of a port project and at the eventual end of a port's life. In the meantime, port operators' decisions on location can have marginal impact only, essentially when deciding port terminal expansions within a limited radius from the main port.

The AHP results for the sub-criteria (see Table 14.3) were consistent with the calculated importance of the major criteria. While three out of the top five sub-criteria figuring in Table 14.3 were sub-criteria of "Geographical Location", the highest weight calculated was that of the Handling Cost of containers associated with the carriers' port cost. As noted in the case of the major criteria, the significance of these three location related sub-criteria for port strategy is mainly in terms of awareness when proceeding to terminal acquisition and in terms of planning new port locations or additional investment. By contrast, the Handling Cost of containers, which scored by far the highest in terms of sub-criteria weight, comes within the realm of managerial and marketing decisions. Cost considerations could even be dictating indirectly the ranking of the relative weights of location sub-criteria: captive trade – be

Table 14.2 Importance of major criteria for transhipment port selection as perceived by global carriers in the AHP survey

Transhipment Port Selection major criteria	Weight
Physical and Technical Infrastructures	16.38%
Geographical Location	35.12%
Port Management and Administration	10.38%
Carriers' Port Cost	38.12%

Table 14.3 Most significant sub-criteria for transhipment port selection as perceived by global carriers in the AHP survey

Top five transhipment Port Selection Sub-criteria of the AHP survey	Weight
Handling Cost of Containers	24.27%
Proximity to Main Navigation Routes	15.12%
Proximity to Feeder Ports	10.26%
Proximity to Import/ Export Area	9.75%
Basic Infrastructure Condition (Water Access, e.g. depth)	8.51%

that in the form of hinterland trade or in the form of feeder potential – ranks lower than proximity to main navigation routes.

In an industry environment where frequency is important, major deviations signify increased journey times. These generate additional fuel costs which automatically translate into higher voyage costs. As will be discussed in the next section, the implications of the preponderance of the cost factor and especially of the handling cost among carriers' selection criteria is significant not only for drawing a medium term marketing strategy or a long-term investment one, but also for competition conditions and the industry's profitability. The last of the top five sub-criteria revealed through the survey, namely Basic Infrastructure Condition, is obviously within the realm of management decisions. However, the cost implications of competition for increasing depth in the era of increasing vessel sizes are equally obvious.

Perception measurement: global carriers vs. terminal operators

The initial results from the surveys of global carriers and port operators revealed that both groups were in agreement on the importance of the major criteria involved in port selection decision-making (see Table 14.4). Although there were differences in the global weights resulting from the two surveys, these were modest. As indicated by the identical ranking of the weights of the major criteria, the general perception of the importance of the four major criteria was exactly the same between the two groups. However, as suggested by differences in the variance of weights for the carrier and port groups, which was 0.68% and 1.88% respectively, the carriers' perceptions of the relative importance of major port selection criteria were more diverse than those of port operators'.

Table 14.4 Major criteria weight differences between Carrier and Port surveys

Groups / Criteria	Carriers	Rank of Importance	Ports	Rank of Importance	Correlation of Weights
Physical and Technical Infrastructures	16.38%	3	23.09%	3	0.96
Geographical Location	35.12%	2	29.60%	2	
Port Management and Administration	10.38%	4	14.26%	4	
Carriers' Port Cost	38.12%	1	33.05%	1	
Variance of weights among major criteria	1.88%		0.68%		

As Table 14.5 suggests, there was agreement on the importance of the top five sub-criteria but not on the internal relative significance of these criteria; the ranking was very different between the two groups.[12] The difference recorded in the weights of the Handling Cost of Containers is not surprising in view of its different place as a major cost item for carriers and a major source of revenue for ports, which would be expected to tilt the intensity of perceptions. However, in both surveys the weight of the Handling Cost is not only the highest ranking one; it is also separated by a marked difference from the weight of the second most important criterion for transhipment port selection in either survey. The second most importance sub-criterion is revealed through the AHP survey to be different for carriers and ports. The second ranking sub-criterion for carriers is Proximity to Main Navigation Routes. Ports rank this sub-criterion only fourth with a much lower weight than carriers. While carriers in search for the lowest cost solution (Baird, 2002b) would calculate transhipment costs to include the part of costs associated with any required route deviation, the ports would tend to attribute higher importance to Proximity to Feeder Ports or to Basic Port Infrastructure; in the case of the latter ports also seem to credit their efforts to provide an adequate Basic Port Infrastructure with some more impact on transhipment port selection than their customers do.

These results have interesting implications for both the marketing researches of the ports but also at a more fundamental level for planning purposes. The agreement on the importance of costs is underlining the competitive pressures both carriers and ports face and the acknowledgement of these pressures by both groups. The degree of

Table 14.5 Most significant sub-criteria for Transhipment Port selection as perceived by Carriers and Ports

Attributes	Global Weight: Carriers' survey	Criteria Ranking by Global carriers	Global Weight: Ports' survey	Criteria Ranking by Ports
Handling Cost of Containers	24.27%	1	18.19%	1
Proximity to Main Navigation Routes	15.12%	2	10.06%	4
Proximity to Feeder Ports	10.26%	3	10.50%	2
Proximity to Import/Export Area	9.75%	4	9.03%	5
Port Basic Infrastructure	8.51%	5	10.21%	3

this acknowledgement is not the same. The results of the two surveys suggest that neither the weight of the Handling nor the weight of the Proximity to Main Navigation are of similar levels. The results of the two surveys clearly indicate that the ports' and the carriers' perception of the importance of these two attributes for transhipment port selection is not identical.

Searching for transhipment purchase attributes: exploring differences

The results in Table 14.6 show the performance rating of the six ports subject to the carriers' evaluation in the last part of the AHP survey. Port performance was evaluated by carriers on a 5-point Likert scale, on the basis of the 12 sub-criteria used in the first part of the AHP survey. Performance was rated for the transhipment function of the ports, although evidently not all carriers surveyed were necessarily using the ports involved as transhipment hubs. However, either directly – as in the majority of cases – or indirectly through participation in an alliance, global carriers do have knowledge and experience of major container ports.

Table 14.6 suggests that the scores achieved by the alternatives included in the decision alternative part of the survey had different dispersion as indicated by the standard deviation values (see Figure 14.2). Research on carrier selection criteria (Brooks, 1985, 1995) and freight transport choice (Mangan et al., 2002), has used the Aaker and

Table 14.6 Port Performance and sub-criteria importance evaluated by 18 global carriers

Sub-criteria Acronym \ Port	1	2	3	4	5	6	
	Performance Score (Maximum possible score = 90, minimum possible score = 0)						**Importance**
BIC	77	83	69	66	33	73	8.51%
TIC	83	83	61	62	52	74	4.92%
IML	67	64	60	57	57	80	2.94%
PIEA	78	61	69	57	74	69	9.75%
PFP	75	81	61	57	63	73	10.25%
PMNR	79	86	60	68	64	81	15.12%
MAE	77	77	58	65	57	69	3.48%
VTAT	77	77	64	64	52	67	4.35%
PSS	72	74	64	60	58	67	2.54%
HCC	37	43	60	61	59	54	24.27%
SCC	39	44	55	55	58	55	6.53%
TOEC	50	44	54	59	47	60	7.32%

Note: For explanation of acronyms, see Figure 14.2.

Day model (Aaker and Day, 1980) to distinguish between determinant and non-determinant factors for the choice of carrier according to their importance in terms of perception among customers and potential customers and the existence of significant differences in terms of performance. Importance and performance have been used to highlight potential areas for improving customer satisfaction through traditional Importance-Performance Analysis (IPA) (Martilla and James, 1977), categorising attributes on the basis of Importance-Performance score combinations. If the Aaker and Day (1980) perspective is adopted then the importance shifts to measuring disparities in the performance rating of alternatives in order to deduce purchase determinants. Brooks (1985) had combined effective carrier choice with the survey results to derive such determinants of choice.[13]

Brooks (1995) researched differences in importance evaluations between groups of shippers for different geographic and customer type segments. However, unlike shippers, global container carriers can hardly be segmented into groups yielding eventually alternative marketing strategies (Kotler and Armstrong, 2001)[14] for transhipment port service providers on the basis of comparisons between groups of either users or potential users. The global character of the service provision of the carriers surveyed leaves no scope for geographical segmentation. An initial testing for differences on the basis of geographic location of headquarters

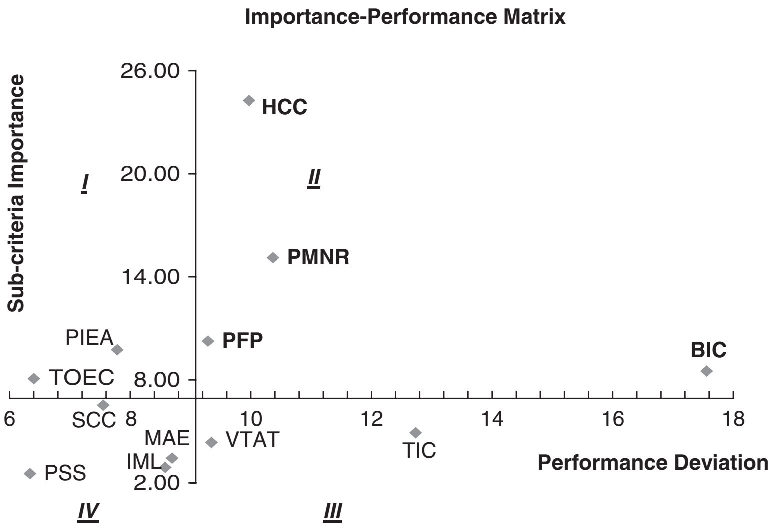

Figure 14.2 Revealing purchase determinants for transhipment port selection through AHP

BIC: Basic Infrastructure Condition
TIC: Technical Infrastructure I
ML: Intermodal Links

PIEA: Proximity to Import/Export Areas
PFP: Proximity to Feeder Ports
PMNR: Proximity to Main Navigation Routes

MAE: Management/Administration Efficiency
VTAT: Vessel Turn-Around Time
PSS: Port Security/Safety

HCC: Handling Cost of Containers
SCC: Storage Cost of Containers
TOEC: Terminal Ownership/Exclusive Contract Policy

yielded no meaningful results. Cross-continent mergers and acquisitions in liner shipping in recent years have hindered further any meaningful definition of headquarters. Segmenting the group of global carriers using other demographic variables, such as company size, would be arbitrary. By definition, global coverage implies a certain size of operations created either on the basis of the capacity of a single carrier on its own[15] or through the combined membership of an alliance.

The scope for research on variables that could serve for market segmentation in what could be an exercise on "segmenting international markets" (Kotler and Armstrong, 2001) can be wide and belongs to potential extensions of the present research. However, in this section of the paper, the approach was limited to indicating attributes which may claim the title of purchase determinants if importance is combined with the variability of performance perception. The combination of the dispersion of evaluation scores for the alternatives and of the AHP weights calculated through the carrier and port surveys can produce a meaningful guide on the scope for competition for transhipment volumes among the top container ports world-wide. At a second phase the results can also assist in providing a basis for drafting an investment strategy for both terminal operators and port authorities.

Sub-criteria were plotted as purchase determinants in two dimensions: (1) the importance of the sub-criteria in terms of AHP weights (vertical axis) and (2) the standard deviation of the performance scores for the sub-criteria as calculated from the scores of the alternatives included in the 5th level of the AHP survey (calculated from Table 14.6). In order to intercept differences and classify attributes in the four quadrants of Figure 14.2, the origin of the axes was set at the level of the median of the relevant values.[16]

Quadrant II of Figure 14.2 includes the attributes/sub-criteria with the most significant combination of importance and performance scores in terms of the AHP weight and standard deviation values respectively. Figure 14.2 clearly points to the Handling Cost of Containers as the attribute which more clearly separates itself from the two Geographical Location sub-criteria, namely Proximity to Main Navigation Routes and, to a lesser degree, Proximity to Feeder Ports. The case of the Basic Infrastructure Condition seems marginal but it should be noted that it registers the highest level of differences in its performance scoring as measured by the standard deviation value.

As discussed in the previous section, the revealed high importance of geography-related criteria has little relevance to drawing any type of strategy be that marketing or investment in the short and medium term despite their confirmation as purchase determinants in Quadrant II. The suggestion that the Handling Cost of Containers and the Basic Infrastructure Condition (water access etc.) are the relevant purchase determinants to focus on by ports is eventually painful for transhipment port operators and port authorities. The combination points to price competition and investment in increasing port depth as being the only controllable purchase determinants. Even more poignantly the latter sub-criterion/purchase determinant can be extremely significant in decision-making for port selection beyond mere transhipment, in an era characterised by fast changing average and maximum vessel sizes (Cullinane and Khanna, 2000). Other sub-criteria remain at best in the position of "qualifiers" and not as "order-winners" as the terms are defined by Hill (1993) in the case of manufacturing.

Conclusions and Implications for Further Research

In the global container terminal industry, "Handling Cost of Containers", "Proximity to Main Navigation Routes", "Proximity to Import/Export Areas", "Basic Infrastructure Condition (Water Access, e.g. depth)", and "Existing Feeder Network" were revealed through the AHP survey to be the five service attributes with the highest importance weight above the global mean value for all sub-criteria. However, Geographical Location attributes are beyond the control of terminal operators/port authorities and even in the case of expansion there is little margin to alter substantially the geographical location of port provision. Once the location of a port/terminal is determined, port operators can only compensate for unfavourable deviation costs that carriers might have to incur through either reducing Handling Costs or investing on Basic Port Infrastructure.

While transhipment traffic under the control of independent operators has to co-exist with more captive traffic of terminals close to shipping lines (Baird, 2002b), the AHP reading of the subjective perception of global carriers is grim for the prospects of attracting this traffic. The main means according to the results of AHP would be price wars which port themselves would not necessarily consider as a prospect.[17] However, price discounts have been observed recently for transhipment cargo.[18]

Moreover, the confirmation of the Handling Cost of Containers as the most important attribute under the control of port/terminal operators which ports can compete on to attract transhipment cargo, points to additional difficulties for port management. As labour costs can even exceed 60% of total operating costs for container terminal operators (Baird, 1999), the introduction of labour-saving cargo-handling equipment and information technology (Haralambides, 2002) to reduce handling-costs – even if it could take place without significant capital requirements – can hardly be imposed without friction. Port history is fraught of examples of slow and painful port restructuring problems unless policy measures are taken.

The confirmation of the importance of the handling cost and of the basic infrastructure conditions in transhipment port selection suggests a market where least cost strategies may have to be applied under the strain to improve basic infrastructure conditions including the all-important depth. If competition from "offshore" transhipment mega-hubs suitable for the mega-ships of the future (Baird, 2002b) is added in the picture, then the competitive pressures on existing ports are clearly to multiply. Ports will find themselves in the worst possible position of having to compete on handling-costs while there is little possibility that the additional costs created by the need to accommodate larger vessels will be undertaken by anyone else but themselves. Only port/terminal operators with no binding ties to ports may find themselves placed any better as only they would have a realistic choice to shift to more competitive locations.

Appendix: Introductory page of the survey questionnaire

Explanation and Examples of Terms and Scales used

1. Explanation of Criteria:
The research evaluates 4 major criteria in their roles in transhipment decision making.

(1) Port Physical and Technical Infrastructure: This criterion refers to Basic Infrastructure Condition (including water access, e.g. depth), Technical Infrastructure (including port facilities and equipment, size of container stacking area, and I.T., i.e. Information Technology), Inter-modal links (including port access: rail, road, barge).
(2) Port Geographical Location: The proximity to the import and export centres, Proximity to corresponding feeder ports, and proximity to main navigation routes.
(3) Port Management and Administration Perspective: Port Management and Administration Efficiency, Vessel Turn-Around Time, and Port Security/Safety.
(4) Carriers' Terminal Cost: Container Handling Cost, Container Storage Cost, Terminal Ownership/Exclusive Contracts Policy.

2. Examples of terms and Scales used:
IF you think criterion A is 9 times more important than criterion B in attracting global container carriers to use the ports' transhipment service, then please circle as follows:

CRITERION	Intensity of Relative Importance	CRITERION
Physical and Technical Infrastructure (A)	⑨ 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Geographical Location (B)

Circling ⑨ means: From transhipment ports' perspective, (A) factor (Physical and Technical Infrastructure) has extreme importance for attracting global container carriers to use the port when compared with (B) factor (Geographical Location).

IF you think criterion B is 9 times more important than criterion A in attracting global container carriers to use the ports' transhipment service, then please circle as follows:

CRITERION	Intensity of Relative Importance	CRITERION
Physical and Technical Infrastructure (A)	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 ⑨	Geographical Location (B)

This means: According to the Scale of relative importance below, from transhipment ports' perspective, (B) factor (Geographical Location) has extreme importance in attracting global containers carriers to use the ports' transhipment service when compared with (A) factor (Physical and Technical Infrastructure).

3. Scale of Relative Importance:

Intensity of Relative Importance	Definition
9	Extreme importance
8	Demonstrated to extreme importance
7	Demonstrated importance
6	Strong to Demonstrated importance
5	Essential or Strong Importance
4	Moderate to Strong Importance
3	Moderate Importance of one over another
2	Equal to Moderate Importance
1	Equal Importance

Notes

1. Historically, the organisation of modern liner shipping progressed from the East-West routes. For data see Containerisation International, 2002 monthly issues: January, February, April, May, July and August. Also February 2003 issue, pp. 5–7. See also UNESCAP (2001). For the relation of the three principal routes with the introduction of global services see Lim (1996).
2. The four leading port operators in 2001 and 2002 were HPH, PSA, APM Terminals, and P&O Ports (Damas and Motlley, 2003). Leading global terminal

operators in terms of container throughput in 2012 were PSA International, Hutchinson Port Holdings, APM terminals and DP World (Drewry, 2013).

3. The world port container throughput was 230 million TEUs in 2002, and 33 million of them were estimated to be transhipment containers (Flynn, 2002). For shares of transhipment in the total traffic of major ports see also Fleming (2000) and Baird (2002b). The top five Asian container transhipment ports in 2004 were Singapore, Hong Kong, Shanghai, Kaohsiung and Busan (Heymann, 2006).
4. The geographical designation of these Asian countries has been according to the classification in recent documents (UNCTAD, 2001; Comtois, 1994).
5. This involved two rounds of Delphi surveys as responses had become uniform after the second round. See Lirn et al. (2003).
6. A total of 14 port selection literatures were reviewed to decide the initial port selection criteria.
7. Although Saaty (2000) indicated that the AHP survey results could still produce consistent answers even if the number of major criteria was as high as 7, it is indicated in recent literature that when the number of major criteria exceeds 5, the inconsistency index increases markedly, see Bodin and Gass (2003).
8. The trend towards larger vessels has been well documented and predictions on vessels up to 10,000 TEU entering in service before 2010 (Baird, 2002a; Richardson, 2002) seem close to be fulfilled. In October 2003, a letter of intent to build eight 9,500 TEU ships was signed between Seaspan in Vancouver and Samsung (Richardson, 2003). According to the Editorial of Alphaliner (2014a), the largest containership of 18,270 TEUs is to be surpassed by a 19,000 TEUs vessel near the end of 2014.
9. In two instances replies were sent from carriers' regional headquarters, either referred there by the global headquarters or for practical reasons as not to delay the results beyond a short period which would create problems with the time-base of the survey.
10. These were again selected based on their ranking by total container throughput on the basis of 2001 volume data in Containerisation International Yearbook 2002.
11. Unless ship sizes deployed in the East-West trades reach and exceed 10,000 TEUs, see UNESCAP (2001).
12. The rank correlation coefficient (Spearman's correlation index) was 0.25 which is not statistically significant at the 5% level with one-tail testing as the critical value is 0.7818 while the correlation coefficient remained high at 0.92.
13. Brooks (1985, 1995) has successfully transposed the Aaker and Day concept of purchase determinant in a maritime context looking for salient determinants of carrier choice in liner shipping.
14. For a comprehensive analysis of market segmentation for consumer and business markets see Kotler and Armstrong (2001), Chapter 7.
15. While individual carrier size within the top 20 ocean container carriers surveyed in terms of capacity and number of vessels ranged from 120,319 to 773,931 TEUs and from 32 to 312 vessels in 2002, the range of alliance capacity ranged between 300,612 TEUs (87 ships) to 637,684 TEUs (255 ships) as at end 2001 (OECD, 2002). Among the top 20 ocean container carriers, carrying capacity ranged between 246,998 TEUs and 2,697,379 TEUs and the number of vessels from 49 to 574 in June 2014 (Alphaliner, 2014b).

16. The use of mean values of importance-performance ratings to categorise attributes (Martilla and James, 1977) is a popular option (Matzler et al., 2003; Chu and Choi, 2000). The use of the median as the crossing point in constructing the Importance-Performance Model can avoid the strong bias influences derived from outliers in the six alternatives performance evaluation. The application of the median in importance performance analysis was also recommended in earlier literature (Oh, 2001; Martilla and James, 1977). The use of the median in Figure 14.2 has allowed the clear discernment among criteria where higher variability existed pointing to attributes that could be classified as a potential purchase determinant.
17. See http://www.singapore-window.org/sw02/020410re.htm, accessed November 17, 2003.
18. At the time of the writing of the final draft of the paper Busan, South Korea's busiest container port, and Kaohsiung Port both discounted port charges to transit/transhipment container cargo (Damas and Motllery, 2003 and UNESCAP, 2002). PSA has also applied a discount for container operators who tranship more than 400 TEUs of loaded or empty transhipment containers per calendar month in its Tuticorin Container Terminal (Inchcape Shipping Services, 2014).

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15

A Competitive Analysis of Chinese Container Ports Using the Analytic Hierarchy Process

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Over 20% of the world's container traffic occurs from Asian ports. China's entry into the market has stimulated this process significantly. Since China adopted a liberalized economic policy in the 1970s, its economy has grown at an average rate of 10% or more per annum. In particular, the efforts and investments that have been poured into its container ports are conspicuous because approximately 90% of the country's international trade (by volume) is handled through maritime transport. However, Chinese ports (especially, container ports) face a number of problems such as bureaucratic administration, insufficient facilities, lack of service and commercial orientation, and inefficient operation. This study aims to identify the competitiveness of container ports in China, including Hong Kong, from an outsiders' perspective by using the analytic hierarchy process framework and provide managerial and strategic implications. As expected, the findings reveal that in terms of competitiveness, Hong Kong, Shanghai, and Yantian rank first, second, and third, respectively.

1 Introduction

As an interface linking sea and inland transportation, a port is an integral platform, serving as a base for logistics, production, information

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transfer, and international trade, as well as a springboard for the economic development of the hinterland. For servicing these functions adequately, a port should be able to effectively and efficiently accommodate ships and other modes of transport within terminals. Currently, by volume, approximately 90% of global trade is handled through seaports. Therefore, ports play a significant role in transferring economic wealth to national as well as international economies.

As the world's economic powerhouse, China has enjoyed double-digit growth rates over the past two decades (IMF, 2002). Again, about 90% of China's international trade is carried out via sea transportation (UNCTAD, 2002). Thus, container ports in China are regarded as crucial trade facilitators (Haralambides and Veenstra, 1996). Consequently, the efficiency and effectiveness of its ports is important to China's central government. However, in general, China's ports face a number of problems such as a lack of port facilities, poorly connected infra- and superstructures, bureaucratic administration, and inefficient operation (Cullinane and Song, 2001). These problems will increase in significance as China's economy increasingly faces the challenges of globalization, symbolized by its entry into the World Trade Organization. In addition, China is facing acute port congestion owing to limited water depth along the southeast coast of China, especially Shanghai (Cullinane, Cullinane and Wang, 2003).

For mitigating these problems and handling increased trade volumes, China has launched large-scale development plans (e.g., Yangshan Project near Shanghai) and relaxed regulations and laws relating to maritime transportation so as to stimulate smooth cargo operations within and beyond the port areas (Ha and Zhang, 2000). These efforts are striking enough to have attracted the attention of port operators in the region who compete directly with China for cargoes.

In general, port competition refers to the development and application of differentiated strategic alternatives for attracting a greater number of customers to competitive ports (Frankel, 1987; Heaver, 1995). It is essential for a port to obtain and sustain a competitive edge over its competitors. Thus, present-day container ports should be operated considering this strategic point. However, many diverse factors should be accounted for, for identifying the factors contributing to the overall competitiveness of a port. These include the expansion of port facilities, modernization of equipment, leasing of terminals to major container lines (so-called dedicated terminals), identification and development of feeder routes, maintenance of competitive tariffs relative to other ports, and enhancement of efficiency.

Bearing the above in mind, this study aims to investigate empirically the competitiveness of container ports in China using the analytic hierarchy process framework. Under this framework, elements and factors influencing competitiveness are identified in the context of China's container ports. Section 2 lists brief statistics of Chinese container ports. Section 3 discusses the methodological issues of the model used, and Section 4 describes the process of collecting data and extracting meaningful attributes and factors that influence port competitiveness in an established framework. Section 5 describes our empirical analysis, and Section 6 contains the discussion and conclusions of this study.

2 Chinese container ports: statisics

It can be said that China's exports and imports are almost entirely dependent on sea transport because 90% of its total trade is handled via ports. A brief review of Chinese ports shows that Hong Kong is the largest container port in the country (in fact, in the world); it grew at 11.6% in 2000, with 1.7 million TEUs handled. However, the latest figures show that the cargo volume through the port has stagnated since, with single-digit growth rate in 2002 and 18.1 million TEUs handled (Drewry Shipping Consultants, 2002). The port of Shanghai handled 7.4 million TEUs in 2002, making it the world's fourth largest port after Hong Kong, Singapore, and Busan. Since the late 1990s, the Shanghai port achieved spectacular growth rates of 21.7% in 1998, 37.3% in 1999, 33.8% in 2000, and 45.7% in 2001. The Dalian and Qingdao ports in the northern part of China are relatively small, but even these ports recorded higher growth rates of 37.6% and 38.4%, respectively, in 2002. Table 15.1 provides an overview of major container ports in China.

Container volumes handled at ports in mainland China are expected to surpass that handled at Hong Kong by 2006. Short-term growth rates will be enormous, for example, 391% growth by 2011 (UNCTAD, 2002). As mentioned in the previous section, however, Chinese ports face various problems. Therefore, it is important to measure their relative competitiveness from an outsider's perspective. For this purpose, the present study relies on the perceptions of its regional competitors, who are either directly or indirectly involved in port operations and management, such as Korea, Japan, Taiwan, and Singapore.

Geographically, this paper covers the ports of Hong Kong, Shanghai, Yantian, Qingdao, Tianjin, Xiamen, Dalian, and Shekou, all of which are major ports in the country and are ranked among the top 50 worldwide

Table 15.1 Container traffic handled at major ports in China

(Unit: Million TEUs)

Port	Actual Statistics		Forecasted Statistics	
	2001	**2002**	**2006**	**2011**
Hong Kong	17.2	18.1	20.1	22.2
Shanghai	5.6	7.4	15.8	27.4
Shenzhen*	4.8	6.4	8.0	15.3
Qingdao	1.9	2.6	2.9	4.8
Tianjin	1.8	2.5	3.1	5.1
Xiamen	1.3	1.5	1.7	2.8
Dalian	1.1	1.4	1.7	2.8

Note: *Shenzhen includes Shekou, Chiwan and Yantian.
Sources: Compiled from *Containerisation International Yearbook* (various issues).

in terms of TEUs handled per annum (Containerisation International Yearbook, 2001).

3 Model

The analytic hierarchy process (AHP) is an established methodology for making decisions and *ranking priorities*, using quantifiable or intangible criteria. Saaty (1980) defined the concept of AHP as a combination of assessments (or perceptions) both subjective and objective into an integrated framework based on ratio scales from simple pairwise comparisons. The associated technique involves three steps: (i) structuring a hierarchy, (ii) making pairwise comparisons to yield priorities, and (iii) synthesizing the priorities into composite measures of decision alternatives or options (Wedley et al., 2001). Given its applicability to business decision-making, resource allocation, priority rating, or *performance evaluation problems*, AHP has been used in a variety of industries (Ramanathan and Ganesh, 1995; Chwolka and Raith, 2001; Beynon, 2002; Tzeng et al., 2002).

A particularly useful feature of AHP is its applicability to the measurement of intangible criteria along with the tangible by using ratio scales (Badri, 1999). In addition, by breaking problems into their constituent parts and relating the parts in a logical manner (i.e., descending in gradual steps from the large scales to the small scales), an analyst can connect the small problems to the large by using paired comparison (Vargas, 1990), which is a useful background for the current research.

In a few cases, AHP has been applied to maritime transport and logistics. For example, Frankel (1992) applied AHP to shipping policy decision-making and Kumar (2002) to debates over liner shipping competition. However, these two studies were limited only to analytical and conceptual discussions of the respective issues using AHP. Recently, Haralambides and Yang (2003) applied fuzzy set theory, an advanced version of AHP, to the international ship registry, especially, for flag choice. As an initiative for empirical application of the AHP framework to port competitiveness, this study executed a step-by-step process under the framework. The following contains a descriptive explanation of various AHP stages (see Appendix I for technical details), which will be applied to Chinese container ports for measuring *perceived* competitiveness, as described in section 5.

First Stage: ***Establishing Decision-Making Hierarchy***

The starting point of AHP analysis involves establishing the hierarchy of associated decision-making choices in the form of a network structure. This can be done by (i) setting the ultimate decision goal or assessment at the top of the hierarchy, (ii) locating critical criteria for achieving the goal in the middle of the hierarchy, and finally (iii) listing identified alternatives that are linked with the aforementioned criteria and the ultimate decision goal in the bottom part of the hierarchy. In this study, the ultimate goal is "Chinese Port Competitiveness," which is placed at the top of the hierarchy. The critical criteria, i.e., elements and attributes of port competitiveness, identified using the technique described in Section 4, are located in the middle of the structure. Finally, the sampled container ports in China (i.e. the alternatives) are listed in the bottom part of the hierarchy. Figure 15.1 shows the AHP-derived conceptual framework for port competitiveness, which is described above.

Second Stage: ***Determining Weights for Criteria and Alternatives***

In this stage, pairwise comparisons are made for determining relative weights of the identified criteria and sampled alternatives (see Appendix II for details). The rationale behind doing so is to assign higher weights or values to factors that are more important than others (i.e. elements and attributes in terms of AHP), thus ensuring that they are paid more attention toward when making a decision or assessment. The process is based on the computational procedures suggested by Saaty (1980 and 1984).

Third Stage: *Evaluating Overall Ranking of Alternatives*

The final step involves evaluating the overall values of the alternatives by summing up the multiplied weight values of each criterion and alternative. By performing this step, we can rank the alternatives by relative competitiveness–ports with higher values ports are considered more competitive.

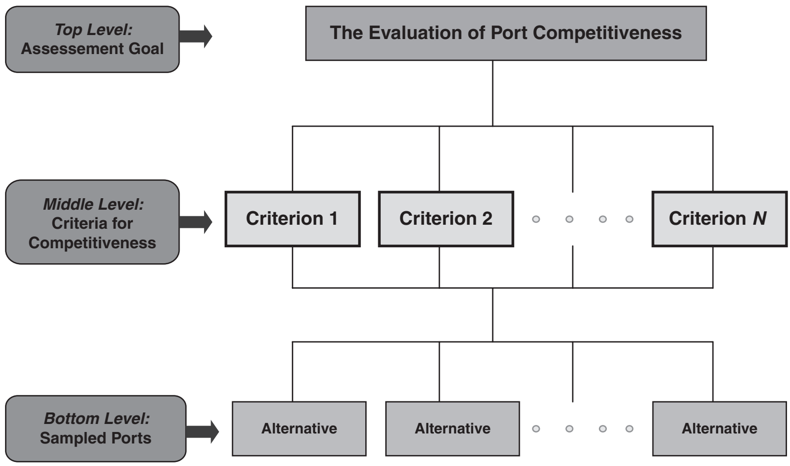

Figure 15.1 A conceptual framework of port competitiveness

4 Data

Applying the model to a real case requires operationalization (Simon and Burstein, 1985), a task that involves finding appropriate empirical proxies for theoretical variables. This section describes the manner in which relevant data are collected for measuring competitiveness under the AHP framework.

This study focuses on elements associated with port competitiveness from the perspectives of geographical location, as well as logistics and operational services offered by the ports in the sample considered herein. The necessary information and data were collected through a series of surveys of a group of experts—350 professionals such as shipowners, shipping company executives, shippers, terminal operators, and academics and researchers from the region. The surveys—both face-to-face and telephonic interviews—were conducted over two months in 2002. Among 350 interviewees, 180 respondents were received successfully, and their business areas are shown in Figure 15.2.

The interviewees were requested to describe freely any intrinsic factors that might relate to port competitiveness. Throughout the survey, 73 detailed elements or factors related to port competitiveness were extracted, and these are listed in Table 15.3.

There were some duplicated and correlated items among the extracted elements. For adjusting those items, a group of specialists was selected

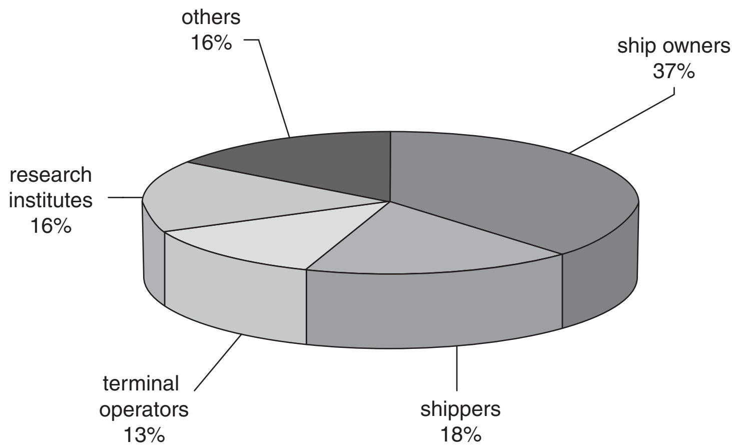

Figure 15.2 Business areas of respondents

Table 15.2 Random Consistency Index

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
M	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53

(see Saaty and Vargas, 2001 for detailed and justified processes). The group was made up of 70 members, including academic researchers as well commercial analysts, from working-level to board directors, engaged in container port businesses. The 70 members identified the five most important criteria related to the competitiveness of port businesses. These are *cargo volume*, *port facility*, *port location*, *service level,* and *port expenses*, which are interestingly more or less in line with the factors previously identified by various researchers (e.g. Foster, 1979; Slack, 1985; Murphy et al., 1988 and 1992; Brooks, 2000; Malchow and Kanafani, 2001). However, port expenses, a factor that influences competitiveness significantly, was excluded from this study because it is difficult to effectively collect data about and compare the factor for various ports given the heterogeneity in accounting practices across ports in China. The details of the other items are as follows:

Cargo Volume — The ability to handle a greater volume of cargo makes the port preferable from the users' viewpoint. Cargo includes exports, imports, and transhipments.

Table 15.3 List of the Elements of Port Competitiveness

- application of EDI system
- average hours of port congestion
- berth/terminal availability
- building Port MIS
- capacity of transportation connectivity
- capacity/status of facilities available
- cargo volume of handling transhipment
- changes in social environments
- changes in transport and cargo function
- complete preparation of multimodal transport
- concentration of volume by export/import
- customs clearance system
- dredging: yes or no
- easy access to port
- economic scale of hinterland
- effectiveness of terminal operations
- existence of cargo tracing system
- existence of port hinterland road
- existence of terminal operating system
- existing pattern of navigation routes
- extent of port EDI
- financial factors of port
- free time of container freight station
- frequency of ships calling
- handling charge per TEU
- handling volume of export/import cargo
- inland transportation cost
- inter-linked transportation network
- internal politics
- loading time
- location factors of the port concerned
- market position within the area
- mutual agreement of port users
- navigation distance
- nearness to hinterland
- nearness to main trunk
- number of liners calling at ports
- ability of port personnel
- port accessibility
- port congestion
- port facilities
- port marketing
- port operation
- port operation by government
- port operation by local autonomous entity
- port operation by private sectors
- port operation strategies
- port operation time
- port ownership
- port productivity
- port service
- port size
- port tariff
- possibility of mutual reference of electronic computation network
- price competitiveness
- response of port authorities concerned
- road network to be fully equipped
- sea transportation distance
- securing deep draft
- securing exclusive use of equipment
- securing fairway
- securing navigation facilities/equipment
- securing railroad connection
- status of national economy
- sufficiency of berth
- sufficiency of securing information equipment
- technical factors of port
- terminal facilities
- trade market
- trade/commerce policy
- transportation distance
- types of port operation/management
- world business

Port Facility — The greater the capacity, the higher is the competitiveness. Port facilities include both infra- and superstructures such as berths, cargo equipment, and stowage capacity.

Port Location — Having a good location is considered to increase port competitiveness. Port location includes geographical aspects such as hinterland accessibility and convenience of vessel entry, as well as future development conditions and possibilities.

Service Level — The higher the overall quality of service (e.g. speedy and reliable services) that is provided to users in a port area, the higher is the port's competitiveness.

For calculating the empirical values of those elements, it is necessary to define the identifiable or representative attributes of each criterion so that measurable or quantitative data can be extracted easily. As for *cargo volume*, port throughput (either in terms of TEUs or tones) forms the basis of evaluation. The attributes of *port facility* include wharf facilities, handling equipment, and storage facilities. Among these attributes, berth length is the representative attribute of port facility because the number of berths, amount of equipment, and storage capacity usually depend on the berth length. The attributes of *port location* include liner service frequency, geographical location, hinterland economy, and potential for future development. However, it is difficult to represent geographical location, hinterland economy, and future development potential quantitatively. Thus, liner service frequency is adopted as the representative attribute of port location. Finally, the representative attribute of *service level* consists of information systems—cargo handling information, cargo tracing information, and port management information system (Port-MIS)—implemented in a port because these systems can be regarded as key service items in the current business environment. Table 15.4 lists the identifiable and representative attributes employed in this study. Detailed information about each of the four attributes was compiled from the *Containerisation International Yearbook* (2002).

After the representative attributes are identified, a hierarchical structure is established as the starting point for the analysis mentioned in the previous section, as shown in Figure 15.3.

5 Empricial analysis

As a starting point for empirical analysis, element weights are computed by pairwise comparisons of the elements. In addition to the surveys mentioned in section 4, the expert knowledge of 70 port management

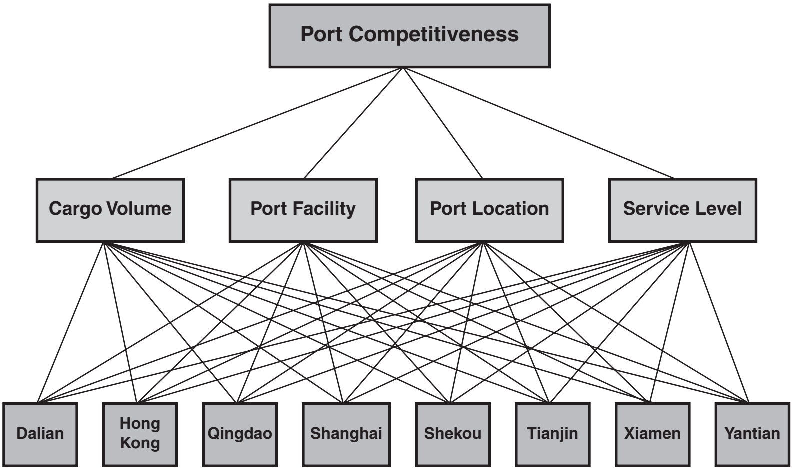

Figure 15.3 A hierarchical structure for Chinese port competitiveness

Table 15.4 Elements and Attributes for Port Competitiveness

Elements	**Cargo Volume**	**Port Facility**	**Port Location**	**Service Level**
Attributes	Throughputs handled	Berth length	No. of liners calling at ports	information service

and operations professionals, including shipowners, shippers, terminal operators, academics and researchers from national and local institutes, were requested to indicate the relative importance of each of four elements (i.e., pairwise comparison) on a scale of 1 (low) to 9 (high), discarding 0 (see Appendix II for the Questionnaire used for pairwise comparisons). Table 15.5 summarizes the outcome of the calculation based on the three stages described in Section 3 and equations (1)–(8) in Appendix I.

It can be interpreted from Table 15.5 that port location (0.452) is considered the most influential factor for competitiveness, followed by port facility (0.198), cargo volume (0.178), and service level (0.174). This result implies an interesting perspective that the competitive edge in the industry is still hardware-related, rather than software; in other words, physical location and facilities play a more vital role than service quality. The port industry is still regarded as a traditional industry in the region.

In addition, the consistency ratio is 0.026, which is lower than 0.1, the critical value. Therefore, the survey results are confirmed to be effective and consistent. Table 15.6 shows the attributes values in percentage, derived from the equations in section 3, for the sampled container ports in China.

After calculating the two preliminary values, an overall evaluation of the competitiveness of Chinese container ports can be made by calculating the weights of elements, listed in Table 15.5, and the attributes values of each Chinese port, listed in Table 15.6. Using the third stage described in section 3, the final outputs of the values indicating their relative competitiveness among the sampled ports were determined; these are listed in Table 15.7. It can be inferred from the table that Hong Kong is the most competitive port with an overall value of 0.2097. Shanghai is the second with a value of 0.0866, followed by Yantian (0.0717), Qingdao (0.0449), Shekou (0.0385), Dalian (0.0348), Tianjin (0.0339), and Xiamen (0.0298).

Table 15.5 Pair Comparison and Element Weights

Elements	**Cargo Volume**	**Port Facility**	**Port Location**	**Service Level**	**Weight [*w*(.)]**	**Priority**
Cargo Volume	1	7.20	0.12	0.16	0.178	**3**
Port Facility		1	0.22	5.70	0.198	**2**
Port Location			1	3.20	0.452	**1**
Service Level				1	0.174	**4**

Lamda = 4.07; CI = 0.024; CR = 0.026

Table 15.6 Attribute Values for Chinese Ports

(Unit: %)

	Dalian	**Qingdao**	**Shanghai**	**Shekou**	**Tianjin**	**Xiamen**	**Yantian**	**Hongkong**
Cargo Volume	0.0310	0.0651	0.1727	0.0222	0.0526	0.0332	0.0661	0.5570
Port Facility	0.0693	0.0898	0.1722	0.0491	0.0300	0.0107	0.1774	0.4016
Port Location	0.0690	0.0552	0.1241	0.0897	0.0966	0.0276	0.1931	0.3448
Service Level	0.0893	0.0893	0.1250	0.1429	0.1071	0.1250	0.1429	0.1786

6 Discussion and concluding remarks

The findings of the empirical analysis confirm the general perception that Hong Kong is the most competitive port in China, followed by Shanghai and Yantian. These three ports handle the majority of container traffic in the country. Furthermore, Hong Kong is the number one port worldwide, Shanghai is the most promising port in mainland China, and Yantian is the most competitive port in South China.

The research results provide another interesting insight. That is, "location" still plays the most significant role in the evaluation of a port's competitiveness. Geographical location is fixed and "cargo volume" shares a close relationship with location—this is particularly true in the context of China. These two are considered beyond control in competitiveness; they are to be taken as granted. However, port "facilities" and "services" are deemed capable of manipulation. Therefore, understandably, many ports worldwide have invested considerable effort toward the facilities and services elements for enhancing and sustaining a certain level of competitiveness against other ports.

However, ports located in the Chinese mainland should undertake great efforts to improve overall for catching up with the world-class port in Hong Kong. This recommendation is based on the outcome that Shanghai, the second-best port in the sample and the most competitive port in the Chinese mainland, scores 0.0866, which is far lower than Hong Kong's score of 0.2097. From the perspective of policy-makers and port operators in China, reducing the gap between these two areas within a reasonable period is the key to long-term prosperity.

Finally, in an attempt to evaluate the competitiveness of China's container ports, this study employed the well-established analytic hierarchy process methodology. Relevant information and data were collected from primary and secondary sources, and manipulated under the framework of the chosen method. The necessary primary data came from the neighbouring countries including Korea, Japan, Taiwan, and Singapore. This is because China's remarkable growth has a great direct or indirect impact on these adjacent ports.

This paper makes a meaningful contribution to existing literature on port competitiveness evaluation by combining quantitative and qualitative data, and using a well-accepted model with attributes well exposed to competitive analysis in the industry. This approach can be applied in a variety of ways to decision- and policy-making processes at any port in the world, and it clearly shows the areas that a port operator or port authority should focus on for improving that port's competitiveness. However, a major shortcoming of this study is that financial data was not included in the analysis, thus inevitably leading to biased evaluation. This drawback can be overcome as China becomes a more open society and the relevant data and information is accessible and reliable. In spite of this flaw, this study opens a door for further research in the field of port competitiveness analysis using both qualitative and quantitative data within the same analytical framework.

Acknowledgements

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Appendix I: technical matters of AHP method

First stage

As the first step of the analysis, a set of problems under consideration is analysed and divided into a hierarchical structure. The top level of the hierarchy is an overall goal that the problems pursue. Here, detailed elements of each level exclusive to the overall goal are 7 ± 2, that is, the maximum allowable weights. Because too much information may lead to a meaningless choice or outcome, a certain controllable amount of information (in this case, "attributes") is desirable (Miller, 1956; Wilkinson, 1965). Alternatives are listed in the bottom level of the hierarchy. In principle, this is in line with the stability of the principal eigenvalue to small perturbations when n is small and plays a central role in consistency measurement.

Second Stage

Pairwise comparisons are made for the detailed elements of each level (Saaty, 1980 and 1984). If n is the number of comparative elements, a decision maker will be required to perform $\frac{n(n-1)}{2}$ pairwise comparisons.

The values used as measures for the pairwise comparisons are $\frac{1}{9}$, $\frac{1}{8}$, …, $\frac{1}{2}$, 1, 2, …, 9 (Saaty et al., 1977; Saaty, 1980). The element weights at each level are computed from the pairwise comparisons for each level. At this time, because answers to decision-makers are not expected to be perfectly consistent, a consistency index is used for measuring the degree of consistency. For obtaining the criteria weights in the AHP method, the following procedure is adopted:

The number of criteria n is $A_1, \ldots, A_n$. If their original weights are $w_1, \ldots, w_n$, the comparative values of the weights of A_1 and A_j (that is, a_{ij}) satisfy the following equation:

$$a_{ij} = \frac{w_i}{w_j} \tag{1}$$

Equation (2) shows the constitution of the comparison matrix A using a_{ij}.

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots\cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots\cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots\cdots & \frac{w_{n1}}{w_n} \end{bmatrix} \tag{2}$$

When this comparison matrix A is multiplied with the vector of weights (w), the vector $n{\cdot}w$ is obtained as follows:

$$A \cdot w = n \cdot w \tag{3}$$

Equation (4) expresses (3) in detail.

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots\cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots\cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots\cdots & \frac{w_{n1}}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \\ w_n \end{bmatrix} \tag{4}$$

Equation (4) is manipulated to the following for determining the eigenvalue:

$$(A - n \cdot I) \cdot w = \mathbf{0} \tag{5}$$

Here, for $w \neq 0$, n must be A's eigenvalue when w is A's eigenvector. The eigenvalues $\lambda_i (i = 1, \ldots, n)$ are all 0, with one exception. As the sum of the diagonal elements is n, the only λ_i that is not 0 is λ_{max}. It follows as $\lambda_i = 0$, $\lambda_{max} = n(\lambda \neq \lambda_{max})$. Therefore, the weighted vector w for $A_1, \ldots, A_n$ is the normalized eigenvector ($\Sigma w_i = 1$) for A's principal eigenvalue λ_{max}.

However, to solve complex problems, we must obtain w' because it is unknown. The value of w' can be obtained by computing pairwise comparison matrixes, which are based on the interviewees' responses (in this case, decision makers). Hence, the problem transforms to $A' \cdot w' = \lambda'_{max} \cdot w'$, where w' is a normalized eigenvector and λ'_{max} is the principal eigenvalue. In reality, the more complex a circumstance becomes, the more difficult it is to expect consistent answers from decision makers. As such, because A' is not consistent, λ'_{max} always remains bigger than n. This is clarified in Saaty's Theorem (Saaty, 1985), expressed as (6):

$$\lambda_{\mathbf{max}} = n + \sum_{i=\mathbf{1}}^{n} \sum_{j=i+\mathbf{1}}^{n} (w'_j a_{ij} - w'^{\mathbf{2}}_i)^{\mathbf{2}} / w'_i w'_j a_{ij} \cdot n \tag{6}$$

That is, $\lambda_{max} \geq n$ using (6) at all times. Equality is possible only if consistency exists. Consistency scales are shown in (7), which is called a *consistency index* (CI).

$$CI = \frac{\lambda'_{\mathbf{max}} - n}{n - \mathbf{1}} \tag{7}$$

When the reciprocal pair-comparison matrix A is absolutely consistent, the CI is 0. As CI values increase, the level of inconsistency increases. A CI value lower than 0.1 indicates an acceptable consistency level. If a diagonal element is 1 and the symmetric elements of a matrix share a reciprocal relationship, the average M can be obtained through a series of computations of the CI of A being randomly put $\frac{\mathbf{1}}{\mathbf{9}}, \frac{\mathbf{1}}{\mathbf{8}}, \ldots, \frac{\mathbf{1}}{\mathbf{2}}, 1, 2, \ldots, 9$.

Table 15.7 Evaluation Values of the Competitiveness of Chinese Container Ports

Port	Cargo Volume (0.178)	Port Facility (0.198)	Port Location (0.452)	Service Level (0.174)	Overall Values [Ranking]	
Dalian	0.0310	0.0693	0.0690	0.0893	**0.0348**	[6]
Qingdao	0.0651	0.0898	0.0552	0.0893	**0.0449**	[4]
Shanghai	0.1727	0.1722	0.1241	0.1250	**0.0866**	[2]
Shekou	0.0222	0.0491	0.0897	0.1429	**0.0385**	[5]
Tianjin	0.0526	0.0300	0.0966	0.1070	**0.0339**	[7]
Xiamen	0.0332	0.0107	0.0276	0.1250	**0.0298**	[8]
Yantian	0.0661	0.1774	0.1931	0.1429	**0.0717**	[3]
Hongkong	0.5570	0.4016	0.3448	0.1786	**0.2097**	[1]

According to Equation (8), a *random consistency ratio* (CR) can be obtained via dividing the computed CI values by *M*, the values of which are determined from Table 15.2:

$$CR = \frac{CI}{M} \tag{8}$$

In addition, CR values can be used as an alternative index of consistency: if the CR values are lower than 0.1, a weighting solution can be considered acceptable.

Third Stage

As the final step, the "evaluated values" (in numeric terms) of the elements in each level are calculated by multiplying the relevant data with the corresponding weights computed via pairwise comparison. The evaluated values or numbers indicate the level of a port's competitiveness. The higher the obtained score, the more competitive is the port.

Appendix II: questionnaire survey form

The purpose of this survey aims to assess your opinions towards the relative importance of *four factors* related to the competitiveness of container ports in a way of pair-comparison. The four factors include *cargo volume*, *port facility*, *port location* and *service level* whose details are described below. In respect of the pair-comparison, you are requested to express <u>which factor is more important</u> and <u>how important the factor is</u> compared with its counterpart.

Part I. general information

The four factors are extracted from the previous studies as the vital attributes to port competitiveness. The definition of each factor is given below for your reference before going the questions.

Cargo Volume:	A port handling more cargoes is the more preferable from a perspective of users. Cargoes include exports, imports and transhipment.
Port Facility:	A port having the greater capacity is the more competitive. Facilities include both infrastructure and superstructure.
Port Location:	A port located at a good (i.e. strategic) point is deemed to enjoy a competitive edge against its competing ports. Location means geographical aspects such as hin terland accessibility, convenience of vessel entry, and further development plans, possibilities and potentials.
Service Level:	A port providing the higher quality of operating services is deems to enjoy a competitive edge against its competing ports.

In making pair-comparison of the relative importance between any two factors above, the following *nine scales* are to be used.

① **Equal Importance** in case of both factors having the same weight.

③ **Fair Importance** in case of a factor having the slightly more weight than the other factor.

⑤ **Strong Importance** in case of a factor having the more weight than the other factor.

⑦ **Very Strong Importance** in case of a factor having the much more weight than the other.

⑨ **Absolute Importance** in case of a factor having the absolute weight over the other factor.

Note: ②, ④, ⑥ and ⑧ are in the middle of each relevant scale (e.g. ⑥ is between ⑤ and ⑦).

Part II. Pair Comparison

Question 1.

In comparing between *Cargo Volume* and *Port Facility*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Cargo Volume ( ) vs. Port Facility ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Question 2.

In comparing between *Cargo Volume* and *Port Location*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Cargo Volume ( ) vs. Port Location ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Question 3.

In comparing between *Cargo Volume* and *Service Level*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Cargo Volume ( ) vs. Service Level ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Question 4.

In comparing between *Port Facility* and *Port Location*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Port Facility ( ) vs. Port Location ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Question 5.

In comparing between *Port Facility* and *Service Level*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Port Facility ( ) vs. Service Level ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

Question 6.

In comparing between *Port Location* and *Service Level*, which factor is the more important and how important it is relative to the other factor?

Which factor is the more important?	Port Location ( ) vs. Service Level ( )
How important is it?	① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

– The End –

Thank You for Your Co-operation

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