AN OPERATIONAL APPROACH FOR CONTAINER CONTROL IN OCEAN SHIPPING

by

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I, Qiang Gao, hereby grant permission to the Head Liberian at Acadia University to provide copies of this thesis, on request, on a non-profit basis.

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ABSTRACT

The purpose of this thesis is to investigate and model the process of container control in a typical liner shipping company. A two stage model is developed that can be used to obtain optimal (cost minimizing) decisions for both the size of a company's container complement and the allocation of containers within the company's shipping service. The model lends itself to practical application in the sense that it is capable of handling container leasing, purchasing, stocking, and allocating patterns, the data requirements are compatible with the information liner companies routinely gather, and all the solutions are obtainable quickly using a PC-286 computer.

By being of this nature, the development and specification of the model will hopefully contribute to the current small body of literature on container control, while its user friendly operation may make it potentially of practical use to actual container shipping companies.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

Background

A dominant characteristic of the container shipping industry in the 1980s was intense competition. This has been attributed to several causes, including over-tonnaging, the success of the fleets of the newly industrial countries, the transportation demands of traders who likewise found themselves operating in increasingly competitive markets, the diminution of liner conference power and the policy positions of governments such as Canada and the USA which became structured around laissez-faire, free market principles[1]. These very forces, moreover, appear firmly entrenched and therefore the intense global competition witnessed in liner markets during the 1980s looks set to continue throughout the 1990s.

In such highly competitive markets, corporate revenues are tightly constrained and therefore profitability and possibly even corporate survival, depend on an ability to control and minimize cost. An important component of a liner operator's cost structure relates to the costs associated with the acquisition and deployment of containers. These container costs, both capital investment and daily operating, may

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[1] Davies, J. E. (1983a), Legislative Change of the North American Liner Trades: A Study of Causes and Consequences (Ottawa: Economic Research Branch, Transport Canada)

comprise over 20% of a liner operator's total costs[2].

Despite the obvious importance of such container costs, little systematic work has been directed at the problem of identifying procedures for minimising the cost of both a shipping company's stock of containers and their deployment within the company's operational configuration. What does exist are three classes of study all of which have major deficiencies. These classes are:

(1) Studies which focus on the efficient utilization of a given, fixed container stock, further assuming the subset of empty containers to be specified as data. These models attempt to minimise the operating costs of allocating the fixed container stock but, unfortunately, fail to address the capital investment associated with the size of the container stock[3].

(2) General vehicle control models. These, however, are too general to address some of the specific features of the liner shipping industry and thus are of little use in practice[4].

(3) Proprietary software packages, which concentrate on integrating container control into the logistics management

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[2] Davies, J. E. (1983b), "An Analysis of Cost and Supply Conditions in the Liner Shipping Industry", The Journal of Industrial Economics, Vol xxxi No.4, p420

[3] Beaujon, G. J. and M. A. Turnquist (1991), "A Model for Fleet Sizing and Vehicle Allocation", Transportation Science, Vol 25, No.1

[4] See footnote 3.

function so as to monitor the position and status of the individual container, as opposed to minimising the requisite stock of containers[5].

On the critical problem of identifying formal techniques for establishing the optimal (cost minimizing) stock of containers there is thus virtually no published works in the public domain.

The author has, in fact, first hand experience of these problems, for between 1988 and 1991, I was employed by Tianjin Marine Shipping Co. (TMSC) in the department responsible for its container control operation. Like many shipping companies, the container stock employed by TMSC was determined by a simple rule of thumb--the "Threefold Principle", whereby the number of containers employed is set at three times total vessel capacity regardless of cargo volume and structure, sailing schedule, etc. Moreover, the day to day control of this container fleet was determined by the personal judgement of the prevailing management rather than by any formal optimisation technique. The result was a perennial mismatch of container supply and demand in terms of both the aggregate container stock and the numbers employed in particular geographic locations. This personal experience with the reality of the container control problem, coupled with the

[5] "Spreading the EDI Message", Cargo Systems International, September 1988, and GE Information Services (1990), Equipment Management System, System Description, (U.S.A.: GE Information Services)

frustration of discovering that there were no readily available accepted principles for its resolution, was the primary motivation behind this thesis.

As a starting point, and to assess whether my experience in Tianjin Marine Shipping Co. (TMSC) was unique or perhaps typical in the business of ocean shipping, I circulated a questionnaire to over 100 liner shipping companies, including all of the world's principal shipping lines, inquiring into their container control procedures. Of the 30 replies, most stated that they employed simple rules--for example, rules based on an initial budget of containers to be carried, multiplied the "turn time" of the specific container of a line. And like TMSC, none of the companies was satisfied with the performance of their current procedures, with one exception. However, this exception said that they believed that with further applications of information technology it would be possible to significantly increase the current productivity of their fleet[6].

As I expected, then, my own experience at TMSC reflected an industry-wide problem, a problem, moreover, that was both practically important and yet, strangely, which was unexplored territory in the literature on container shipping.

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[6] Davies, J. E. and Q. Gao, (1992): Questionnaire to 100 principal liner shipping companies. (Canada: Acadia University, Economics Department), see Appendix 1

Objective

In view of the noticeable absence of previous work, the primary purpose of this study is to develop a formal mathematical model capable of dealing with container leasing, purchasing, stocking, and allocating so as to yield least cost solutions for both container capital investment decisions (size of container stock) and day to day operating decisions (allocation of empty containers) under a variety of plausible service patterns. It is further intended that the model be capable of practical implementation as opposed to being simply a theoretical and academic exercise.

Methodology

A major difficulty in pursuing these objectives is the previously described lack of relevant work on the subject. Consequently the study cannot be constructed upon a foundation of agreed principles as established by previous works in this field. Hence, circumstances dictate that, to some extent, we must invent the wheel. Starting from first principles, however, requires that we need precisely to define our topic, and express it in the terminology of economics and mathematics. Moreover, to ensure that the topic does not become merely an exercise in academic navel gazing, our definitions must be such as to be practically relevant as well as theoretically sound. Operationally, this means that any assumptions used to develop theoretical arguments must be compatible with actual industry behaviour. Similarly the mathematical methods employed must be capable of being used in practice.

Scheme of Work

In chapter 2, the relevant aspects of the container shipping industry are identified, including the evolution of containerisation, the effects of the introduction of the container on the operations of liner shipping companies, the relative importance of container costs to total costs, and the pattern of container movement in a typical liner shipping system. Such descriptions provide the background and context necessary for our subsequent discussions.

Chapter 3 seeks to identify which type of mathematical model is likely to be most appropriate to the specific problem of identifying the optimal stock of containers. To this end, we first review what previous work there is which, directly or indirectly may be related to our study. The previously described lack of relevant material here consequently drives us to consider, in larger scope, the mathematical methods generally applicable in the economic world which may be of import to our study. Specifically, inventory, network, simulation and mathematical programming models are analyzed. In all cases, the practical circumstances encountered in the liner shipping industry are matched against the conditions necessary for the proper application of each model in order that the most appropriate approach may be identified.

Chapter 4 is the central part of the thesis. Here, we first describe our problem precisely, make some basic assumptions, and show the necessity of a two-stage approach in developing the model. In the first stage, we identify any imbalance between supply and demand of containers given the outbound cargo demand pattern at each port on the shipping route. Subsequently, in the second stage, a integer programming model is constructed to correct the imbalance in terms of least capital and operating costs. In this way a solution is given to show the costs minimizing control path for both the size of the total container stock and its deployment by a shipping company.

The practical performance of the model is evaluated, in chapter 5, by running the model with three hypothetical cases using a PC-286 computer. These cases are selected so as to test for the absolute existence of a solution and also the sensitivity of the solution to changes in any service variables.

In chapter 6, the model is used to identify the possible existence of economies of scope in container control in the liner shipping industry. It is hypothesised that the existence of such economies may partially explain the pattern of merger and co-operation that have recently been witnessed in the liner shipping industry.

Finally, chapter 7 summarizes the thesis and identifies the principal conclusions and limitations of the study.

CHAPTER 2

AN OVERVIEW OF THE CONTAINER SHIPPING INDUSTRY

Introduction

The purpose of this chapter is to give a survey of container shipping industry in order to provide some context to the problem addressed by the thesis. In particular, the chapter will focus on the origin of containerisation, its impacts on the operations of liner shipping companies, the relative importance of container costs to total costs, and the container moving system.

Description of Ocean Containers

According to the ISO (International Standards Organisationn)[1], a freight container is an article of transport equipment that satisfies the following criteria:

(a) It is of a permanent character and accordingly strong enough to be suitable for repeated uses;

(b) It is specially designed to facilitate the carriage of goods, by one or more modes of transport, without intermediate reloading;

(c) It is fitted with devices permitting its ready handling, particularly its transfer from one mode of transport to another;

(d) It is so designed as to be easy to fill and

[1] Van Den Burg, G. (1975) Containerisation and Other Unit Transport (London: Hutchinson Benham), p58-59

empty;

(e) It has an internal volume of 1 cubic metre (35.3 cubic feet) or more.

For ocean shipping, the mostly frequently used container sizes are 20 ft (20x8.5x8) and 40 ft (40x8.5x8).

The Advent of Containers in the Liner Shipping Industry

Man has been experimenting with containers since the dawn of commercial history. The merchants who first sought to improve cargo handling and protection by placing two small parcels in the same crate or using sealed amphorae took the earliest steps toward containerisation as we know it today. Over the centuries other attempts were made to simplify cargo movement and consolidate shipments into larger, standardized parcels. However, these efforts usually were defeated by limitations in the technology of cargo handling and movement.

Some advances occurred in the handling of bulk commodities when casks and barrels were replaced by specially designed ships into which oil, coal, or grain could be poured. However, there was relatively little progress with the rest of international shipping, namely that part of the industry which carries so-called general cargo. Through the 1950's, general cargo continued to be handled "break-bulk" style. This refers to the movement of freight, generally one parcel at a time, onto the truck or rail car that carried it from the factory or warehouse to the docks. There each parcel was unloaded and hoisted by cargo net and crane off the dock and onto the ship. Once the package was in the ship's hold, it had to be positioned precisely and braced to protect it from damage during the ocean crossing. This process was performed in reverse at the other end of the voyage. Thus, the movement of ocean freight was slow, labour-intensive, and expensive[2].

Although the idea of streamlining cargo loading operations by putting separate cargo consignments into boxes was by no means new--in 1931 the Royal Commission on Transport (UK) advocated its use--its development was difficult to achieve in practice due to a variety of factors, including the reluctance of unions to accept labour saving improvements, conservatism of management in planing new investments and the inherent difficult of marking changes in an international industry. However, the utility of the container concept was demonstrated convincingly during the Korean War of 1953, which demanded the rapid transport of huge volumes of war material[3].

Shortly after the end of the Korean war, in 1956, Sea-Land, which had its origins in road haulage, started the world's first regular containership service using converted break-bulk tonnage, between New York and Puerto Rico. This pioneering service followed the successful conclusion of

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[2] Johnson, K. M., H. G. Garnett (1971), The Economics of Containerisation (London: George Allen & Unwin Ltd.)

[3] Davies, J. E. (1980) The Regulation of Liner Shipping: A Study of Motives and Consequences PhD Dissertation, University of Wales, UK, p102-03

experimental shipments in the previous year between New York and Houston. Port handling costs and times were reduced drastically. Four years later, in 1960, Matson introduced the world's first purpose build container vessel on its US West Coast-Hawaii service. But for almost a decade other shipping lines ignored or rejected the potentialities of containerisation even though by 1966 Sea-Land had nineteen container ships and Matson fourteen.

The turning point appears to have been in 1965 when Sea-Land announced its intention to enter the trans-Atlantic trade with container ships. The reaction of established lines on that route was immediate: each announced its intention to modernise its existing vessels and then to build specialist container ships. Ports in the US east coast and in Europe soon followed with their plans for container berths. Similar developments took place in the Pacific trade when the Japanese government announced in 1966 a massive container ship and berth development programme.

Since 1966 the growth of container services has been explosive. In that year the first edition of the American trade Journal "Container News" was published. Its container shipping guide provides evidence of the rate at which containerisation spread. The May 1966 edition reported only 5 shipping lines operating container services from the USA. The January 1967 edition listed 38 lines serving over 100 ports in Europe, latin America, the Near East, the Far East, Africa, Australia from the US East and West coast, and Great Lakes ports. In June 1969, the number of lines had risen to 88 and number of ports served to almost 200[4].

Along with the expansion of container services, there was a dramatic increase in the volume of containerised traffic. This is illustrated in Table 2.1 which shows the growth in container traffic during the critical decade of the 1970s when the container concept became transformed from a revolutionary innovation to a standardised, globally accepted technology.

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[4] Chadwin, M. L., J. A. Pope, and W. K. Talley (1990) Ocean Container Transportation: An Operational Prospective (New York: Talor and Francis)

Table 2.1

World Seaborne Containerised Traffic

Growth 1970-1981 (million tons)

Year	Volume	Indexed Growth
1970	47.3	100
1971	58.9	124
1972	77.0	163
1973	108.2	229
1974	123.7	262
1975	127.3	269
1976	158.1	334
1977	182.3	385
1978	214.7	454
1979	235.1	497
1980	255.5	540
1981	280.2	592

Source: Dally, H. K. (1983), Container Handling and Transport, a Manual of Current Practice (England: C.S. Publications Ltd.), p3

Advantages and Disadvantages of Containerisation

The container system provides the opportunity to manipulate standard units of cargo by highly mechanised means throughout the journey from first packing place to final destination. There is an opportunity to make large cost savings in entire transport costs by standardising the methods of carriage and transfer between modes. Essentially, the goods are packed into large boxes providing protection from the weather and bad handling throughout their transit. The boxes can be transferred between modes efficiently and quickly.

Advantages of Containerisation

There are large gains in productivity by the shipping company when using containers to transport goods when compared to the performance of break-bulk services. However, it takes efficient organization to reap the full benefits inherent in greater use of mechanical equipment.

The most important advantage of containerisation is the reduction in total time taken to transport goods from manufacturer to consumer. This, in turn, can save the manufacturer other costs inherent in the order cycle for goods from the customer-that is the lead time from order placing to delivery. To speed delivery, most manufacturers must store their products close to the market. But the speed of the transport mode has an effect on the amount of stock held in warehouses in order to make guaranteed deliveries. The saving in delivery time accomplished by containerisation is by reason of the shorter transfer time needed when moving the goods between modes.

The faster handling rate for containerized cargo in port makes larger vessel possible, thereby reaping the advantages of economies of scale, which accordingly reduces the shipping operator's costs.

With conventional break bulk cargo handling methods, high costs are involved not only in terms of packaging goods to prevent damage in transit but also on account of the large amount of documentation needed and the high insurance premiums consequent on damage and pilferage risks. Containerisation has brought benefits by lowering these costs.

Finally, handling containers in marine terminals leads to lower labour costs and higher labour morale after the initial reduction in the size of the dock labour force. The lower costs are due partly to the reduction in manpower needed to handle the same throughout across a container berth as compared to a conventional berth. The labour morale of those working is higher because of the better working conditions that can be provided[5].

[5] Edmund, J. G. (1986) "The Shipping Industry, the Technology and Economics of Specialisation" Transport Study (UK: Loughborgough University of Technology, Gordon and Breach Science Publishers), Vol 15.

Disadvantages of Containerisation

Obviously, there are some major disadvantages attached to the container system although to listen to people engaged in the container business, this fact is not readily apparent. The container system sets out to provide a door to door service which involves more complex control mechanisms, especially in keeping a record of where individual containers have been sent and where they are located within any vessel.

To initiate a system, a great deal of very sophisticated equipment must be provided, most obviously handling equipment but also computer equipment to track the position and movement of containers. This calls for a large amount of finance for investment for both the equipment itself and for training programmers and other skilled people to operate it.

To earn the required returns on such high levels of capital investment, intensive use is a necessity and intensive use implies complex organisation of the whole system to ensure that the throughput of containers is sufficiently high to warrant the expenditure.

There is still a great deal of cargo that cannot be containerised and on routes where containers have taken a major share, this non-containerisable cargo can be subjected to delays because the conventional service must of necessity be less frequent. This could mean higher conventional liner freight rates[6].

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[6] See footnote 5

The Impact of the Introduction of Container Technology on the Liner Shipping Industry.

The containerisation of international trade brought about marked changes in liner shipping industry. The essence of containerisation is the revolution of packing in ocean shipping, which brought about three fundamental progresses: (a) faster port turn round time (b) faster inland delivery time (c) durable packing. The major effects that containerisation of general cargo have had on the shipping industry can be identified within six broad areas.

Heavy Capital Investment

Heavy capital investment is necessary in ships, containers and port handling equipment to maximise the use of the system and capitalise on its undoubted advantages. This type of investment calls for detailed and careful planning of both the technological system and the management administration regime if adequate returns are to be earned.

Table 2.2 shows that the cargo handling expenditures in Port of Halifax in 1990 accounts for more than 16% of its total direct expenditures.

Table 2.2

Total Direct Expenditures of Port of Halifax in 1990

Item	Amounts (CAD millions)
Cargo Handling	58.8
Fuel and Water	23.5
Port Services	13.2
Other Vessel Expenditure	15.6
Cruise Passenger Expenditure	1.8
Crew Expenditure	6.9
Surface Transportation	161.9
General Services	74.0
Total	**355.7**

Source: Gardner Pinfold Consulting Economists Ltd (1991) The Port of Halifax Economic Impact Study (Canada: Gardner Pinfold Consulting Economists Ltd.)

The Radical Change of External Organizations

In order to take the advantage of economies of scale, to achieve a high level of return, and indeed to generate the necessary investment funds, the external relationships of shipping organizations have undergone radical change. The setting up of consortia of shipowners to run container services, often across national boundaries, has made container shipping companies much more co-operative. The common features of most consortia are joint marketing and capacity co-operation, achieved by individual firms pooling their factors of production[7].

The Change of Operations and Personnel Attitudes

The internal organization and attitude of the shipping company personnel has changed as it is no longer possible to sit back and just sell ship space. The complete container service must be sold to the customer to utilise the container fully and this necessitates shipping company personnel becoming involved in the conduct of total transport of goods from manufacturer to consumer.

The shipping company must have a detailed knowledge of what is arriving at the port so that the ship can be loaded quickly and without delay while the cargo is checked. It is important to know the weight, contents and destination of each container so that the loading plan can be calculated before the ship arrives, thus minimising port time.

Regular and Frequent Service Requirement by Shippers

In break-bulk liner trades, the requirement for regular and frequent services is a potent influence on service patterns. Although containerisation removed the bounds on ship size imposed by the rate of handling in conventional systems, a new one superseded it, namely, sailing frequency.

The longest sailing interval shippers will tolerate places a new restriction on ship size via the amount of traffic that can be generated during this interval. In most

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[7] Hugo van Driel (1992), "Co-operation in the Dutch Container Transport Industry", The Service Industries (London) Vol 12 No.4

cases the problem was overcome by route amalgamation or by the ability of some lines to serve a bigger share of the market in the new competitive environment.

Today, on the larger and more competitive container trades, there is a marked proclivity on the part of shipping companies to offer weekly service intervals and even, in some cases, fixed day sailing schedules. The shortening of service intervals does have a price. It could lead for instance to the deployment of smaller, and therefore less cost effective, ships than would be warranted by consideration of route length alone. The three factors of route length, market size, and frequency constraint, determine in large part both vessel size and the competitive scenario witnessed on any container trade[8].

Control of Containers

For the shipping line, the most obvious administrative change has been the establishment of a new department--equipment control, which is responsible for all aspects of control of containers, including purchasing, leasing, locating, positioning, repairing. Meanwhile, the costs associated with container control became a completely new item in the company's balance statement, an item which may

[8] Pearson, R. and J. Fossey (1983) World Deep-Sea Container Shipping (England: Gower Publishing Company Ltd.), p93

account for over 20% of total costs[9]. Viewing its essential role in our topic, we will discuss it in more detail subsequently.

Container Transport System

The introduction of freight containers eliminates several of the shortcomings of conventional break-bulk transportation. In the ideal situation the shipper loads the containers at his shipping dock, closes the door and has the container moved within a system in which each element is specially adapted or designed for the carriage of containers only, without the contents of the container having to be handled again until they are unloaded by the consignee.

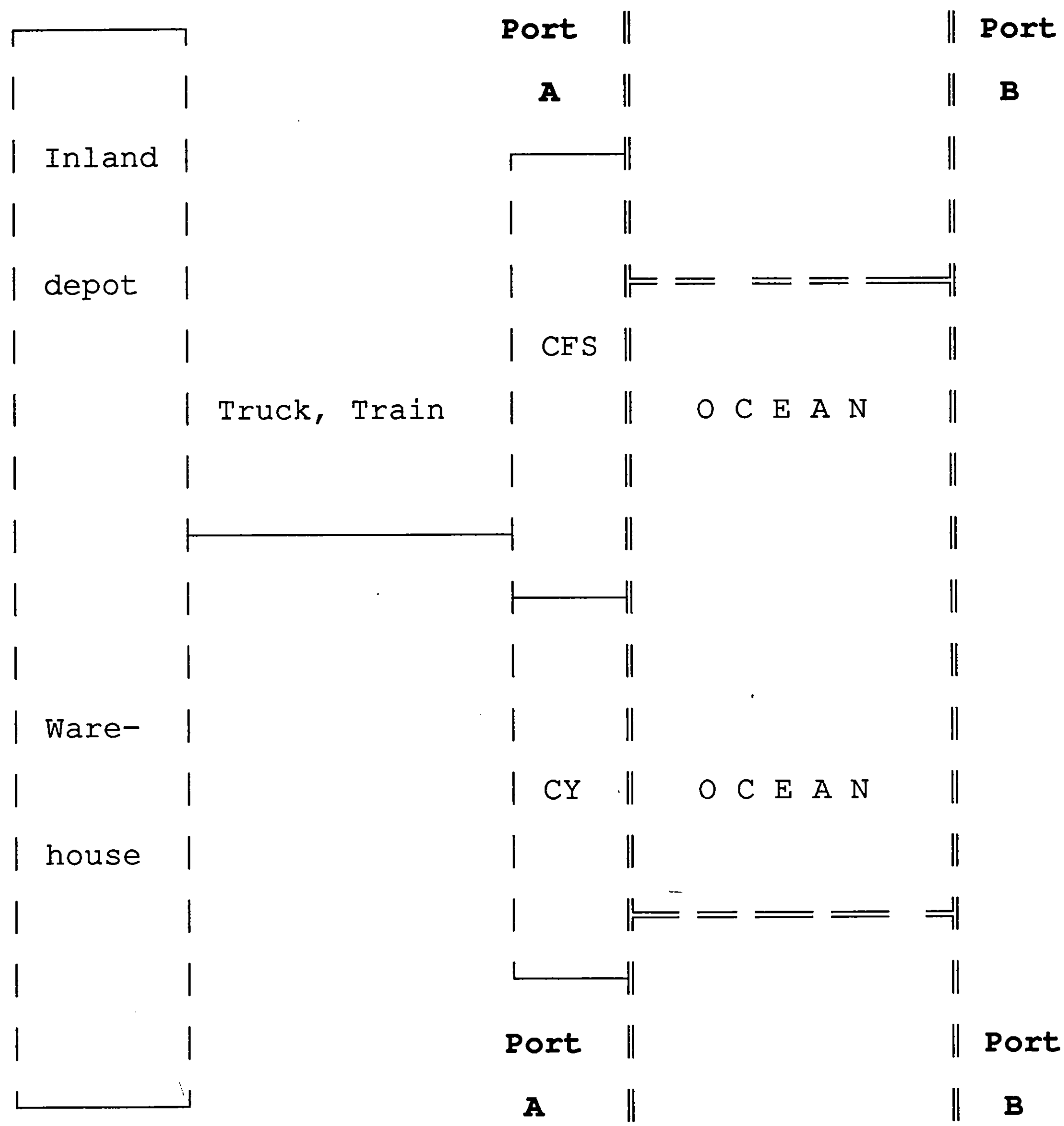
The container transport system describes the overall pattern of movement of containers engaged in door-to-door transport services, effected by using both containerships and alternative transportation modes, either land-based or water-based.

Figure 2.1 is a diagrammatic layout of a typical intermodal container transport system.

[9] Davies, J. E. (1983) "An Analysis of Cost and Supply Conditions in the Liner Shipping Industry" The Journal of Industrial Economics, Vol xxxi No.4, p420

Figure 2.1

A Simplified Intermodal Container Transport System



The containership travels between ports A and B. In a specific port, say port B, full containers are loaded and shipped to port A. After being unloaded in the CY (container yard) of port A, full containers are either unpacked in the CFS (container freight station) of port A, or transported to consignee inland by train or truck. After being unpacked by the inland consignee, they are returned either to the shipping company's inland depot or other designated warehouse, or directly to a CFS near the port for subsequent outbound reuse.

The containership and the container itself are the essential parts of the system, especially in the context of our study, which focuses on the viewpoint of shipping operators rather than their customers or the operators of other modes. Therefore, we will discuss them in more detail below.

Containership Network

A containership network is an inter-port network over which only containerships move containers. It may be described either as origin-to-destination, i.e., the same containership transporting cargo from its origin port through the network to its cargo destination, or as mainline. In this latter case, the same containership does not provide containership services for cargo from its origin port to its destination port, but provides a containership service including either feeder or transhipment services. Because the latter is more general in terms of practical application, we will just consider mainline networks.

A feeder main network is depicted in Figure 2.2. The main network, ABCD, has a connecting feeder network, AEFG, feeding container cargo into and out of A, a port common to both networks. A relatively small vessel serves feeder network AEFG and a relatively large one operates along main network ABCD. In Figure 2.3, transhipment main networks are depicted. Main networks ABCD and BCFE have in common ports B and C, which can serve as transhipment centres. Thus, at ports B or C, containers going to ports on one network are transferred from vessels operating on the second network to ships serving the first network.

In Figure 2.4, a combination of feeder and transhipment main networks has been created by merging 2.2 and 2.3. Main networks ABCD and CDEF have a feeder network AGHI[10].

Figure 2.2

A Feeder Main Network

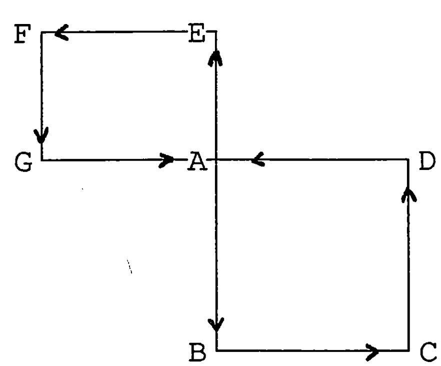
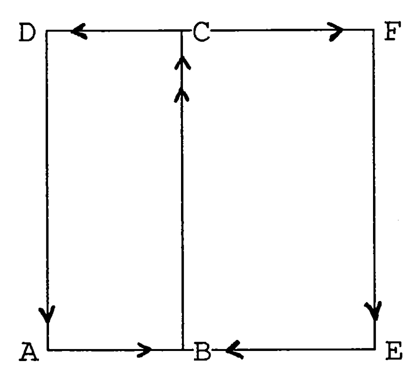


Figure 2.3

A Transshipment Main Network

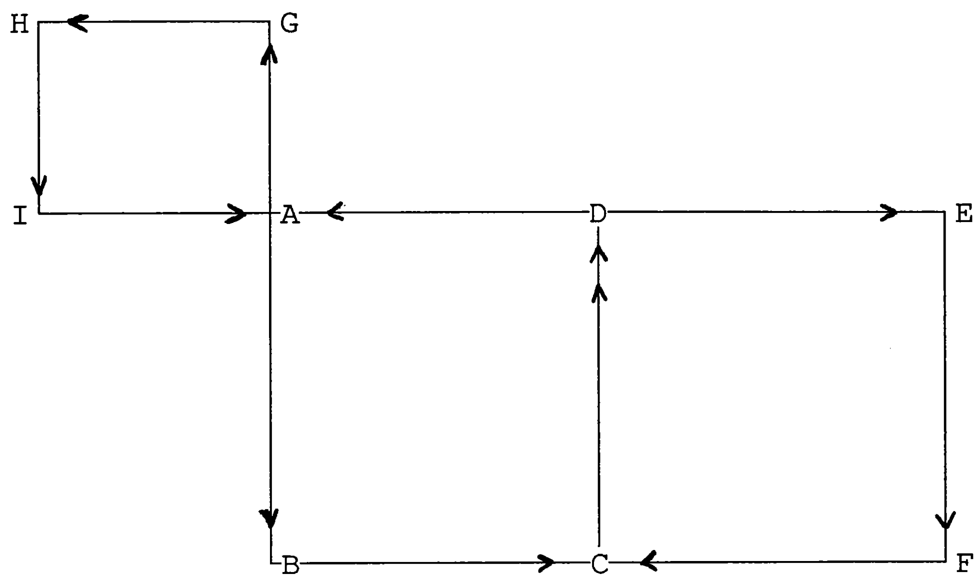


[10] see Footnote 4, p93-96

Figure 2.4

A Combination of Feeder and

Transshipment Network

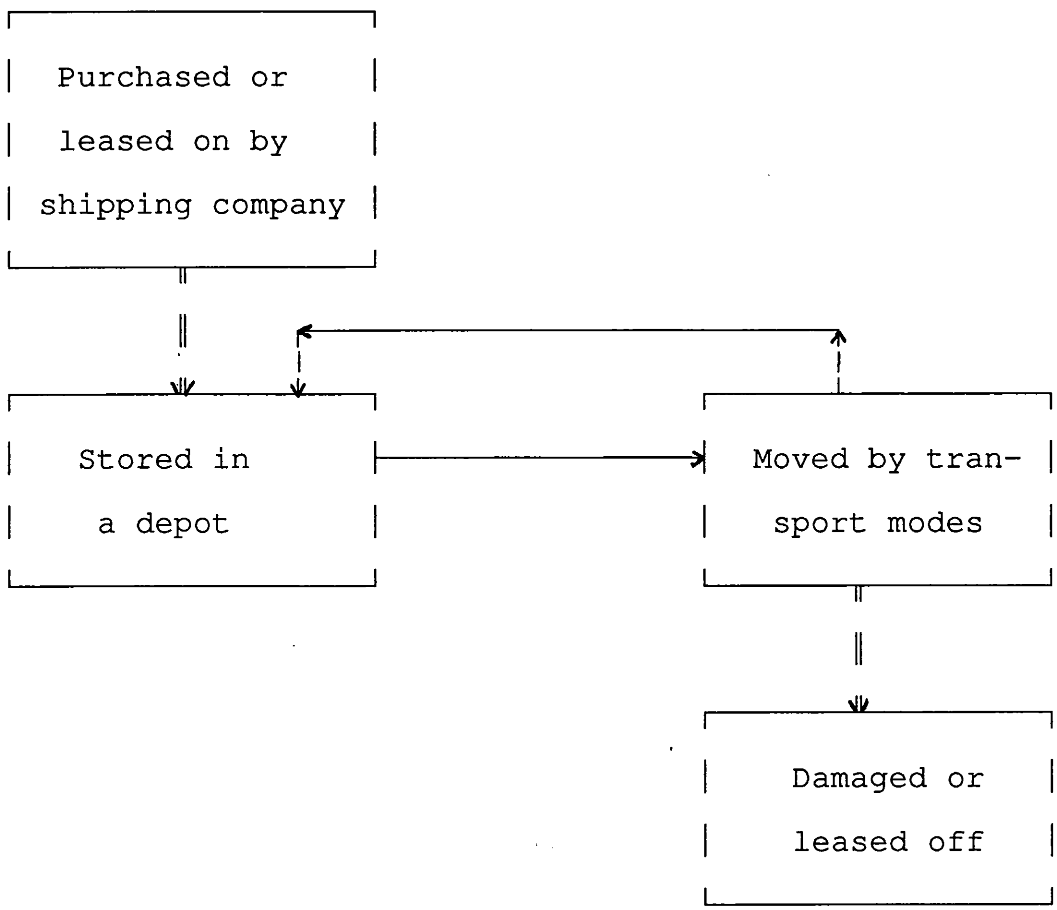


The Pattern of Container Movement

The pattern of movement of an individual container during its entire life cycle in a container transport system can be depicted as in Figure 2.5, below.

Figure 2.5

A Flow Chart of Container Movement



The above figure illustrates that a container shipping company purchases, or leases on, a container as long as there is new cargo demand for that extra container. It then stores it in company's depot or other warehouse designated by company for subsequent cargo use. Movement of the container includes transporting the full container and repositioning it when empty through intermodal services. This has been explained in detail earlier, in Figure 2.1. A container will disappear from a company's fleet either when it is totally damaged or leased off by the company. Hence, purchasing, leasing, stocking, and repositioning are four basic dimensions of empty container movement.

The Significance of Container Costs in Shipping Lines

Table 2.3 shows the cost structure of a typical containership operating on the North Atlantic in 1984. Container capital investment was $1,987,080 per year, while maintenance, repair, insurance, and positioning of empty containers were $3,347,604. Total container cost was $5,334,684, which accounts for 22% of total yearly vessel costs. This calculation does not, however, include the cost of container storage.

Table 2.3

Yearly Vessel Cost Calculation

(Designated Vessel)

Service speed: 17 kts	Consumption: 50tons+2 1/2 tons OMD
G.R.T.: 31,000	Capacity: 1800 TEU
Operating Days: 358 days	No. of Voyages: 12

	Amount (US $)
Crewing	
Crew	709,800
Crew changes	42,900
Insurance	
Hull & machinery	225,000
P&I (incl.supplementary calls)	62,000
War risk, strikes	19,000
Deductible	31,000
Repairs & Maintenance	
Drydocking Provisions (half of biennial)	165,000
Voyage, running & other maint.provisions	110,000
Stores & Spares & Supplies	
Deck spares	20,000
Engine	13,000
Spares, incl. transport	61,000
Lube oil	146,000
Catering supplies	17,000

Victualling	37,000
Water and other	9,000
General Admin. & Other	
Management	90,000
Rentals	3,500
Communication	3,500
Sundries	13,000
Capital Annual Vessel Amortisation Rate*	3,480,667
Capital Containers+	**1,987,080**
Voyages	
Fuel	1,334,024
Port charges	1,594,440
Cargo charges	10,091,136
Container maintenance, repair and insurance, and Positioning of empty containers	**3,347,604**
T O T A L	**23,612,851**

* Straight line over 15 years

\+ Straight line over 10 years

Source: Calculated from Philippe I. Georges & Associates (1985), North Atlantic Containers Shipping Costs Study, (Ottawa: Canadian Transport Commission, Research Branch), p65, 98.

If we consider the costs structure of a complete shipping company, the position of container costs is noticeable as well, as shown in Table 2.4.

Table 2.4

The Cost Structure of Container Companies+

Company I		Company II	
Terminal cost	15%	Terminal costs	21.5%
Container costs	13%	Transport costs	9.6%
Transport costs*	9%	Commissions	16.0%
Commissions	5%		
Port charges	4%	Port charges	4.8%
Bunkers	10%	Positioning	4.0%
Vessel costs	24%	Overheads & promotion	4.8%
Administration	10%	Vessel Costs	21.7%
Other fixed costs	10%	Equipment	9.6%
		Bunkers	8.0%

Company I--small company operating primarily in trades from Europe to East Mediterranean, south Africa and Australia

Company II--large company operating on North Atlantic

+ Figures based on normal budgeted load factor of 75%, all 1980 figures.

* Transport costs are the costs of moving containers from inland points to/from port.

Source: Davies, J. E. (1983), "An Analysis of Cost and Supply Conditions in the Liner Shipping Industry", The Journal of Industrial Economics" Vol xxxl No.4, p420

For company I, the container costs, i.e., "container cost" plus "transport cost", accounts for 22% of company's total costs. Similarly, for company II, container costs, i.e., "transport costs" plus "positioning costs" plus "equipment costs", comprise 23.2% of total costs.

In general, the cost structure of any shipping company will vary in accordance with its operational environment. It is clear, however, that the costs arising from container control are of considerable magnitude, accounting conservatively for about 20% of the total costs of container shipping operator. The composition of these costs will be discussed in more detail below.

Purchasing and Leasing Costs

Container line operators have the option of owning their containers outright, leasing them long term, or having a predetermined number of owned containers being supplemented by leased containers as they may be required. The third option serves to take care of any fluctuations in the demand for containers and the ability to address surges for short term demands. The rationale of leasing containers on a long term basis rather than purchasing them is usually found in tax or cash flow reasons. Short term leases are on a per diem basis, the rate charged depending on the type of container, where it is picked up and where it is finally deposited. In addition, there would be a drop off charge imposed, depending on whether the container is deposited in a surplus or high demand area.

The purchase price of a 20ft dry steel container is around $3000, while that of a 40ft is about $4000-5000. For rental prices, a 20ft is around $1.5, and a 40ft is $2.8 per day[11].

Nearly 50% of the world's international land-ocean container fleet is owned by container leasing companies. Many of the leasing companies try to deal in all-purpose containers in the most popular sizes because they are widely used and because they can be employed in many diverse circumstances and locations. However, with the growing demand for refrigerated and other specialized containers, most large companies must have some specialized containers on hand.

The evolution of the container leasing industry appears to have been strongly influenced by financial considerations. Large monetary investments in containers and facilities are converted into leases that will provide a profit after repayment of interest on borrowed capital.

Container Storage Costs

While not being used, empty containers are stored in a CFS (container freight station) depot or warehouse which may be either owned or leased by the operator, to wait for suitable cargo. The storage fee, which occurs in the form of rent if the depot is leased by operator, or shadow price if owned by operator, varies by area. Generally, for a 20 ft

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[11] Philippe I. Georges & Associates (1985) "North Atlantic Containers Shipping Costs Study" (Ottawa: Canadian Transport Commission, Research Branch), p30

container, it is some $0.5 per day, while for a 40ft container, it is $1.0 per day.

Container Insurance Costs

The container line which owns its own equipment will protect its large investment by insurance.

This insurance generally covers total losses, warehouse risks, strikes, risks and civil commotions and third party liabilities.

Container Repairs and Maintenance Costs

The cost of maintenance of the container inventory is a significant factor. Boxes are handled many times and are susceptible to damage. The approach to this varies from operator to operator, with some undertaking their own repairs and refurbishing, others contracting out, whilst another option is to obtain insurance cover, i.e. a damage protection plan.

Empty Containers Positioning Costs

This is the cost of repositioning an empty container from one port where it is not needed to another port where it is required. The necessity for repositioning arises from imbalance of trade. The costs associated with the re-positioning include lift on-off costs and inland transport costs in both ports.

Conclusions

The advent of the container brought about a revolutionary change in the shipping industry. It reduced transport costs and decreased cargo delivery times, thereby, contributing significantly to the development of international trade. For shipping lines it allowed the realisation of increased scale economies which, in turn, promoted the formation of consortia, merger and corporate growth. However, the new technology and methods of operation created a new task for the shipping company--container control--and created a new and significant cost item--container costs. These costs may comprise over 20% of a liner company's total costs.

The container transport system describes the movement of containers in ocean shipping. Typically this system comprises a combination of mainline, feeder and transshipment services. Having established this, our task now is to model the system with a view to identifying the minimum stock of containers needed to accommodate the trade moving through the system and the optimal deployment of those containers within the system. This is addressed in the next two chapters.

CHAPTER 3

IDENTIFICATION OF MATHEMATICAL TOOLS

Introduction

This chapter is devoted to identifying which types of mathematical techniques are likely to be most appropriate to our problem of minimising the stock of containers needed to serve any particular liner trade. As we have already pointed out, the appropriate selection of mathematical methods is essential given the lack of previous work on the subject.

To this end, the previous work related directly or indirectly to this topic is first reviewed. Then we introduce the principal mathematical techniques that have been applied to the economic and business world. Subsequently, those mathematical methods either used successfully in previous research, or seeming to be potentially most useful, are given further discussion to assess if they are really appropriate to our specific problem. From this list, we will ultimately endeavour to isolate that particular technique or techniques likely to be most suitable.

Review of Previous Work

The most popular rule on container control is the "Threefold Principle"[1], which says that the number of containers required by a liner operator should be three times

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[1] Philippe I. Georges & Associates (1985) North Atlantic Containers Shipping Costs Study (Ottawa: Canadian Transport Commission, Research Branch), p28

the operator's all vessel capacity. This rule comes from the idea that one set of containers is needed in one port, a second set is used in vessel, and the third is put in another port. Considering current practices in liner shipping , there is no doubt that this idea, based on two port sailings and low calling frequencies, is long out of date.

Recognizing this, several authors have begun to address the problem of empty container distribution. Generally, this is perceived to be a problem of allocating the containers available at a surplus terminal from an earlier loaded shipment, to a demand terminal in preparation for subsequent loaded transport. Potts[2] has solved the problem for the movements of empty containers in Australia using the standard out-of-kilter algorithm. White[3] builds a space-time network referred to as a dynamic transshipment network and again solves the distribution problem by using the out-of-kilter algorithm. Ermol'ev, Krivets and Petukhov[4] pose the problem of supplying ports with empty containers in time to prepare for subsequent seaborne shipment. They build a dynamic network model where empty containers will be transported by using the

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[2] Potts, R. B. "Movement of Empty Containers in Australia", Paper presented at OR Society of Victoria, Melbourne, Australia.

[3] White, W. W. (1972) "Dynamic Transhipment Network: An Algorithm and its Application to the Distribution of Empty Containers", Networks 2, p211-36

[4] Ermol'ev, Y. M., T. A. Krivets, and V. S. Petvkhov (1976) "Planning of Shipping Empty Seaborne Containers", Cybernetics 12, p646-64

loaded container lines. Florez[5] builds a dynamic transsshipment network solved using two alternative linear programming algorithms. This is an operational model to be used by the management of a shipping line prior to the departure of every vehicle (vessel, truck, train or barge) from any location in the network (ports and inland terminals)[6].

Virtually all of these works focus on the efficient utilization of a given, fixed container stock. The subset of empty containers is further assumed to be specified as data. The models thus attempt to find the most efficient routing for these empty containers. While such formulations point to the benefits associated with reducing operating costs, they unfortunately fail to address both the appropriateness of the initial capital investment and some of the actual operating costs routinely incurred, such as extra storing, handling, and maintaining.

Beaujon and Turnquist[7], however, have sought to develop a general optimal model for fleet sizing and vehicle

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[5] Florez, H. (1986), Empty-Container Repositioning and Leasing: An Optimization Model, Ph.D Dissertation, Polytechnic Institute of New York.

[6] An rather comprehensive review of vehicle management models is presented by: Dejax, P. J. and T. G. Crainic (1987), "A Review of Empty Flows and Fleet Management Models in Freight Transportation", Transportation Science, Vol 21 No.4

[7] Beaujon, G. J. and M. A. Turnquist (1991) "A Model for Fleet Sizing and Vehicle Allocation" Transportation Science, Vol 25, No.1

allocation. The strength of this research is that it takes dynamic and uncertainty conditions into account. The model answers such questions as: (1) How many vehicles should be in the fleet? (2) Where should vehicle pools be located? (3) How large should these pools be at any given time? (4) At any given time and location, how should available vehicles be allocated to loaded movements, empty movements and vehicles pools? This model represents the latest research in the field of general vehicle control. Its weakness is that it is too general to address some of the specific features of the liner shipping industry, in particular container self-production and leasing, as will subsequently be shown.

Survey of Mathematical Techniques Used in the Business World

The principal mathematical methods that have been used to analyze business problems are: queue theory; graph theory and network techniques; game theory; simulation theory; optimal control theory; mathematical programming method (MP); and inventory model. Each will now be considered in turn.

Theory of Queues

A "queue" is a waiting line of units demanding service at a service facility (counter); the unit demanding service is called the "customer" and the device at which or the person by whom it gets served is known as the "server". Here are a few realistic examples of this customer-server mechanism.

(a) Vehicles demanding services arrive at a garage, and, depending on the number of employees, one or more vehicles may be repaired at a time.

(b) In a telephone exchange, incoming calls are the customers who demand service in the form of telephone conversations.

(c) Passengers demanding tickets queue up in front of a ticket counter.

It is not difficult to see that all of these cases have some basic features in common:

(a) Input process: If the occurrence of arrivals and offers of service are strictly according to schedule, a queue can be avoided. But in practice this is not so and in most cases arrivals are controlled by external factors.

(b) Services mechanism: The uncertainties involved in the service mechanism are the number of servers, the number of customers getting served at any time and the duration and mode of service.

(c) Queue discipline: All other factors regarding the rules of conduct of the queues can be pooled under this heading. One of these is the rule followed by the server in taking the customers in service, such as "first-come, first-served", "last-come, first-served", and "random selection for services".

The field of queuing theory is most often applied to telecommunication systems, transportation (road, rail and air), maintenance and service systems, inventory and production control. It is possible for a container system to be regarded as a waiting-line problem, with cargo as customers, the empty containers as server and the vessels as counters. However, a queue mainly deals with an uncertainty system. Indeed, the word "Queue" itself means a stochastic process in Queue theory.

In the liner shipping industry, the ship sailing schedule is fixed. Moreover, as will subsequently be shown, analytic convenience obliges us to assume that cargo flow is known in advance, and that the empty container volume is predictable. This indicates that the container system we address is a certain system instead of stochastic process. Therefore, queue theory is an inappropriate technique for analysing the ocean shipping industry[8].

Graph Theory and Network Techniques

In simple terms, a graph represents relations between sets of objects and graph theory is directed towards studying some of the many possible properties of these objects within the representation. Generally, graphs are used to model a variety of problems that deal with the discrete arrangements of objects. Most of the applications of graph theory are on design and analysis of communications networks; analysis of electrical networks; analysis of printed circuits boards;

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[8] Moder, J. E. and S. E. Elmaghraby (1978) Handbook of Operation Research (New York: Van Nostrand Reinhold Company), p352-90

computer flow charts; traffic studies; logistics, etc[9].

Network techniques include program evaluation and review techniques (PERT), critical path methods (CPM), shortest path analysis, and maximal flow analysis. For example, the heart of critical path is a network portrayal of the plan for carrying out a project. Such a network shows the precedence relationships of the elements of the program leading to the program's completion. Elements of the project include three basic factors:

(a) What immediately precedes this element ?

(b) What can be done concurrently ?

(c) What immediately follows this job ?

With these questions answered, we are equipped to draw an arrow diagram of a project. The diagram has two elements:

(a) An arrow or arc represents the activities of the project under consideration.

(b) A node or event represents the intersection of activities.

The node rule for an arrow diagram is that no activity can start from an event until all activities entering this event are complete[10].

For our problem, the sequence of ports forms a network, and most previous works in examining this problem are solved

[9] see Footnote 6, p147-80.

[10] Whitehouse, G.E. and B. L. Wechsler (1976), Applied Operations Research: A Survey, (New York: John Wiley and Sons, Inc.), p223-84

by using network techniques. Hence, we will reexamine this technique later in more detail.

Game Theory

The theory of games was first given a systematic development by Von Neumann and Morgenstern (1944). This original development considered primarily economic applications, mainly because they are easily quantifiable. However applications in other social sciences, especially political science, have been developed to study such things as the mechanisms behind bargaining and negotiation, and coalitional behaviour in political power systems.

The extensive form of an N-person game gives, in logical order, the possible moves in a game. Each move is assigned either to player (personal move) or to chance (random move). At a personal move, the options available to the player and the information given to him are made explicit. At a random move, a probability distribution is specified. Finally, at each terminal position of the game, a pay off or outcome can be expressed by a vector (p1..pn), where pi represents the utility to player i of the given outcome.

Generally, the extensive form is represented by a game tree with a distinguished node (initial position). Each node represents a position of the game, each arc, a move. Information is indicated by the use of information sets: essentially, two positions belong to the same information set if a player must move at each position and if that player cannot distinguish between them. A strategy is a rule which tells a player what to do, i.e., which alternative to choose, at each information set.

It can been seen that game theory is efficient in explaining the outcome of gaming problems, especially negotiating and bargaining. Unfortunately, in our topic, there is no kind of group engaged in gaming. Nobody responds to a shipping operator's decision on container control in the way, for example, that they would respond to a cut in price[11].

Simulation Theory

Simulation is defined as the use of a system model that has the desired characteristics of reality in order to reproduce the essence of actual operations. It has also been defined as a representation of reality through the use of a model or other device which will react in the same manner as reality under a given set of conditions.

Simulation is useful in solving a business problem where the values of relevant variables are not known or are partly known in advance and there is no easy way to find these values. The problem is linked to situations in which information changes sequentially and where no ready-made formula is known for the nth (last) term. The only known fact is a rule (recursion relation) which allows us to find the next term from the previous terms. Basically, the only way to

[11] see Footnote 6, p451-84

discover the nth term is to apply the same rule over and over again until the nth term is reached. Simulation utilizes a method of finding successive states in a problem by repeatedly applying the rules under which the system operates. This successive linkage of one particular state to a previous state is an essential feature of simulation.

Three principal variants of simulation are widely used:

(a) Operational Gaming Method. Operational gaming refers to situations involving a conflict of interest among players or decision makers within the framework of a simulated environment.

(b) The Monte Carlo Method. This is a simulation by sampling techniques, that is, instead of drawing samples from a real population, they are obtained from a theoretical counterpart to it. It involves determining the probability distribution of the variables under consideration and then sampling from this distribution by means of random numbers to obtain data.

(c) System Simulation Method. This is a process in which the analysis of a complex problem is processed through a model which reproduces the operating environment.

System simulation differs from the Monto Carlo approach in several aspects. The principal distinction is that this method generally draws samples from a real population instead of drawing samples from a table of random numbers. No theoretical counterpart of the actual population is used in system simulation.

Forecasting models in econometric theory, such as simultaneous equations systems and time-series models, can be regarded as a specific case of simulation models. They are either system simulations or Monte-Carlo simulations[12].

Unfortunately, unlike some other analytic techniques like mathematical programming, which yield optimal solutions to problems, a simulation approach guarantees nothing more than a usable solution. There may be no way of telling how nearly optimal the solution we get is. However, simulation may be the most attractive, if not the only, way to analyze certain systems. Our task of optimising the number of containers in a transport system clearly has elements that lend themselves to a simulation exercise. As such, simulation will be reexamined in more depth[13].

Optimal Control Theory

The theory of optimal control deals, in general, with systems the behaviour pattern of which may be influenced (controlled) by parameters (controls) that may be chosen subject to certain restrictions. It is the aim of optimal control theory to establish a method for selecting these parameters such that a stated goal is achieved in an optimal

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[12] Thierauf, R. J. (1978), An Introductory Approach to Operations Research, (New York: John Wiley & Sons, Inc.), p317-44

[13] Plane, D. R. and G. A. Kochenberger (1972), Operations Research for Managerial Decisions, (Illinois: Richard D. Irwin, Inc.), p203-04

manner, e.g., with minimum cost, or at a maximum profit.

We consider a simple system, the state $(x_1(t), \ldots, x_n(t))$ at time t of which may be described by a system of n first order differential equations:

$$\mathbf{x}' = f\ (\ t, \mathbf{x}, \mathbf{u}(t)\ )\ \ldots\ldots\ldots\ldots(1)$$

where, $\mathbf{u}(t) = (u_1(t), \ldots, u_m(t))$ is the vector value of the control **u** at time t, and, where f has the components $\phi_1, \ldots, \phi_n$. In general, practical considerations dictate that the values of the controls may not be chosen freely but are restricted to a given subset U of Rm:

$$\mathbf{u}(t)\ \varepsilon\ U \quad \text{for all } t \quad \ldots\ldots\ldots\ldots(2)$$

U is called the control region

The problem is how to choose the controls **u**, subject to the restriction (2) in such a manner that the corresponding solution **x** of equation (1) (trajectory) transfers **x**(t) from a given initial state:

$$\mathbf{x}(0) = \Theta\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

to a given terminal state:

$$\mathbf{x}(t) = \mathbf{x}^T\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

at some, not necessarily specified, time T > 0 such that

$$\int_0^T \phi_0(t,\mathbf{x}(t),\mathbf{u}(t))\,dt\ \ldots\ldots\ldots\ldots(5)$$

assumes the smallest (or largest) possible value. (Note that the special choice of the initial state does not amount to a loss of generality. Equation (3) may always be obtained by a translation of coordinates.)

A control for which (5) assumes the smallest (largest) value is called an optimal control and the corresponding trajectory **x** is called an optimal trajectory.

Optimal control theory deals with a system that is both continuous, and which possesses an immediate feedback mechanism within system, which requires that the control is immediate. Our container control system is not of these properties. Therefore, it cannot be readily handled by optimal control theory[14].

Mathematical Programming Method (MP)

MP is perhaps the most important group of quantitative techniques available for business operations and management decision making. MP refers to a group of mathematical techniques of allocating scarce resources to achieve an objective within the bounds of environmental constraints.

The general problem in MP is to find the values of some variables which will optimize (maximize or minimize) the value of the objective function subject to a set of side constraints, which can be formulated in the following general form:

[14] see Footnote 6, p295-313.

Maximize (or minimize):

$$F = \Sigma_{j=1}^{n} C_j X_j$$

Subject to:

$$\Sigma_{j=1}^{n} a_{ij} X_j \leq b_i \qquad i=1, \ldots, m.$$

$$X_j \geq 0 \qquad j=1, \ldots, n.$$

where,

F: Value of the objective function which measures the effectiveness of the decision.

X_j: Variables that are subject to the control of the decision maker.

Cj: Unit profit contribution of a production or unit cost of an input which is known.

a_{ij}: Production (or technical) coefficients that are known.

b_j: available productive resources in limited supply.

The objective function is a mathematical equation describing a functional relationship between several variables and the outcome of the decisions. The outcome of management decision making is the index of performance, and is generally measured by profits, sales, costs, time, and so on. Thus, the value of the objective function in MP is expressed in monetary, physical, or some other terms, depending on the nature of the decision to be made. The objective of the decision maker is to select the values of the variables so as to optimize the value of the objective function. Frequently, the decision maker is confronted with a sequence of interrelated decisions over time and has to optimize the overall outcome, i.e., the decision-making process is dynamic, rather than static.

The variables whose values are to be chosen are called the decision variables in MP. The production quantity, price, number of days of plant operations, units of a product shipped to different markets are only a few of the many examples of decision variables. Also, they may be discrete or continuous, depending on the problem being analyzed,

All the above shows that MP looks like a fine method for our specific objective. However, MP is a general concept, which includes several different programming techniques, such as: LP (Linear Programming); IP (Integer Programming); DP (Dynamic Programming); 0-1P (Zero-One Programming); and SP (Stochastic Programming), etc. We will analyze these method separately to see how they may be used to solve our problem.

Inventory Model

Inventory models relate to systems that seek to stock physical goods in order to satisfy a demand for these items over a specified time period. The basic problems to be solved are when and how much to order. The optimum inventory decision is the one which minimizes simultaneously the following costs:

(a) Order cost: the fixed cost of starting up a production run or of placing an order for items from an outside vender. This cost is usually assumed to be independent of the number of units ordered or produced. Hence order cost per unit is a monotonic decreasing function of units ordered.

(b) Handling cost: the cost of carrying items in storage. The major components of this cost includes the cost of capital invested in the items, storage costs, insurance costs, depreciation costs, and the like. It is assumed that handling costs vary directly with the level of inventory and the length of time the item is held in stock.

(c) Purchase or production cost: the cost per unit of buying or making a unit of product. The purchase price will become important when 'quantity discount' or 'price breaks' can be secured for purchases above a certain quantity or when economies of scale suggest that per unit production cost can be reduced by a larger production run.

(d) Shortage costs: the penalty costs for running out of stock when there is a demand for an item. This cost includes the losses of potential profit and the loss of good will[15].

Intuitively, container control is an inventory management problem, in that it refers to both a stock of physical goods--

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[15] Whitehouse, G. E. and B. L. Wechsler (1976) Applied Operations Research: A Survey (New York: John wiley & Sons, Inc.), p285-328

namely containers--needed to satisfy a demand for them over some specified time period, and also the problem of the optimal management of these physical goods (containers). These common features drive us to do some further review on the inventory model as a mathematic tool for our problem.

Reexamination of Mathematical Methods

Available for the Problem.

After a survey of mathematical methods used in the economic and business fields, we have tentatively selected four mathematical methods--simulation method, network theory, inventory method and mathematical programming techniques which seem to be relevant to our specific problem. We will now test them further to assess their suitability to our specific problem of container control.

Unique Features of liner Shipping Industry

Our task is to develop operational procedures for optimal container control in the liner shipping industry. This specific goal requires that our research should reflect the unique features of this industry. Of principal importance in this respect are:

(1) The alternative between holding and reallocating empty containers describes the possible movement of containers within a closed system. Such a system sustains an initial container stock. If there is no mechanism for exchanges between this system and the outside, the total number of containers remains unchanged. Container leasing provides a

new way to control containers, i.e., under some space-time and cost limitations, leasing on or off, when surplus or insufficiency arises, changes the container stock. The container leasing operation acts as a bridge between the inside and the outside of the system. It is shown later that the leasing on-off of containers is really the only practical way to integrate container sizing and allocating decisions.

(2) The container self-production[16], brought about by devanning of full containers into empty, adds to our research's difficulty. Not all containers unloaded earlier in a port are reusable. Some of them might not be devanned. Therefore, we should firstly analyze the self-production process and identify whether any repositioning in/out of empty containers is necessary for subsequent outbound shipment when surplus or insufficiency of empty containers may happen.

Criterion for Selection

The criteria for the selection of an appropriate mathematical approach should reflect the specific characteristics of the container system. Our principal goal is to identify firstly the imbalance within a container system, and then, to give the operative path to get the optimal solution, under a certain service pattern. Hence, the

[16] Rail and motor carrier transportation systems have the feature of self-production as well. However, we regard self-production as a unique feature of the container shipping industry in the sense that unlike train and motor carriers, the container itself is not mobile, its movement depends on a carrier (truck or train). This, consequently, makes the self-production of containers much more complicated than those of rail and motor carriers.

first criterion is that the method should be of either analysing or optimizing ability, and also that this kind of analysis or optimisation be applicable to our specific environment. The pattern of container movements is both discrete in that it depends mainly on vessels' frequency, and dynamic, since we are interested in optimising container movements over time. Therefore, the second criterion is that the mathematical method should be capable of dealing with discrete and dynamic systems instead of merely continuous and static systems.

The purpose of this study is to develop a practically operational method for container control. While too complex a method may be theoretically excellent it may lack practicality which is not what we need. Based on this consideration, we define our container system as certain[17], which means the all inputs of this system are known in the time that the decision is made.

Reexamination of Potential Mathematical Techniques

Inventory models can deal with discrete or continuous, static or dynamic and certain or uncertain systems. They can also do both analysis and optimisation. The essential nature of an inventory model, however, is to minimize the total cost,

[17] The "certain-deterministic" hypothesis is a very strong one. Although stochastic approaches have played an important role in the modelling other transportation modes, in view of the data requirement and the running environment of the model, a deterministic approach may be more suitable for container control, given current management practices of liner shipping industry.

which is a trade-off between order (purchase) cost and holding cost. The more units are ordered or purchased per period of time, the less are the order or purchase cost per unit, but the more are holding costs, and vice versa.

For example, suppose we have an inventory system with only two kinds of costs, order cost and holding cost. Now let W be the total units needed in the period, k be the order cost per time, r the holding costs per unit, K the number of orders, and m the average holding time.

$$\text{Total Cost} = Wk/2m + mr$$
$$= Kk+Wr/2K$$

In the container system, the concept of order can be understood as the leasing, purchasing and positioning of containers. Obviously, the cost of order is connected directly with the number of units of containers ordered, which does not satisfy the basic condition of general inventory model. Also there is no trade-off between a container's order costs and holding costs (storage and insurance and normal tear and wear). All the container costs are related linearly to the number of containers. Therefore, an inventory model is unlikely to be appropriate for our purpose.

Networks and network analysis are playing an increasingly important role in the description of operational systems. Network flow is also applied into transportation problems.

Consider a directed network G, consisting of a finite set of nodes, N = {1,2,...,m)and a set of direct arcs, S = {(i,j),(k,l),...,(s,t)} jointing pairs of nodes in N. Arc (i,j) is said to be incident with nodes i and j and is directed from node i to node j. We assume that the network has m nodes and n arcs. The minimal cost network flow problem is stated as follows. Ship the available supply through the network to satisfy demand at minimal cost. Mathematically, this problem becomes:

Minimize: $\Sigma_{i=1}{}^{m}\Sigma_{j=1}{}^{m}C_{ij}X_{ij}$

Subject to: $\Sigma_{j=1}{}^{m}X_{ij}-\Sigma_{k=1}{}^{m}X_{ki} = b_i \qquad i=1,2,...,m$

$X_{ij} \geq 0 \qquad i,j=1,2,...,m$

$\Sigma_{j=1}{}^{m}X_{ij}$ represents the total flow out of node i while $\Sigma_{k=1}{}^{m}X_{ki}$ indicates the total flow into node i. These equations require that the net flow out of node i, $\Sigma_{j=1}{}^{m}X_{ij}-\Sigma_{k=1}{}^{m}X_{ki}$, should equal b_i.

The minimal cost flow problem is a linear program and can be solved by either ordinary primal simplex algorithm or out-of-kilter algorithm[18].

Clearly, network flow technique is a combination of network and linear programming methods. It has optimizing

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[18] Bazaraan, M. S. and J. J. Jarvis (1977) Linear Programming and Networks (New York: John Viley & Sons, Inc.), p404-73

ability, is capable of dealing with a discrete system, and is practically operational in the sense that it is easy to find commercialized software package to solve LP problems.

However, this method does not consider the moving behaviour within an individual node (in our problem, a port is a node). This kind of behaviour, including container self production and leasing on-off are critical features of our problem. Another weakness of the method is that it is not dynamic in the sense that it deals only with one period instead of a successive time sequence.

The minimal cost flow may be improved if we could modify the constant--add up an item, y_i to stand for the container leasing on-off and container self-production, add up a time dimension, t, to stand for a successive time period.

Then, the modified model becomes:

$$\text{Min: } \Sigma_{t=1}{}^{T}\Sigma_{i=1}{}^{m}\Sigma_{j=1}{}^{m}C_{ijt}X_{ijt}$$

$$\text{St: } \Sigma_{j=1}{}^{m}X_{ijt} - \Sigma_{k=1}{}^{m}X_{kit} + Y_{it} = b_{it}$$

$$i=i, \ldots, m. \quad t \in [1, T]$$

The purpose of analysing container self-production is to predict the imbalance of containers needed. Although the imbalance is unknown at beginning, as long as we analyze clearly the mechanism of container self production, we can get the imbalance. This falls into the scope of the simulation theory. System simulation can be used to find the mechanism behind the container self production, and to discover a rule (recursive relation) to allow us to obtain the next term from the previous terms.

Conclusions

After reviewing the previous work on the subject, we can now narrow the list of appropriate mathematical tools. Queue theory, graph theory and network techniques, game theory, optimal control theory, and inventory model all possess inherent characteristics that render them inappropriate for our specific purpose: accordingly they can be dropped from consideration. By a process of elimination, then, and because of its compatibility with our problem, a minimal cost flow model, combining network techniques and integer programming, is chosen as our basic optimizing tool. However, the specification and development of such a model based on this approach will necessarily have to be adapted so as to accommodate the self production of containers. System simulation is expected to provide a suitable method for this.

CHAPTER 4

CONSTRUCTION OF THE MODEL

Introduction

Based on our preceding discussions, we can now start the construction of an optimal (cost minimizing) model. The overview of the container shipping industry in Chapter 2 enables us to describe the business conditions that are relevant to the topic, and chapter 3 provides us powerful mathematical tools to realize the goal.

A two stage approach is employed in this chapter to develop the model. In the first stage, system simulation is used to analyze the process of container self production. In this way, a table showing imbalances of container demand and supply is obtained for each port in the service. The second stage constructs a integer programming model, which is a modified formulation of a minimal cost flow model, which shows how these imbalances may be corrected most efficiently.

Additionally, the model will also endeavour to integrate optimally, both the container sizing decisions and the operating decisions of the firm in an optional manner.

Description of the Problem

As depicted in Figure 2.1 in Chapter 2, the port plays a central role in the movements of containers. It is the hub of intermodal transport, and connects several key variables describing the liner shipping system, such as cargo loading/unloading, the sailing schedule, and empty container returning speed. Practically speaking, the shipping company controls the containers just from the point of view of individual ports as is shown below. Therefore, we will put ourselves in the place of each individual port. The set of containers in all individual ports constitutes a complete description of container movements in the whole network of the shipping company.

The CY (container yard) and CFS (container freight station) within the port, and the inland depot and warehouse outside the port, comprise a sub-system of the whole shipping network. However, what we are concerned with in this sub-system is only the returning speed of full containers into empty. The devanning time, a term describing the average returning speed of full containers in a port, proves to be important in the development of our model. There is no need for us to discuss in detail the relationship among inland depot, inland warehouse and port, as this does not directly relate to our purpose.

On the basis of the foregoing discussion, we will establish a stylised liner shipping service consisting of a sailing network that includes a typical feeder and transshipment main network calling at N different ports and permitting M different sailing routes. Given the cargo flow, sailing schedule, full container devanning time in each port, our goal is to estimate, at a given time period in the future, say, t--t+T, how many containers should be stocked in each port in any given time point; how many containers should be employed in total during this time period, and how the operator should manipulate them to reach least costs or maximum profits.

Feeder and transshipment main networks are general to most service network patterns used today. In this kind of network, different ports have different calling schedules. Some ports are called at much more frequently than others.

Figure 4.1 is a typical feeder and transshipment network. In this case, M=3, N=2

G--H--A--F: a feeder route

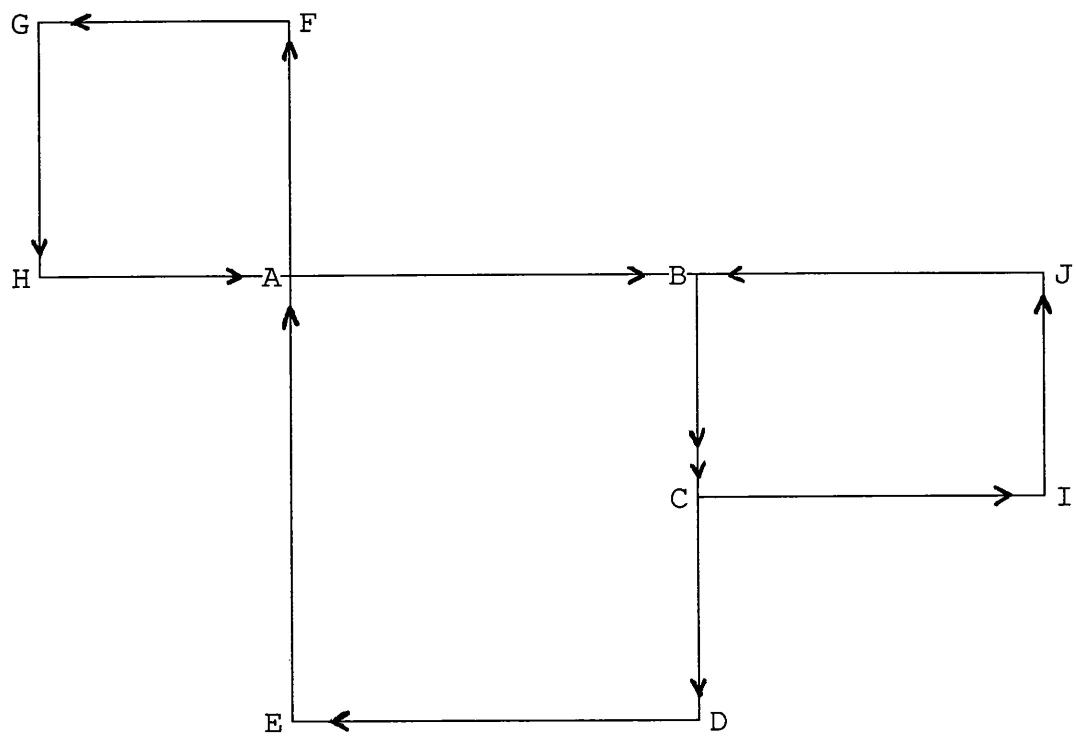
A--B--C--D--E: main route

B--C--I--J: main route

The two main routes have two transshipment points: B and C. For port H, there is only one route, H-A-F-G, passing it. For port A, two routes, A-F-G-H, and A-B-C-D-E, pass it.

Figure 4.1

A Typical Feeder and Transshipment Network



We regard current time as zero point, t is forecast starting time , T is the forecasting time span. Both t and T are absolute calendar days from current time. Thus if t is 15, and T is 90, then the time period of forecasting is from the 15th day to the 105th day from the base of today.

Unlike in some other modes of transport, a containership sailing schedule is deterministic rather than uncertain. A fixed sailing route, and fixed calling time, are basic features of any liner shipping service.

In order to facilitate the preceding discussion, we have to make some assumptions:

(1) We assume that cargo flow, i.e., in/out bound cargo demand in each port in the whole forecast period, t--t+T, is known in the point t. The rationale behind the assumption is that:

(a) It is impossible to predict exactly the cargo demand in today's competitive shipping market. The cost of using a stochastic approach is so high in terms of time and data requirements that it is prohibitive from a practical point of view. Thus, for simplicity, we assume a certain demand.

(b) Our approach is operational. The solution of the model can be re-adjusted continuously according to the feedback of conditions in the cargo market, as well as the ship sailing schedule. Therefore, it is reasonable to assume that an operator can obtain relatively trustworthy cargo forecasting data from such feedback.

(2) We also assume that the penalty for not satisfying cargo demand is too high to be allowed to happen. This is reasonable in the context of today's highly competitive liner markets.

(3) We also assume that full containers are emptied at a constant rate in all ports.

(4) For simplicity we treat all containers as 20' dry standard containers. In practice all other sizes and types of

containers can be handled in the same way as is done here.

The goal of our research is to minimize the cost of capital investment and the operating costs associated with containers as a whole. The means we can adopt to manipulate containers in pursuit of this goal are:

(1) Keep empty containers in a port for some future arrangement.

(2) Position empty containers to other ports under the limitations of vessel space.

(3) Lease on-off some containers within the limitations of leasing market in that port.

Here, the primary purpose of keeping some empty containers in a port is for the subsequent cargo usage. Also, they may be used for future positioning to other ports for eventual cargo demand there, considering any differences among storage fees and vessel space in ports and voyages. By the same token, positioning empty containers to other ports may be necessary for those ports' immediate cargo demand.

First Stage: Identifying Container Imbalances

We adopt a two-stage research strategy. In the first stage, we analyze the self-production behaviour of containers and then calculate any imbalance in the supply and demand for containers at each port on the network. Stage two develops a linear programming model to reach optimal container control, i.e., to minimize any such imbalances.

Variables Definition:

----F(i): The containership sailing schedule of calling at port i. F(i) is a sequential set.

F(i)= { f(i,m,k,j) }

m is the mth route for port i in the network , k is the kth voyage in route m, j is the jth voyage of (m,k) in the whole [t,t+T] period. For example, if f(1,2,3,5)=40, this means that we are considering the third call of route 2 for port 1 in 40th day, which is the 5th call in all the calls for port 1 in whole [t,t+T].

We define :

(1) jj(i)=max (j(i)), the last call for port i in [t,t+T], obviously, j<=0, means the call occurs before t, and f(i,m,k,j) <= t

(2) in f(i,m,k,j), (m,k) and j has strict one-one relationship in a certain port, so, we define function E, E(j(i))=(m,k)(i), Also, f(i,m,k,j) can sometimes be expressed as f(i,j).

(3) for any route h and i within a route, if it is possible to travel from h to i within same (m,k), we define R(i,h)>0, else, R(i,h)<0

----D(i): The average devanning time (days) of full containers in port i. This describes the changing of full containers to empty, and depends on the liner operator's container control level, the distribution of the inbound cargo's consignees, inland traffic and local legislation. Therefore, the devanning speed is rather different among containers. Some containers are returned in one or two days (inbound cargo is "CFS term"[1]). Some might take two or three months (remote inland cargo). In practice <u>average</u> devanning times are unlikely to vary significantly over time. The actual average devanning time, D(i), under our preceding assumption, is constant in any period of time. Container operators can figure it out by experience.

----I(i,j): the amount of inbound full containers in the jth voyage in port i.

----O(i,j): the amount of outbound full containers in the jth voyage in port i.

----B(i,j): the amount of naturally devanned containers between the (j-1)th and the jth voyage in port i.

---

[1] "CFS" is a abbreviation of "container freight station", which is an ocean shipping term. Inbound cargo with "CFS term" will be unpacked in container freight station of the discharge port.

----C(i,j): the amount of extra empty containers needed for the jth voyage after the use of naturally devanned containers available in port i. It describes the imbalance status of container demand and supply. If C(i,j) is negative, it means that there exists spare containers over and above those used on the jth voyage.

----K(i,j): the amount of full containers in the time point of the jth voyage in port i.

Suppose average devanning time in port i is D(i) days. For the all full containers carried into port i by the jth voyage, it takes G(i) days to make them return completely.

The probability of the returning of a specific container in a specific day is 1/G(i).

The expectation of D(i) is:

$$\text{Expectation } (D(i)) = D(i) =$$

$$(1+2+...+G(i))/G(i)=G(i)(G(i)+1)/(G(i)*2)$$

Therefore,

$$G(i)=2D(i)-1$$

We are going to find s(i,j) which is the smallest voyage where there are still some non-returned full containers during the (j-1)th and the jth voyage.

s(i,j) can be obtained:

$$f(i,j-1)-f(i,s(i,j)) < G(i) <= f(i,j-1)-f(i,s(i,j)-1)$$

For any p<s(i,j), in the time period of the (j-1)th and the jth voyage, all the full containers unloaded in the pth voyage have been totally emptied.

The volume of empty containers naturally devanned during the period the (j-1)th and the jth voyage will be:

$$B(i,j) = \Sigma_{p=s(i,j)}^{j-1} I(i,p) * \mathrm{Min}(f(i,j)-f(i,j-1), G(i)-f(i,j-1)+f(i,p))/G(i)$$

B(i,j) describes the self-productivity of port i due to the natural devanning of full containers. C(i,j), the empty containers needed (or left) for the jth voyage besides self-production, equals the difference between O(i,j) and B(i,j):

$$C(i,j)=O(i,j)-B(i,j) \quad i=1,\ldots, N. \quad j=1,\ldots,jj(i).$$

By the same token, we can obtain t(i,j) which is the smallest voyage where there are still some non-returned full containers in the time point of the jth voyage in port i:

$$f(i,j)-f(i,t(i,j)) < G(i) <= f(i,j)-f(i,t(i,j)-1)$$

K(i,j) shows the accumulated amount of full containers in the time point of the jth voyage in port i:

$$K(i,j) = \Sigma_{p=t(i,j)}^{j-1} I(i,p) * [1-(f(i,j)-f(i,t(i,j)))/G(i)]$$

Consequently, we get a table showing the imbalance between demand and supply of containers for all N ports over the whole forecasting period. The range of j in different ports varies according to the amount of voyages performed during the forecasting period, e.g. for port 1, j=1,2,3, there are only C(1,1), C(1,2) and C(1,3), for port 3, j=1,2,..., 10, C(3,1), C(3,2),..., C(3,10). This depends on calling frequency for that port.

Second Stage: Correcting the Imbalance

Now, our problem is how to correct the imbalance identified in the first stage.

Variables definition:

----X(i,j): the amount of empty containers kept in port i after the jth voyage.

----YI(i,h,j): the amount of empty containers positioned from port h to i arriving in the jth voyage.

----YO(i,h,j): the amount of empty containers positioned from i to h leaving in the jth voyage.

Here, $h(i,j)\varepsilon H$:

$H=\{h: \text{exists common } m,k,\ E(i,j(i))=(m,k)=E(h,j(h))\}$

----LYI(i,h,j): the vessel space limitation for the repositioning of empty containers from port h to i arriving in the jth voyage.

----LYO(i,h,j): the vessel space limitation for the repositioning of empty containers from port i to h leaving in the jth voyage.

----ZI(i,j): the amount of containers leased on during the jth and the (j+1)th voyage in port i.

----ZO(i,j): the amount of containers leased off during the jth and the (j+1)th voyage in port i.

Here, we assume that the behaviours of leasing on and leasing off cannot happen simultaneously, which means that ZI and ZO are not allowed to be non-zero at the same time.

----LZIO(i,j): the limitation of containers available for leasing on-off during the jth and the (j+1)th voyage in port i.

----x(i): the storage fee per day per container in port i.

----y(i,h): half of the cost of positioning one empty container between port h and i. As we count twice the costs of positioning empty between i and h in our proceeding model, we adopt, here, "half" of the position fee rate for simplicity and convenience of calculation.

----z(i): delivery cost for leasing on-off containers in port i.

----r(i): rent per container per day in port i.

The integer programming model is:

Minimize:

$$C=\Sigma_{i=1}^{N}\Sigma_{j=1}^{jj-1}(X(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$
$$\Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+$$
$$(ZI(i,j)+ZO(i,j))*z(i)+$$
$$(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-f(i,j))*r(i))$$

Subject to:

(1)

$$\Sigma_{h\varepsilon H}(YI(i,h,j)-YO(i,h,j))+ZI(i,j)-ZO(I,j)+$$
$$X(i,j)-C(i,j+1)=X(i,j+1)$$

i=1,2,...N. j=0,1,...jj-1.

(2)

$$YI(i,h,j(i))=YO(h,i,j(h))$$

i=1,2,...N. j=1,2,...jj-1. hεH

(3)

$$YI(i,h,j)\leq LYI(i,h,j)$$

i=1,2,...N. j=1,2.,..jj-1. hεH.

(4)

$YO(i,h,j) \leq LYO(i,h,j)$

$i=1,2,...N. \quad j=1,2,...jj-1. \quad h \varepsilon H.$

(5)

$ZI(i,j)+ZO(i,j) \leq LZIO(i,j)$

$i=2,3,...N. \quad j=2,3,...jj-1$

(6)

X, YI, YO, ZI, ZO are non-negative integers

----X(i,j), Yi(i,h,j), YO(i,h,j), ZI(i,j), ZO(i,j) are objective variables.

$i=1,2,...N. \quad j=1,2,...jj-1. \quad h \varepsilon H$

----X(i,j)*(f(i,j+1)-f(i,j))*x(i) is the storage charges happening between the jth and the (j+1)th voyage in port i.

----(YI(i,h,j)+YO(i,h,j)*y(i,h) is the cost of positioning empty containers between port i and h in the jth voyage.

----(ZI(i,j)+ZO(i,j))*z(i) is the delivery cost leasing on and off containers during the jth and the (j+1)th voyage in port i.

All these three items express the operating costs.

----(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-f(i,j))*r(i) is cost of owning containers during the jth and the (j+1)th voyage in port i. We treat them the same as the prevailing price in the rental market in port i in that time. This however is a capital cost.

----Constraint (1) expresses the core idea of the model that the container system cannot reach an optimal level unless there is some interchange with the outside. X(i,j+1), the amount of empty containers available after the (j+1)th voyage, equals the amount of containers available after the jth voyage, X(i,j), plus (minus) newly leased on (off) containers ZI(i,j) (ZO(i,j)), plus (minus) positioned in (out) containers in the jth voyage, $\Sigma_{h\varepsilon H}$(YI(i,h,j)-YO(i,h,j)), minus the imbalance, C(i,j+1).

We assume that:

(1) If J≤0 or j≥jj(i)

YI(i,h,j)=0, YO(i,h,j)=0

ZI(i,j)=0, ZO(i,j)=0

(2) The operator has a expectation of the amount of empty containers after the final forecasting voyage, therefore, X(i,jj(i)) are given by the operator in advance.

(3) In practice, there always exists a port where the operator can lease on-off whatever amount of containers it wants, such as in one of largest ports in the world. We assume that is port 1. Also, we assume that in the first voyage of the forecasting period, there are no leasing limitations in any port, which ensures the existence of an optimal solution of the model.

(4) X(i,0) are given. I=1,2..N.

This constraint, combined with constraint (6), also indicates our assumption that the empty containers available should always be more than outbound cargo requirement.

----Constraint (2) shows that the amount of positioned empty containers from h to i arriving in j(i) equals the amount of positioned empty containers from h to i leaving in j(h) voyage.

j(h) can be obtained:

for E(j(i))=(m,k)
    if R(i,h)<0,
        then, E(j(h))=(m,k-1)
        else, E(j(h))=(m,k)

----Constraints (3), (4) and (5), show the vessel space and rental market limitations respectively.

The solution of X, Y, Z gives an optimal trajectory of day to day container control in all N ports over the whole forecasting period [t,t+T]. The operator can summarize the optimal trajectory of day to day operations in all N ports he serves to form a container fleet sizing decision over the whole forecasting period [t,t+T]. In any time within the forecasting period, the optimal container stock is the summation of the full containers in that time in all ports (ΣK), the total full and empty containers in all vessels in that time (ΣO and $\Sigma(YI+YO)$), the empty containers available in that time in all ports (ΣX), and leased on and off new containers in that time in all ports ($\Sigma(ZI-ZO)$).

In this way, the operator can get a complete idea of the optimal container fleet sizing decision over the whole forecasting period, which is based on day to day optimal operating decisions. This realizes the integration of optimal container sizing decisions with routine operating decisions.

Conclusion

This chapter developed a two-stage mathematical model to describe the movement behaviour of containers in a liner shipping company. It allows the operator to minimize the container costs from the point of view of both container stock decisions and the day to day operating decisions. The model employs those techniques which Chapter 3 showed are likely to be most appropriate to the case of liner shipping, namely system simulation and IP. Our next task is to see if it works. This is the object of Chapter 5.

CHAPTER 5

EVALUATION OF THE MODEL'S PRACTICAL PERFORMANCE

Introduction

The model developed in the preceding chapter will now be tested. It is necessary to incorporate some hypothetical data to illustrate the model's application and to evaluate its practical performance. To this end, we employ three cases incorporating different sets of hypothetical data to test different features of the model.

Case 1 is a extreme situation where there is neither container leasing on-off, nor empty repositioning. The purpose of such an extreme case is to test for the absolute existence of a feasible solution. Case 2 describes a reasonable operating situation where there are a certain number of containers available for leasing on-off and where certain vessel space is available for repositioning empty containers. This case seeks to evaluate whether the model makes sense in reasonable operating environments. Notice that it is to be expected that the total operating costs in case 2 should be lower than those of case 1, for the more choices available, the potential for lesser costs should prevail. Case 3 and case 2 differ only with respect to having different rates of operating fees, such as empty container storage fees, leasing container delivery fees, container rent fees, etc.

This is to show the effects of such operating fees on the costs minimizing control path. All the solutions are done on a PC-286 computer.

Hypothetical Data: Three Cases

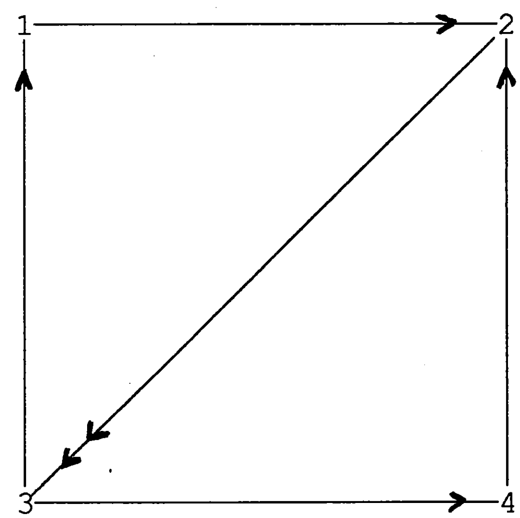
In the sailing network shown in Figure 5.1, we suppose N=4, M=2

Figure 5.1

Sailing Network

Route 1: 1--2--3

Route 2: 2--3--4



There are transshipments in port 2 and 3.

We want to know the costs minimizing control path in the forecasting period: from the 15th day of current time to the 45th day, i.e., t=15, T=30, i.e., solve all X, YI, YO, ZI, ZO. This is the basic problem in each of our three cases.

For each case we assume the same cargo flow, I(i,j), O(i,j), and container devanning speed D(i). We assign case 1 as an extreme situation where the vessel space and container leasing market are in such a short supply that there is no spare space for positioning empty containers on any vessel, and no new containers are available for leasing during the whole period. In other words, all LYI, LYO, LZIO are zero. We also assume the volume of empty containers stored in all ports after final voyage jj, X(i,jj) is unknown, in order to test for the absolute existence of an feasible solution.

Container leasing and repositioning are allowed in cases 2 and 3. Moreover, both cases utilise exactly the same operational conditions, such as conditions for leasing on-off containers, repositioning empty containers, etc. However the various operational fee rates, such as empty container positioning fees, storage fees, delivery fees of newly leased on-off containers, and container rent are set differently, in order to show the effects of different fees on least cost container control paths.

Table 5.1 is the ship sailing schedule, f(i,m,k,j), and cargo flow forecast data, I(i,j) and O(i,j), for all of these three cases. The schedule and cargo data before time t are listed here to calculate the amount of naturally devanned containers B(i,j).

Table 5.1

Sailing Schedule f(i,m,k,j) and Cargo Flow Data I(i,j), O(i,j) for All Three Cases

f(i,m,k,j)	I(i,j)	O(i,j)
-29(1,1,-2,-2)	90	90
-14(1,1,1,-1)	20	90
1(1,1,0,0)	70	20
16(1,1,1,1)	50	30
31(1,1,2,2)	80	40
45(1,1,3,3)	70	50
-22(2,1,-2,-4)	80	70
-11(2,2,-1,-3)	180	60
-9(2,1,-2,-4)	70	70
2(2,2,0,-1)	257	200
6(2,1,0,0)	60	40
15(2,2,1,1)	50	240
21(2,1,1,2)	130	140
28(2,2,2,3)	60	40
36(2,1,2,4)	80	80
42(2,2,3,5)	100	80
-8(3,2,-1,-3)	250	170
-5(3,1,-1,-2)	40	40
6(3,2,0,-1)	30	20
11(3,1,0,0)	150	170
19(3,2,1,1)	80	70
26(3,1,1,2)	180	190
33(3,2,2,3)	20	100
41(3,1,2,4)	60	140
-32(4,2,-3,-3)	60	50
-18(4,2,-2,-3)	70	40
-4(4,2,-1,-1)	30	30
10(4,2,0,0)	80	90
24(4,2,1,1)	10	60
38(4,2,2,2)	40	40

Table 5.2 shows the fee rates for storage, x(i), delivery, z(i), and rent, r(i), for the three cases. These data are known in advance for the whole forecast period.

Table 5.2

<u>Fee Rates for Storage, Delivery and Rent x(i), z(i), r(i)</u>

Poti	Store fee x(i)			Deliv. Fee z(i)			Rent fee r(i)		
	CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3
1	2.4	2.4	.6	100	100	50	3.8	3.8	1.9
2	4.4	4.4	1.1	140	140	70	3.2	3.2	1.6
3	4.	4.	1.	130	130	65	3.5	3.5	1.7
4	3.4	3.4	.85	130	130	65	4.	4.	2.

*: In the present and following tables of this chapter, either "CA", or "C", means "case".

Table 5.3 gives the half of the fee rate of positioning empty containers between i and h, y(i,h).

Table 5.3

Half of the Fee Rates of Repositioning y(i,h)

i	Port 1			Port 2			Port 3			Port 4		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
1				25	25	200	30	30	240			
2	25	25	200				32	32	250	28	28	230
3	30	30	240	32	32	250				26	26	210
4				28	28	230	26	26	210			

Table 5.4 and 5.5 list the limitations of vessel space for positioning empty containers from h to i arriving in the jth voyage, LYI(i,h,j), and from i to h leaving in the jth voyage, LYO(i,h,j).

Table 5.4

The Limitation of Vessel Space LYI(i,h,j)

P i	V j	h=1			h=2			h=3			h=4		
		C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
1	1				0	20	20	0	10	10			
1	2				0	30	30	0	44	44			
2	1							0	19	19	0	4	4
2	2	0	22	22				0	30	30			
2	3							0	9	9	0	22	22
2	4	0	38	38				0	3	3			
3	1				0	16	16				0	5	5
3	2	0	33	33	0	10	10						
3	3				0	42	42				0	5	5
4	1				0	5	5	0	10	10			

Table 5.5

The limitation of Vessel Space LYO(i,h,j)

P i	V j	h=1 C1	h=1 C2	h=1 C3	h=2 C1	h=2 C2	h=2 C3	h=3 C1	h=3 C2	h=3 C3	h=4 C1	h=4 C2	h=4 C3
1	1				0	9	9	0	26	26			
1	2				0	5	5	0	40	40			
2	1							0	5	5	0	14	14
2	2	0	39	39				0	11	11			
2	3							0	11	11	0	22	22
2	4	0	10	10				0	10	10			
3	1				0	30	30				0	39	39
3	2	0	22	22	0	5	5						
3	3				0	10	10				0	19	19
4	1				0	22	22	0	15	15			

Table 5.6 gives the limitation of leasing containers on-off, LZIO(i,j), the values of initial stored empty containers, X(i,0) and final empty container storage, X(i,jj)

Table 5.6

The Limitation of Leasing Containers LZIO(i,j) and Empty Container Stock X(i,0), X(i,jj)

i	j	LZIO(i,j)			X(i,0)			X(i,jj)		
		CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3
1	0				2	2	2			
1	1									
1	2									
1	3								20	20
2	0				70	70	70			
2	1									
2	2	0	20	20						
2	3	0	30	30						
2	4	0	15	15						
2	5								19	19
3	0				0	0	0			
3	1									
3	2	0	30	30						
3	3	0								
3	4								40	40
4	0				8	8	8			
4	1									
4	2								15	15

Through these given data, we can firstly calculate the imbalance table of container demand and supply, C(i,j). The results are shown in Table 5.7. As all the three cases have identical cargo flows and container devanning speeds, they have the same imbalance tables.

Table 5.7

Imbalances Table C(i,j), for All Three Cases

Port i	Voyage j	B(i,j)	K(i,j)	C(i,j)
1	1	47	32	-17
1	2	58	23	-18
1	3	63	62	-13
2	1	188	149	69
2	2	91	103	49
2	3	114	115	-74
2	4	86	89	-6
2	5	74	94	6
3	1	82	117	-12
3	2	94	83	96
3	3	127	135	-27
3	4	105	50	35
4	1	55	27	5
4	2	46	4	-6

The model in the second stage can be run by using a integer programming software package[1]. The final result, the values of control variables, are given in Table 5.8 for each of the three different cases.

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[1] Schrage, L. (1991) User's Manual for Linear, Integer, and Quadratic Programming with LINDO, (CA: Scientific Press), Release 5.0

Table 5.8

The Solutions of the Model

X, YI, YO, ZI, ZO

VARIABLES	CASE 1	CASE 2	CASE 3
X11	19	19	19
YI121	0	0	0
YO121	0	0	0
YI131	0	0	0
YO131	0	26	0
ZI11	0	0	0
ZO11	30	11	30
X12	7	0	7
YI122	0	30	0
YO122	0	0	0
YI132	0	23	0
YO132	0	0	0
ZI12	0	0	0
ZO12	0	0	0
X21	1	1	1
YI231	0	0	0
YO231	0	0	0
YI241	0	0	0
YO241	0	0	0
ZI21	48	48	48
ZO21	0	0	0
X22	0	0	0
YI212	0	0	0
YO212	0	30	0
YI232	0	0	0
YO232	0	10	0
ZI22	0	0	0
ZO22	0	0	20
X23	74	34	54
YI233	0	0	0
YO233	0	11	0
YI243	0	0	0
YO243	0	4	0
ZI23	0	0	0
ZO23	0	0	30
X24	80	25	30

VARIABLES	CASE 1	CASE 2	CASE 3
YI214	0	0	0
YO214	0	0	0
YI234	0	0	0
YO234	0	0	0
ZI24	0	0	0
ZO24	0	0	5
X31	12	12	12
YI321	0	0	0
YO321	0	0	0
YI341	0	0	0
YO341	0	0	0
ZI31	92	84	84
ZO31	0	0	0
X32	8	0	0
YI312	0	26	0
YO312	0	0	0
YI322	0	10	0
YO322	0	0	0
ZI32	0	0	18
ZO32	0	0	0
X33	35	63	45
YI323	0	11	0
YO323	0	0	0
YI343	0	0	0
YO343	0	0	0
ZI33	0	1	30
ZO33	0	0	0
X41	3	3	3
YI421	0	0	0
YO421	0	0	0
YI431	0	0	0
YO431	0	0	0
ZI41	0	6	6
ZO41	0	0	0
X25	74	(19)*	(19)
X34	0	(40)	(40)
X42	9	(15)	(15)
Optimal Objective Value	36976.6	36585.2	22114.8

*: X25, X34, and X42 in case 2 and 3 are given before solving the model.

Case (1) is an extreme case in which all the values of right hand side of inequality constraints, LYI, LYO, LZIO are zero, and the value of X(i,jj) are unknown instead of given. The existence of a feasible solution in such a tight constraint condition shows that this model will yield optimal solutions under reasonable service patterns. The only special situation of no feasible solution happens when X(i,jj) are given specific values. This, however, can be resolved by assigning larger value to X(i,j).

The solution of case 2 describes the normal type of circumstances that shipping operators encounter in their business.

If shipping operators have more choices in controlling containers, i.e., if they can control these containers by means of leasing on-off and repositioning, as in case 2, the total operating costs would be lower than that of less choices, as in case 1.

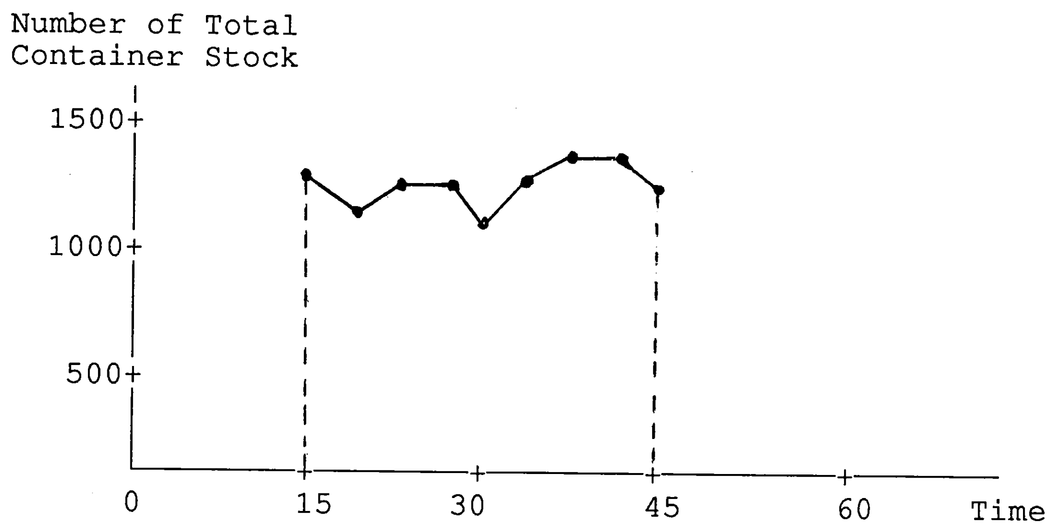
Comparing Case (2) and (3), we can see that there are different optimal paths, i.e., X, YI, YO, ZI, ZO, corresponding to different operational conditions, i.e., x(i), y(i), z(i), and r(i). The lower the positioning cost for empty containers, the greater will be the number of reallocations of empty containers instead of leasing on-off in local rent markets, and vice versa.

As was pointed in Chapter 4, any container operator can summarize the optimal path of day to day operations in the individual ports he serves to form a container fleet sizing decision over the whole forecasting period. A simple and efficient way of generalizing the optimal path of day to day operations into an optimal sizing decision is by using a coordinate diagram. The vertical axis may stand, for example, for the total container stock, while the horizontal axis can express the forecasting time period. In any time within the forecasting period, the total container stock is the summation of the full containers in that time in all ports (ΣK), the total full and empty containers in all vessels in that time (ΣO and Σ(YI+YO)), the empty containers available in that time in all ports (ΣX), and leased on and off new containers in that time in all ports (Σ(ZI-ZO)). Remember, the model has already obtained optimal solutions for the variables, namely X, YI, YO, ZI, and ZO, and K and O are known, therefore the total container stock derived in this way is optimal. The track of such optimal container stocks over the whole forecasting period gives an long term optimal container fleet sizing decision. Figure 5.2 depicts such an optimal path for case 2.

Figure 5.2

Long Term Container Fleet

Sizing Decision



Conclusion

This chapter has shown that the optimising model developed in Chapter 4 is capable of yielding concrete, optimal solutions in a practical shipping environment. The capability of the model was tested by using three different sets of hypothetical data, each set being chosen to test and illustrate a specific characteristic of the model. The solutions yielded in each of the three cases attest to the robustness, adaptability and applicability of the model. Likewise, the fact that the model could be run on a modest PC-286 illustrates the potential of the model in terms of practical application.

CHAPTER 6

ECONOMIES OF SCOPE IN CONTAINER CONTROL

Introduction

This chapter presents an important implication of the model developed in previous chapters.

In recent years, a notable phenomenon observed in liner shipping industry has been individual shipping lines cooperating through the formation of consortia or through merger. At the same time other companies have grown through internal expansion. Together these trends point to an increase in corporate concentration in the liner shipping industry. As evidence of this, a study by Containerisation International showed that between 1986 and 1990 the market share of the world's top 20 liner shipping companies increased from 35% to 39%.[1] The rationale behind this trend towards increasing concentration and various forms of corporate cooperation is undoubtedly complex and will likely include factors such as the desire for larger market shares, larger vessels, increased vessel load factors, and providing shippers more convenient services and schedules. It is also possible that the pursuit of improved container utilization and control may have contributed to this trend. The model developed in

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[1] Brooks, M. and K. Button (1992) Europe '92: Impact on the Provision of Maritime Transport Services (Ottawa: Economic Research Branch, Transport Canada), p31

previous chapters may provide some insights into such a possibility for it may be used to identify (1) if there are any economies of scale in container utilisation and (2) what are the sources of this economies. The purpose of this chapter is to show how the model may be used for these purposes.

As liner shipping is a multiproduct business the nature of any scale economies will be more complex than in any single product activity.[2] The particular type of multiproduct scale economy of greatest relevance to the management of container control is economies of scope.

Economies of scope are the costs savings resulting from simultaneous production of several different outputs in a single enterprise, as contrasted with their production in isolation, each by its own specialized firm[3].

For liner shipping, we interpret output as cargo carried and different output as cargo shipped over different travelling routes. Being interested in the relationship between sharing a container pool and container costs, we only focus on the cost associated with one kind of input--containers instead of the whole bundle of inputs--containership, labour, materials, etc.

Therefore, we can express our task in this way: consider

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[2] Baumol, W. J., J. C. Panzar and R. D. Willig (1982) <u>Contestable Markets and the Theory of Industry Structure</u> (New York: Harcourt Brace Jovanovich, Inc.)

[3] see Footnote 2

two liner operators A and B, who operate in two networks Na, Nb respectively, with Q common calling ports. If these two operators share the container pool in their Q common calling ports, do there exist economies of scope in container control i.e., container cost savings? This is the specific problem which we wish to investigate using our container control model.

Prior to this, however, the chapter first reviews the principal literature on economies of scale/scope in container control or related activities in order to establish what type of contribution to the topic the present study may make.

Literature Review and Approach Selection

Neufville and Tsunokawa[4] analyzed empirically the returns to scale of container ports. The approach they selected was to estimate the underlying production function directly, in terms of the actual resources used and the production achieved, by taking the best fit along the edge of the data, rather than through the middle, as the locus of technically efficient production possibilities.

Antonio[5] reviewed, in broad scope, the empirical literature on economies of scale in the airline industry. He

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[4] Neufville, R. de and K. Tsunokawa, (1981) "Productivity and Returns to Scale of Container Ports", Maritime Policy and Management Vol 8, No.2

[5] Antoniou, A. (1991) "Economies of Scale in the Airline Industry: the Evidence revised", Logistics and Transportation Review, Vol 27, No.2

argued that the existing evidence is not definitive on the widely held view that constant returns to scale prevail. What most of the literature has established is that various aggregate measures of size, without adequate correction for network or technological characteristics, do not confer, per se, any measurable cost advantages.

Roy and Cofsky[6] investigated the production technology of Canadian air service during 1968-1981 by adopting multiproduct approach, disaggregating output and specifying their cost functions in terms of types of product. They concluded that there were economies of scope rather than economies of scale in Canadian air industry.

The studies, made by Caves and Christensen[7], of airlines, railroads, urban buses, and trucking, revealed a strong relationship between output and productivity through increased utilization of existing networks (economies of density). Economies of scale are not an important source of productivity for any growth of these industries.

The approach of empirical analysis, employed by all these researches, is capable of investigating the real behaviour of an industry and obtains a practical understanding of economies

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[6] Roy, R. and D. Cofsky (1985) An Empirical Investigation of Production Technology of Canadian Air Services (Ottawa: Canadian Transport commission, Research Branch)

[7] Caves, D. W. and L. R. Christensen (1988) "The Importance of Economies of Scale, Capacity Utilization, and Density in Explaining Industry Difference in Productivity Growth", Logistics and Transportation Review, Vol 24, No.1

(1):

$$\text{Min } C(A) = \Sigma_{i\varepsilon[Na]}\Sigma_{j=1}^{jj-1}[X(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+$$

$$(ZI(i,j)+ZO(i,j))*z(i)+$$

$$(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-$$

$$f(i,j))*r(i)]$$

Subject to:

1)

$$\Sigma_{h\varepsilon H}(YI(i,h,j)-YO(i,h,j))+ZI(i,j)-ZO(I,j)+$$

$$X(i,j)-C(i,j+1)=X(i,j+1)$$

$i\ \varepsilon\ [Na].\quad j=0,1,\ldots jj-1.$

2)

$$YI(i,h,j(i))=YO(h,i,j(h))$$

$i\ \varepsilon\ [Na].\quad j=1,2,\ldots jj-1.\quad h\varepsilon H$

3)

$$YI(i,h,j)\leq LYI(i,h,j)$$

$i\ \varepsilon\ [Na].\quad j=1,2.,..jj-1.\quad h\varepsilon H.$

4)

$$YO(i,h,j)\leq LYO(i,h,j)$$

$i\ \varepsilon\ [Na].\quad j=1,2,\ldots jj-1.\quad h\varepsilon H.$

5)

$$ZI(i,j)+ZO(i,j)\leq LZIO(i,j)$$

$i\ \varepsilon\ [Na].\ i<>1.\ j=2,3,\ldots jj-1$

6).

X, YI, YO, ZI, ZO are non-negative integers

We assume the charge rate of x, y, z, r are identical for A and B. $i\varepsilon[Na]$ means that i stands for any port in A's operating network Na. By the same token, the minimum total container costs of B would be given by:

(2):

$$\text{Min } C(B) = \Sigma_{i\varepsilon[Nb]}\Sigma_{j=1}^{jj-1}[X(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+$$

$$(ZI(i,j)+ZO(i,j))*z(i)+$$

$$(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-f(i,j))*r(i)]$$

Subject to:

1)

$$\Sigma_{h\varepsilon H}(YI(i,h,j)-YO(i,h,j))+ZI(i,j)-ZO(I,j)+$$

$$X(i,j)-C(i,j+1)=X(i,j+1)$$

$i \varepsilon [Nb]$. $j=0,1,...jj-1$.

2)

$$YI(i,h,j(i))=YO(h,i,j(h))$$

$i \varepsilon [Nb]$. $j=1,2,...jj-1$. $h\varepsilon H$

3)

$$YI(i,h,j)\leq LYI(i,h,j)$$

$i \varepsilon [Nb]$. $j=1,2.,..jj-1$. $h\varepsilon H$.

4)

$$YO(i,h,j)\leq LYO(i,h,j)$$

$i \varepsilon [Nb]$. $j=1,2,...jj-1$. $h\varepsilon H$.

5)

$$ZI(i,j)+ZO(i,j) \leq LZIO(i,j)$$

$$i \in [Nb].\ i<>1.\quad j=2,3,...jj-1$$

6)

X, YI, YO, ZI, ZO are non-negative integers

As they operate separately, their containers move within the respective system of each firm. There are no interactions between the two systems. Variables X, YI, YO, ZI, ZO and parameters f(i,j) stand for their own operational procedures. Mathematically, the solutions of (1) and (2) are equivalent to the solution of (3):

(3):

Min C(A) + Min C(B) =

$$\Sigma_{i\varepsilon[Na+Nb-Q]}\Sigma_{j=1}^{jj-1}[X(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+$$

$$(ZI(i,j)+ZO(i,j))*z(i)+$$

$$(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-$$

$$f(i,j))*r(i)]+$$

$$\Sigma_{i\varepsilon[Q]}\Sigma_{j=1}^{jj-1}[XA(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YIA(i,h,j)+YOA(i,h,j))*y(i,h)+$$

$$(ZIA(i,j)+ZOA(i,j))*z(i)+$$

$$(XA(i,j)+ZIA(i,j)-ZOA(i,j))*(f(i,j+1)-$$

$$f(i,j))*r(i)]+$$

$$\Sigma_{i\varepsilon[Q]}\Sigma_{j=1}^{jj-1}[XB(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YIB(i,h,j)+YOB(i,h,j))*y(i,h)+$$

$$(ZIB(i,j)+ZOB(i,j))*z(i)+$$

$$(XB(i,j)+ZIB(i,j)-ZOB(i,j))*(f(i,j+1)-$$

$$f(i,j))*r(i)]$$

Subject to:

1)

$$\Sigma_{h\varepsilon H}(YI(i,h,j)-YO(i,h,j))+ZI(i,j)-ZO(I,j)+$$

$$X(i,j)-C(i,j+1)=X(i,j+1)$$

$$i\varepsilon[Na+Na-Q],\ j=0,..jj-1$$

$$\Sigma_{h\varepsilon H}(YIA(i,h,j)-YOA(i,h,j))+ZIA(i,j)-ZOA(I,j)+$$

$$XA(i,j)-CA(i,j+1)=XA(i,j+1)$$

$$i\varepsilon[Q],\ j=0,..jj-1$$

$\Sigma_{h\varepsilon H}$(YIB(i,h,j)-YOB(i,h,j))+ZIB(i,j)-ZOB(I,j)+

XB(i,j)-CB(i,j+1)=XB(i,j+1)

iε[Q], j=0,..jj-1.

2)

YI(i,h,j(i))=YO(h,i,j(h))

i ε [Na+Nb-Q]. j=1,2,...jj-1. hεH

YIA(i,h,j(i))=YOA(h,i,j(h))

i ε [Q]. j=1,2,...jj-1. hεH

YIB(i,h,j(i))=YOB(h,i,j(h))

i ε [Q]. j=1,2,...jj-1. hεH

3)

YI(i,h,j)≤LYI(i,h,j)

i ε [Na+Nb-Q]. j=1,2.,..jj-1. hεH.

YIA(i,h,j)≤LYI(i,h,j)

i ε [Q]. j=1,2.,..jj-1. hεH.

YIB(i,h,j)≤LYI(i,h,j)

i ε [Q]. j=1,2.,..jj-1. hεH.

4)

YO(i,h,j)≤LYO(i,h,j)

i ε [Na+Nb-Q]. j=1,2,...jj-1. hεH.

YOA(i,h,j)≤LYO(i,h,j)

i ε [Q]. j=1,2,...jj-1. hεH.

YOB(i,h,j)≤LYO(i,h,j)

i ε [Q]. j=1,2,...jj-1. hεH.

5)

$$ZI(i,j)+ZO(i,j) \leq LZIO(i,j)$$

$$i \in [Na+Nb-Q]. \quad j=2,3,...jj-1$$

$$ZIA(i,j)+ZOA(i,j) \leq LZIO(i,j)$$

$$i \in [Q]. \quad j=2,3,...jj-1$$

$$ZIB(i,j)+ZOB(i,j) \leq LZIO(i,j)$$

$$i \in [Q]. \quad j=2,3,...jj-1$$

6)

X, XA(B), YI, YIA(B), YO, YOA(B), ZI, ZIA(B), ZO, ZOA(B) are non-negative integers

Here, [Na+Nb-Q] is the set of all the ports of A and B except Q common ports. [Q] is the set of all Q common ports. Voyage j of A and B stands for their own voyage sequence. Suffix A, B of X, Y, Z, and C just emphasizes the separate operation of A and B in their common ports.

Now, let A and B co-operate in their container control, i.e., allow them to share a container pool in their Q common ports, and meantime, keep respectively their original cargo flow, sailing schedule, container devanning speed, etc, unchanged.

The combined optimum container cost function is:

(4):

$$\text{Min } C(A+B) = \Sigma_{i\varepsilon[Na+Nb-Q]}\Sigma_{j=1}^{jj-1}[X(i,j)*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+$$

$$(ZI(i,j)+ZO(i,j))*z(i)+$$

$$(X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-f(i,j))*r(i)]+$$

$$\Sigma_{i\varepsilon[Q]}\Sigma_{j=1}^{jj-1}((XA(i,j)+XB(i,j))*(f(i,j+1)-f(i,j))*x(i)+$$

$$\Sigma_{h\varepsilon H}(YIA(i,h,j)+YIB(i,h,j)+YOA(i,h,j)+YOB(i,h,j))*y(i,h)+$$

$$(ZIA(i,j)+ZIB(i,j)+ZOA(i,j)+ZOB(i,j))*z(i)+$$

$$(XA(i,j)+XB(i,j)+ZIA(i,j)+ZIB(i,j)-ZOA(i,j)-ZOB(i,j))*(f(i,j+1)-f(i,j))*r(i)]$$

Subject to:

1)

$$\Sigma_{h\varepsilon H}(YI(i,h,j)-YO(i,h,j))+ZI(i,j)-ZO(I,j)+X(i,j)-C(i,j+1)=X(i,j+1)$$

$$i\varepsilon[Na+Nb-Q],\quad j=0..jj-1$$

$$\Sigma_{h\varepsilon H}(YIA(i,h,j)+YIB(i,h,j)-YOA(i,h,j)-YOB(i,h,j))+ZIA(i,j)+ZIB(i,j)-ZOA(I,j)-ZOB(i,j)+XA(i,j)+XB(i,j)-CA(i,j+1)-CB(i,j+1)=XA(i,j+1)+XB(i,j+1)$$

$i\varepsilon[Q]$, j[8]=0..jj-1

[8] Here, j is considered as the voyage combination of A's and B's voyages. For any $i\varepsilon[Q]$, $j=j_A+j_B$, $jj=jj_A+jj_B$.

2)

YI(i,h,j(i))=YO(h,i,j(h))

i ε [Na+Nb-Q]. j=1,2,...jj-1. hεH

YIA(i,h,j(i))+YIB(i,h,j(I))=

YOA(h,i,j(h))+YOB(h,i,j(h))

i ε [Q]. j=1,2,...jj-1. hεH

3)

YI(i,h,j)≤LYI(i,h,j)

i ε [Na+Nb-Q). j=1,2,...jj-1. hεH

YIA(i,h,j)+YIB(i,h,j)≤LYI(i,h,j)

i ε [Q]. j=1,2,...jj-1. hεH

4)

YO(i,h,j)≤LYO(i,h,j)

i ε [Na+Nb-Q]. j=1,2,...jj-1. hεH.

YOA(i,h,j)+YOB(i,h,j)≤LYO(i,h,j)

i ε [Q] j=1,2,...jj-1. hεH

5)

ZI(i,j)+ZO(i,j)≤LZIO(i,j)

i ε [Na+Nb-Q]. i<>1. j=2,3,...jj-1

ZIA(i,j)+ZIB(i,j)+ZOA(i,j)+ZOB(i,j)≤LZIO(i,j)

i ε [Q]. j=2,3,...jj-1

6)

X, XA(B), YI, YIA(B), YO, YOA(B), ZI, ZIA(B), ZO, ZOA(B) are non-negative integers

Comparing equations (3) and (4), we can see that:

(1) For the objective function, all the terms have

exactly the same meaning if we separate the second part of the objective function of equation (4) (i.e., in the Q common ports) into one component for A and one for B.

(2) All the constraints in (3) and (4) are the same except in the Q common ports where the constraints in equation (3) are expressed in separate forms while those in equation (4) in combined forms. Therefore, the difference between equation (3) and (4) can be generalized mathematically as:

Equation (3)′: Min: $f(x)$

St. $g(x) \leq 0$

$h(x) \leq 0$

Equation (4)′: Min: $f(x)$

St. $g(x)+h(x) \leq 0$

Now, we want to demonstrate that the optimal solution of Equation (4)′ is not greater than that in (3)′.

If x is a feasible solution of (3)′, then, $g(x) \leq 0$, $h(x) \leq 0$. So, $g(x)+h(x) \leq 0$. Hence, any feasible solution of (3)′ is also a feasible solution of (4)′. On the other hand, if y is a feasible solution of (4)′, then, $g(y)+h(y) \leq 0$. However, it does not necessarily indicate both $g(y) \leq 0$ and $h(y) \leq 0$. Hence, y is not necessarily a feasible solution of (3)′. Therefore, the feasible solution space of (4)′ is bigger than that of (3)′. A bigger feasible solution space means a smaller optimal value for minimizing the same objective function. This indicates that the optimal solution of equation (4)′ is not greater than that of (3)′.

Therefore,

$$\text{Min } C(A+B) \leq \text{Min } C(A) + \text{Min } C(B)$$

This means that the co-operation of A and B in container utilization results in less container costs than those if they were to operate separately. This clearly indicates that there are economies of scope in container control in the liner shipping industry.

The above procedure used for proving the existence of economies of scope also reveals the mechanism underlying this existence. The co-operation in containers of A and B shortens the waiting time of empty containers in port, $(f(i,j+1)-f(i,j))$ due to the shortening of time span between successive voyages. This speeds up the containers' turnover and increases the utilization of containers for A and B as a whole. The combined container pool lowers the required buffer level, $X(i,j)$, for subsequent cargo demand below that required if A and B were to operate separately[9]. These two factors affect both container fleet costs and operating costs, which together serve to reduce container costs and confer economies of scope.

It is worth pointing out that in the practical operation of a shared container pool, the cost connected with the interchange of containers between companies should not be

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[9] Without combination of A's and B's container pool, the requirement for buffer level in any of the Q common ports is $X(i,j) \geq XA(i,j)+XB(i,j)$. After combination, the requirement becomes $X(i,j) \geq \text{Max}(XA(i,j), XB(i,j)$

ignored, a cost which includes the transshipment of empty containers from A's depot to B's, and the difficulty of controlling containers transferred in/out. For example, company A may need to use company B's container which is leased by B from a leasing company C. If B want to DI (direct interchange) the container to A, it has to pay leasing company C for the sub-leasing. After agreement by C, A has to pick it from B's depot. This procedure will require some money and time expenditures on communication by fax, telex, computer, and delivery by truck and crane.

Considering such transaction costs, we can modify (4) so as to account for them thus:

(5):

$$\begin{aligned}
\text{Min } C(A+B) = {} & \Sigma_{i\varepsilon[Na+Nb-Q]}\Sigma_{j=1}^{jj-1}[X(i,j)*(f(i,j+1)- \\
& f(i,j))*x(i)+ \\
& \Sigma_{h\varepsilon H}(YI(i,h,j)+YO(i,h,j))*y(i,h)+ \\
& (ZI(i,j)+ZO(i,j))*z(i)+ \\
& (X(i,j)+ZI(i,j)-ZO(i,j))*(f(i,j+1)-f(i,j))*r(i)]+ \\
& \Sigma_{i\varepsilon[Q]}\Sigma_{j=1}^{jj-1}((XA(i,j)+XB(i,j))*(f(i,j+1)- \\
& f(i,j))*x(i)+ \\
& \Sigma_{h\varepsilon H}(YIA(i,h,j)+YIB(i,h,j)+YOA(i,h,j)+YOB(i,h,j)) \\
& *y(i,h)+ \\
& (ZIA(i,j)+ZIB(i,j)+ZOA(i,j)+ZOB(i,j))*z(i)+ \\
& (XA(i,j)+XB(i,j)+ZIA(i,j)+ZIB(i,j)- \\
& ZOA(i,j)+ZOB(i,j))*(f(i,j+1)-f(i,j))*r(i)]+ \\
& t(i)*(XA(i,j)+XB(i,j))
\end{aligned}$$

---t(i): the cost per transaction of containers pooled in port i

---All constraints are the same as in (4).

After adding up the term t(i)*(XA(i,j)+XB(i,j)), it is not mathematically necessary for C(A+B) ≤ C(A)+C(B). The inequality depends on the value of t(i). This result is illustrated in following by an example.

Hypothetical Example: Verification And Implication

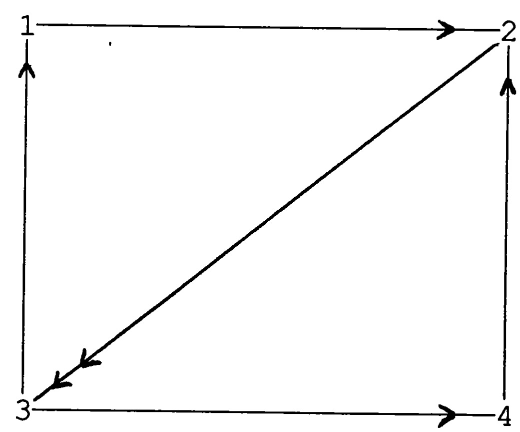
We suppose the sailing networks of operator A and B as Na and Nb.

Figure 6.1

The Sailing Network of Operators A and B

Na: 1--2--3

Nb: 2--3--4



There are two common ports in port 2 and 3.

We want to know the minimum container costs under the optimal container control path in the period of the 15th day of current time to the 45th day , i.e., t=15, T=30.

In order to verify the preceding conclusion, we present three operational situations: (1) A and B operate separately; (2) A and B operate sharing container pools in port 2 and 3 without transaction costs; and (3) A and B operate sharing container pools in port 2 and 3 with some degree of transaction costs. We assume all of these three situations have the same cargo flow, sailing schedule, etc.

Table 6.1 is the ship sailing schedule and cargo flow data for all of these three situations. The schedule and cargo data before time t are listed here to calculate the amount of naturally devanned containers B(i,j). Here, m stands for the operator, say, m=1, means A, m=2, B, k is the kth voyage in their respective calling schedule, j is the jth voyage in total calling schedule.

Table 6.1

Sailing Schedule and Cargo Flow Data of Operators A and B in All Three Situations

f(i,m,k,j)	I(i,j)	O(i,j)
-29(1,1,-2,-2)	90	90
-14(1,1,1,-1)	20	90
1(1,1,0,0)	70	20
16(1,1,1,1)	50	30
31(1,1,2,2)	80	40
45(1,1,3,3)	70	50
-22(2,1,-2,-4)	80	70
-11(2,2,-1,-3)	180	60
-9(2,1,-2,-4)	70	70
2(2,2,0,-1)	257	200
6(2,1,0,0)	60	40
15(2,2,1,1)	50	240
21(2,1,1,2)	130	140
28(2,2,2,3)	60	40
36(2,1,2,4)	80	80
42(2,2,3,5)	100	80
-8(3,2,-1,-3)	250	170
-5(3,1,-1,-2)	40	40
6(3,2,0,-1)	30	20
11(3,1,0,0)	150	170
19(3,2,1,1)	80	70
26(3,1,1,2)	180	190
33(3,2,2,3)	20	100
41(3,1,2,4)	60	140
-32(4,2,-3,-3)	60	50
-18(4,2,-2,-3)	70	40
-4(4,2,-1,-1)	30	30
10(4,2,0,0)	80	90
24(4,2,1,1)	10	60
38(4,2,2,2)	40	40

Table 6.2 shows some fee rates for storage, delivery and rent for the three situations. The transaction costs happen only in common ports of 2 and 3 in situation 3

Table 6.2

Fee Rates for Storage, Delivery, Rent and Transaction x(i), z(i), r(i) and t(i)

Port i	Stor. fee x(i)	Delive Fee z(i)	Rent fee r(i)	Transaction cost t(i)	
	SI 1,2,3	SI 1,2,3	SI 1,2,3	SI 1,2	SI 3
1	2.4	100	3.8	0	
2	4.4	140	3.2	0	100
3	4.	130	3.5	0	145
4	3.4	90	4	0	

*: In the present and following tables of this chapter, all of "SITU", "SI", and "S' mean "situation".

Table 6.3 gives the half of the fee rate of positioning empty containers between i and h.

Table 6.3

Half of the Fee Rates of Repositioning y(i)

PORT	Port 1	Port 2	Port 3	Port 4
	SI 1,2,3	SI 1,2,3	SI 1,2,3	SI 1,2,3
Port 1		25	30	
Port 2	25		32	28
Port 3	30	32		26
Port 4		28	26	

Table 6.4 and 6.5 list the limitations of vessel space for positioning empty containers from h to i arriving in the jth voyage, LYI(i,h,j), and from i to h leaving in the jth voyage, LYO(i,h,j).

Table 6.4

The Limitation of Vessel Space LYI(i,h,j)

Port i	Voyage j	h=1 SITU 1,2,3	h=2 SITU 1,2,3	h=3 SITU 1,2,3	h=4 SITU 1,2,3
1	1		20	10	
1	2		30	44	
2	1			19	4
2	2	22		30	
2	3			9	22
2	4	38		3	
3	1		16		5
3	2	33	10		
3	3		42		5
4	1		5	10	

Table 6.5

The Limitations of Vessel Space LYO(i,h,j)

Port i	Voyage j	h=1 SI 1,2,3	h=2 SI 1,2,3	h=3 SI 1,2,3	h=4 SI 1,2,3
1	1		9	26	
1	2		5	40	
2	1			5	14
2	2	39		11	
2	3			11	22
2	4	10		10	
3	1		30		39
3	2	22	5		
3	3		10		19
4	1		22	15	

Table 6.6 gives the limitation of leasing on-off containers, LZIO(i,j), and the given values of X(i,0) and X(i,jj)

Table 6.6

<u>The Limitations of Leasing Containers LZIO(i,j)</u>

<u>and Empty Container Stock X(i,0) and X(i,jj)</u>

Port i	Voyage j	LZIO(i,j)	X(i,0)		X(i,jj)	
		SITU 1,2,3	S1.A, S1.B	S 2,3	S1.A, S1.B	S 2,3
1	0		2	4		
1	1					
1	2					
1	3				10	20
2	0		40	80		
2	1					
2	2	20				
2	3	30				
2	4	15				
2	5				38	76
3	0		45	90		
3	1					
3	2	30				
3	3					
3	4				20	40
4	0		4	8		
4	1					
4	2				8	16

The final result, the minimum costs of these three situations is given in Table 6.7.

Table 6.7

<u>The Minimum Costs of A, B and A+B</u>

variables	SITU 1.A	SITU 1.B	SITU 2	SITU 3
Optimal Objective Value	17247.7	46470.8	52868.0	63815.0

All the operation variables, such as X, Y, Z, along the optimal control path, satisfy the technical efficiency requirement of a production function. The costs obtained in this way are consequently eligible to be used to test for economies of scope.

In the Table 6.7

$C(A)=17247.7$

$C(B)=46470.8$

$C(A+B)=52868.0$

$C(A+B,t)=63815.0$

Therefore,

$$C(A+B) < C(A)+C(B) < C(A+B,t)$$

This shows the existence of economies of scope in container control. In our example, the transaction costs is large enough so that there are diseconomies of scope instead of economies of scope. Consequently there will be a level of transaction cost beyond which economies of scope becomes diseconomies of scope.

Conclusion

Merger, co-operation and internal expansions of liner shipping companies are world-wide trends. This chapter revealed one reason that may underlie this trend, namely the existence of economies of scope in container control in the container shipping industry. The multi-product analysis of contestable market theory provides a powerful tool for the analysis of such economies. This, combined with the container control model previously developed in Chapter 4, overcomes the weakness of the prevailing empirical analysis of economies of scope, namely the difficulty of obtaining the production function required to isolate the source of economies of scope.

Both a mathematical proof and an example indicate the existence of economies of scope of container control provided that the transaction cost incurred in sharing container pools does not rise above a certain level.

CHAPTER 7

SUMMARY AND CONCLUSION

The movement of containers is perhaps the most obvious function of the liner shipping business. Not surprisingly, the costs associated with the acquisition and movement of containers constitute an important component of a liner operator's costs structure. These costs include the purchase and lease of containers, the storage of empty containers, container repair and maintenance, container insurance, and the reallocation of empty containers. Such costs may account for over 20% of the total costs of a container shipping service.

The primary consideration of this study was to attempt to find a way to minimize these container costs as a whole in order to increase the operator's efficiency and profits.

The thesis developed a model for the costs minimizing control of both a shipping company's stock of containers and their deployment within the company. A two-stage approach was employed in the model. First, we identified the number of containers needed for a certain outbound cargo demand. This task was complicated by a unique feature of the liner shipping industry, namely the self- production of empty containers through devanning (or emptying) the full. In the second stage, a integer programming solution was given to show the costs minimizing control path for both the size of the total container stock and its deployment by the firm.

The practical performance of the model was evaluated by running the model with the hypothetical situations, two of which are typical of the situations likely to be encountered by a real world liner operator, using a PC-286 computer. It was shown that the model does yield optimal solutions and is thus a practically useful tool.

An important further use of the model was to test for the existence of economies of scope in container control in the liner shipping industry. The optimal model approach developed in the thesis was shown to be capable of fulfilling the requirement of the analysis of economies of scope, i.e., production along the set of technically efficient production possibilities, something which is difficult to satisfy using empirical data. Additionally, the optimal model approach was not only able to test for the existence of economies of scope, but could also reveal the mechanism underlying such economies in terms of the interaction of various inputs and outputs. It was concluded that there do exist economies of scope in container control by sharing equipment pools among liner companies, something which partially explains the phenomenon of merger, co-operation and corporate growth that have recently been witnessed in the liner shipping industry. However, it was pointed out that diseconomies of scope in container control would appear when the transaction cost incurred in sharing a container pool is not neglectable and significantly contributes to the total container costs.

In conclusion, then, it appears that the model developed in this thesis is capable of dealing with container leasing, purchasing, stocking, and allocating decision so as to yield least cost solutions under a variety of plausible service patterns. The data required to run the model, moreover, are compatible with the information liner companies routinely gather, and all the solutions are obtainable quickly using a PC-286 computer. By being of this nature it is hoped that the thesis offers a modest practical as well as academic contribution to the important subject of container control.

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