國立交通大學

交通運輸研究所

博士論文

No. 034

定期航運航線規劃與收益管理之研究

Service Route Planning and Revenue Management for the Liner Shipping Industry

研　究　生：丁士展

指導教授：曾國雄

中華民國九十二年七月

定期航運航線規劃與收益管理之研究

Service Route Planning and Revenue Management for the Liner Shipping Industry

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國立交通大學
交通運輸研究所
博士論文

A Dissertation
Submitted to Institute of Traffic and Transportation
College of Management
National Chiao Tung University
in Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy
in
Engineering

July, 2003
Hsinchu, Taiwan, Republic of China

中華民國九十二年七月

博碩士論文授權書

(國科會科學技術資料中心版本，92.6.17)

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91 學年度第二學期取得博士學位之論文。

論文題目：定期航運航線規劃與收益管理之研究

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論文口試委員會審定書

本校　交通運輸　研究所　丁士展　君

所提論文　定期航運航線規劃與收益管理之研究

合於博士資格水準，業經本委員會評審認可。

口試委員：

指導教授：

研究所所長：　　　　教授

中華民國　九十二　年　七　月　十五　日

PhD.Thesis(9).DOC

A DISSERTATION OF Shih-Chan Ting

ENTITLED **Service Route Planning and Revenue Management for the Liner Shipping Industry**

WAS ACCEPTED AS PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

Committee

Dissertation Advisor

Director

Institute of Traffic & Transportation

National Chiao Tung University

Date : 92.07.15

phD.Thesis(10).DOC

定期航運航線規劃與收益管理之研究

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摘　要

定期航運業為資本密集的產業，航運公司航線服務涵蓋全球或區域內的港口。為維持定期的航線服務，必須投入相當大的資金，如貨櫃船隊、貨櫃、機具以及貨櫃碼頭等的投資，並指派代理行執行當地的業務。然而面臨競爭激烈的市場，運價不易提升，又因航線貿易量的不平衡，增加許多空櫃調度成本，更增加了運價下跌的壓力，造成航商難以獲得合理的利潤乃至虧損。有鑑於此，航商必須大幅改變其業務經營方式，導入收益管理的觀念，以克服市場的激烈競爭與波動。收益管理已在航空運輸業行之多年且獲致良好的成效，其主要是利用機位分配與定價的手段獲取航次最大的收益；相對於航空運輸業，定期航運較少使用收益管理有關的系統或模式來執行業務活動。因此，本研究對於收益管理應用在運輸業或其他產業之研究做一完整的整理，分析定期航運之產業問題與發展趨勢，針對其營運特性開發收益管理系統與相關模式，提供航運公司建立與導入收益管理系統之參考。

本研究提出一套定期航運收益管理模式(Liner Shipping Revenue Management, LSRM)，其包括兩個主要部分的功能：(1) 長期規劃 – 包括顧客管理、成本管理、市場監控、航線規劃與船隊排程；(2) 短期營運 – 包括貨載

需求預測、艙位分配、定價、貨櫃調度、動態艙位控制；該系統亦必須與運費收入、成本、貨櫃存量等資料庫以及會計系統串連整合。定期航運收益管理以有效的艙位分配與定價方法，考量空櫃調度狀況，配合精確的掌控輸儲成本與市場貨載需求，攬載邊際貢獻較高之貨載，達到艙位分配使用收益之最佳化。

定期航線、船期一旦決定開航後，不易在短期間內改變或停航，因此，在航線開航前必須經過整體的規劃，進行船隊排程與成本分析。在定期航運收益管理系統中，航線規劃與船隊排程的功能可以提供企劃人員規劃新航線、調整或整合航線網路的決策支援，使得航線的貨載潛能達到最大。本研究提供系統分析的方法，利用動態規劃構建船隊排程模式，以及重新釐清在航線規劃時成本分析的各個成本項目，幫助企劃人員在許多的碼頭船席時間窗限制下決定最佳的船隊排程，並且較準確的估計航線固定成本與貨載的變動成本，有助於航線可行性的分析。本動態船隊排程模式所導出的排程策略除了靠港、離港的時間船期外，亦包括港口間的航速與碼頭起重機的調配，而不是暫時排定的粗略船期。此外，本模式可以延伸用以整合航運公司內的航線或是聯盟間的航線網路，讓幅軸式服務網路運作更有效率，縮短轉運時間，增加服務頻次，而且經由模式排定的船期，可因為船舶油耗與停港時間的節省而減少航線成本。

貨櫃船艙位分配為影響定期航運公司收益與船舶容量利用率的重要決策，在面對激烈競爭的市場與貨載運輸需求不確定的情況下，航商應透過更精緻的艙位分配與定價以獲取航次的最大利潤。本研究針對艙位分配的問題，利用數學規劃與模糊多目標規劃方法構建兩個貨櫃船艙位分配模式。考量定期航運貨載變動成本較大的特性，在第一個模式(SA1)目標上採取航次總邊際貢獻(總運費收入減總變動成本)最大化，並加入可能發生空櫃調度成本的運量不平衡因子。另外，第二個模式(SA2)則同時處理在艙位分配時需考慮的兩個目標，亦即

航次的貨載邊際貢獻與代理行的滿意度，以及處理貨載運輸需求與貨重的不確定性。模式應用在國內航運公司遠歐航線上，與現行的分配比較結果顯示本模式在艙位分配上不僅可獲得較佳的收益並可兼顧代理行的滿意度，以及考量貨載重量的分配。

關鍵字：定期航運、收益管理、航線規劃、船隊排程、成本分析、艙位分配、數學規劃、動態規劃、模糊多目標規劃。

Service Route Planning and Revenue Management for the Liner Shipping Industry

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Abstract

Liner shipping is a capital-intensive industry. Provision of liner shipping services, often offering global or regional coverage, requires extensive infrastructure in terms of container ships, equipment (e.g. containers, chassis, trailers), terminals and assigns agencies. With the current fiercely competitive market, freight rates cannot be increased easily, and it is costly to reposition empty containers due to trade imbalances. As a result, liner companies have difficulty generating reasonable profits and even run deficits. Therefore, liner carriers require dramatic changes in operational practices to face this tough and fluctuating market. Revenue management (RM), alternatively known as yield management (YM), can be defined as the integrated management of price and inventory to maximize a company's profitability. RM has been enabling airlines to sell the right service to the right customer, at the right time for the right price, and thus achieves the highest amount of revenue possible. Proven to be an effective tool in the airline industry, RM has considerable potential for the liner shipping industry.

To provide carriers with a good solution to build RM systems, the RM concept

is introduced to the industry to create a liner shipping revenue management (LSRM) model, which consists of two major components: (1) long-term planning, which can assist with longer term customer management, cost management, market monitoring, service route planning and ship scheduling; and (2) short-term operations, which can assist with voyage revenue optimization in terms of demand forecasting, slot allocation, pricing, container inventory control and dynamic space control. Additionally, such a system should be integrated with freight revenue, cost, container inventory database and accounting systems.

In the proposed LSRM system, service route planning and ship scheduling are aimed to provide decision support to plan new service routes and modify or integrate current service network so that companies can maximize the shipment potential. Since a service route of a containership fleet, once determined, is hard to alter for a certain period of time, the initial ship scheduling decision and cost analysis should be made carefully after comprehensive studies and planning. Liner shipping companies can benefit greatly from using systematic methods to improve ship scheduling and cost analysis on service route planning. This study proposes a dynamic programming (DP) model for ship scheduling and clarifies cost items for planning a service route. This can help planners make better scheduling decisions under berth time-window constraints, as well as to estimate voyage fixed costs and freight variable costs more accurately. The proposed DP ship scheduling model derives an optimal scheduling strategy including cruising speed and quay crane dispatching decisions, rather than a tentative and rough schedule arrangement. Additionally, the model can be extended to cases of integrating one company's or strategic alliance partners' service networks to gain more efficient hub-and-spoke operations, tighter transshipment and better level-of-service. This improvement not only gives this new mathematical model, but also could yield cost savings due to decreases of vessel fuel consumption and port time.

Containership capacity is a vitally important consideration since there is no revenue derived from unused space. Thus, containership capacity allocation is an important issue since carriers must avoid unused space on a voyage in order to derive the highest possible revenue from containership capacity. In the face of uncertain cargo demand and fiercely competitive markets, liner carriers should refine their business activities to maximize voyage profits through careful consideration of slot allocation and pricing. In this study, some relevant containership slot allocation models are formulated and implemented through mathematical programming and fuzzy multi-objective programming. The objective of the proposed slot allocation model (SA1) is to maximize the total freight contribution instead of freight revenue, due to high variable costs in the liner shipping. We considering the possibility of a continuous worsening situation of trade imbalances, so trade imbalance factors and repositioning costs are included in the objective function. The other one (SA2) of the models is proposed to deal with two conflicting objectives: carrier's freight contribution and agents' degree of satisfaction, as well as fuzzy constraints, i.e. uncertainties of cargo transportation demand and weight. Interactive fuzzy multi-objective linear programming with fuzzy parameters is applied to solve this problem. We illustrate this slot allocation model with a case study of a Taiwan liner shipping company to test its efficacy. Results show the model's applicability and excellent performance in practice.

Keywords: Liner shipping, revenue management, yield management, service route planning, ship scheduling, cost analysis, slot allocation, mathematical programming, dynamic programming, fuzzy multi-objective programming.

誌　謝

論文研究與口試期間承蒙交通部張家祝次長、成功大學陳春益教授、海洋大學林光教授、中國海事專科學校吳榮貴校長、交通大學馮正民教授、汪進財教授撥冗審閱，指正思慮不嚴謹、疏漏之處，並惠賜許多寶貴的建議，使本論文疏漏謬誤之處得以匡正，在此致上最深之謝意。

在此由衷的感謝影響我最深的師父 – 曾國雄老師，是我從碩士班到博士班的指導老師。他像父親般的關懷我，像朋友般的信任我，在我研究屢遭挫折時適時給我啟發、鼓勵。每當我論文進度停滯時，就會接到他關懷的電話，關心我的進度，跟我談一些 Idea 與新方法，鼓勵我繼續「玩」下去，曾老師總是用快樂的態度不斷的「玩」研究，沒有他的勉勵，我可能還在原地踏步。曾老師可以把三學分的課上六個鐘頭，每次都拖著裝滿 Paper 與教材的旅行箱來上課，這種教學熱忱與對學生的付出，是我終生學習的表率。曾老師平易近人的作風和對學術研究嚴謹的態度，給我許多啟發，是一位亦師、亦父、亦友的長者。

感謝汪進財所長、馮正民教授、藍武王教授、黃承傳教授、徐淵靜教授、黃台生教授、許鉅秉教授的教導，使我在專業知識、研究態度及為人處事上有所增長。此外，一路上不斷給予我鼓勵與支持的學長、學姊、學弟、學妹、好友，以及洪瑛瓔、柳美智小姐、所有職員們，感謝你們的關懷與協助，在此深深表達謝意。

特別感謝我親愛的家人，給予我莫大的支持、鼓勵與包容。郁瑄在我疲累時為我泡茶按摩；紹耘睡覺前的親吻與童言童語，都為我帶來繼續奮鬥的動力；良美無怨的承擔照顧與教育孩子的工作，讓我有自己的空間得以完成學業；獨居在虎尾的母親，也能體諒我無法常回去探望，浩瀚親恩，永銘於心。最後，將此論文獻給我最愛的家人與在天上庇佑我的父親，感謝你們在我求學的過程中給予的關懷與鼓勵，願將這份榮耀與你們分享。

丁士展　謹誌

中華民國九十二年八月三日

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Chapter 1

Introduction

In this chapter, research motivation, background, purposes and methods are described. Additionally, liner shipping operations are characterized and revenue management is introduced to the liner shipping industry as below, followed by research framework and overview of this dissertation.

1.1 Research motivation and background

Shipping is a service industry that generally provides cargo transportation of international trade. Approximate 90% cargo volume of international is transported by sea. Often, the shipping industry is categorized into two major sectors: (1) the bulk shipping which provides services mainly in the transportation of raw materials such as crude oil, coal, iron ore, and grains; and (2) the liner shipping which provides services in the transportation of final and semi-final products such as computers, manufacturing product and other consumption goods…etc. Cargo carried by liner shipping has come to be known as general cargo. Liner shipping is to provide regular services between specified ports according to time-tables and prices advertised well in advance (Jansson and Shneerson, 1987). The service is, in principle, open to all shippers and in this sense it resembles a public transportation service. The provision of such a service, often offering global coverage, requires extensive infrastructure in terms of ships, agencies, and equipment. Liner shipping operations are characterized as follows:

1. More large containerships to be deployed to main trade routes

Technological developments in ship design and construction, and the ensuing economies of scale of larger ships, have also promoted trade, particularly that of developing nations, by making economical the transportation of goods over long distances. Carriers have been conducting the incessant drive to cut costs through the deployment of larger ships. Nowadays, containers are increasingly carried by specialized cellular container ships many of which are able to carry more than 5,000 TEUs, while designs for 8,000, 10,000, or even 15,000 TEU ships are already on the drawing boards of naval architects. These so-called post-Panamax ships have been deployed to east-west main trade routes, and many of similar type ships are under construction and delivered in a couple of years.

2. Trade imbalance and surging repositioning costs

One of the major cost items in liner shipping has to do with containers. The container flow across the world does not coincide with the routing of container ships, because containers do not spend all their time onboard ships. They need to be picked up and delivered at inland locations, maintained, and repaired, or may be repositioned. On main west-east trade routes, more cargo moves in one direction compared to the other. Such a route is known as an unbalanced route, or a route with trade imbalance. This is the case, for instance, of the Far East – Europe and Asia – U.S. west coast, two of the three main liner routes where most of the full containers travel westbound and eastbound respectively.

3. High fixed costs and freight variable costs

To keep pre-advertised time schedules, ships of one fleet must leave ports of call regardless of whether they are full or not. Voyage costs thus become fixed (i.e. independent from the amount of cargo loaded). Next, imagine the admittedly simplified case where, minutes before the ship sets sail, an unexpected customer arrives at the port with one container to the ship. If the vessel has unfilled capacity, which is often the case in liner shipping, its operator would be tempted to take on the extra container even at a price as low as merely the extra (marginal) cargo-handling costs involved in taking the container onboard. If this were to become common practice among operators, competition among them would push prices down to the level of short-run marginal costs and consequently the liner service would not be sustainable in the long-run, as operators would not be able to cover full costs (most importantly capital costs such as depreciation allowances for the eventual replacement of the ships).

4. Undifferentiated services

Apparently, containerization makes it increasingly difficult to justify price segmentation on the basis of the alleged need for different treatment of goods according to their particular characteristics (e.g. volume, stowage, cargo-handling). Major service quality variables are considered to be similar: the provision of information and EDI systems; logistics services; better coordination and integration with inland transport companies; ownership of terminals and equipment; frequency of service; geographical coverage; and efficient response to the requirements of customers.

5. Price wars and destructive competition

The industry with over capacity and lower price elasticity of demand is highly competitive with freight rates fluctuating wildly even in the course of a single week. A pessimistic concept in explaining the structure of liner shipping markets is that of destructive competition (Davies, 1990). This process, whereby competition will eventually lead to the destruction of the liner service itself, provides the basis for some new perspectives on the market structure of liner shipping.

6. Streamlining terminal operations

Port industry has invested a lot in order to cope with the technological requirements of containerization. Modern container terminals equipped more efficient quay cranes have been built, and more efficient organizational forms including privatization have been adopted in an effort to speed up port operations. Operational practices have been streamlined, the element of uncertainty in cargo flows largely removed, forward planning has been facilitated, port labor regularized and customs procedures simplified. These developments took place under the firm understanding of governments and local authorities that ports now constitute the most important link and node in the overall door-to-door transport chain.

7. Hub-and-spoke operations

Capital intensity and large ships in this industry obliges container ships to limit their ports of call at each end to some of hub ports such as Singapore, Hong Kong, and Rotterdam, from where a great deal of containers are further transshipped with feeders to regional and local ports. A complex hub-and-spoke networks have thus developed, thus fine-tuning and optimization of service network and schedules have been demanding by carriers.

8. Strategic alliances

Regularity and frequency of service, the two imperatives of liner shipping, combined with deploying very large container ships, can easily lead to low capacity utilization for independent carriers. Therefore, strategic alliances have formed in order to extend economies of scale, scope and network, through strategies such as the integrating of individual service networks, vessel sharing (i.e. joint fleet), slot-chartering, joint ownership and/or utilization of equipment and terminals and similar endeavors on better harmonization of operations. Alliances are also coalitions of carriers, but contrary to the route-based character and price-setting objectives of conferences, alliances aimed at rationalizing operations, rather than involving in price-setting strategies.

Tough and fluctuating liner shipping markets require a dramatic change in operational practices. Liner carriers may utilize revenue management systems to increase profits by using slot allocation and pricing. A conceptual liner shipping revenue management (LSRM) model will be proposed, which is concerned with the integrated operations of long-term customer management, cost management, route planning and ship scheduling, as well as short-term cargo demand forecasting, container inventory control, slot allocation, pricing and dynamic space control. In the proposed LSRM system, long-term service route planning, ship scheduling and short-term slot allocation are discussed and relevant models are developed as presented in next chapters.

1.2 Research purposes and methods

Revenue management (RM), alternatively known as yield management (YM), can be defined as the integrated management of price and inventory to maximize a company's profitability. It is also currently defined as the application of disciplined tactics that predict consumer behavior at the micro-market level and optimize product availability and price to maximize revenue growth (Cross, 1998). The effectiveness of RM derives from its focus on revenue and then using the basic techniques of RM to convert market uncertainty to probability, and probability to revenue gain. An example is the airline industry, which has been investing millions of dollars in sophisticated revenue management systems that have brought hundreds of millions of dollars in benefits. RM enables airlines to sell the right service to the right customer, at the right time for the right price, and thus achieves the highest amount of revenue possible. Today, all major U.S. airlines utilize RM systems, and airlines around the world also practice revenue management or are actively exploring these techniques.

In transportation industries revenue management has been introduced and shown to successfully solve problems related to perishability, fixed capacity, high capacity, variable costs, demand and market segmentation, advance sales and bookings, stochastic demand, historical sales data, and also assist forecasting capabilities (Kimes, 1989). The aforementioned characteristics are also found in liner shipping operations. Proven to be an effective tool in the airline industry, revenue management has considerable potential for the liner shipping industry.

Since liner shipping is a capital-intensive industry, the liner companies must invest large sums on vessels and containers. With the current fiercely competitive market, freight rates cannot be increased easily, and it is costly to reposition empty containers due to trade imbalances. Liner companies have difficulty generating reasonable profits and even run deficits. Therefore, operators should enhance service route planning and ship scheduling over the long term. In addition, they should build revenue management systems to increase more profits by using slot allocation and pricing.

In the liner shipping industry containership capacity is a vitally important consideration since there is no revenue derived from unused space. Thus, liner companies should avoid unused space on a voyage in order to derive the highest possible revenue from containership capacity. Interviews with persons in charge of slot allocation and pricing in liner companies in Taiwan indicate that most liner companies are still using RM systems that are far from comprehensive, dynamic, computerized and integrated. Therefore, a concerted effort is needed to improve liner shipping revenue management by more effectively utilizing RM techniques to enhance operations.

In addition to RM for the short-term operations, in the long-term planning, there are five key functions, customer relationship management, market monitoring, cost management, service route planning and ship scheduling. The latter two functions are aimed to provide decision support to plan new service routes and modify or integrate the current service network so that companies can maximize the shipment potential. Since a service route of one containership fleet, once determined, is hard to alter for a certain period of time, the initial route planning and scheduling decisions should be made carefully after a thorough study and planning. It is highly desirable to plan new routes and rearrange service network by some analytical methods. A more improvement of ship scheduling and cost estimates could yield additional profits or cost savings.

In this study, the revenue management concept is introduced to the industry to create a liner shipping revenue management (LSRM) model, and some relevant models of the LSRM functions are formulated and implemented through dynamic programming, mathematical programming and fuzzy multi-objective programming in this study.

1.3 Research framework and overview of dissertation

As indicated in Figure 1.1, there are three main research issues addressed in Chapter 3, Chapter 4 and Chapter 5 respectively. This illustration serves as a graphical outline of this dissertation. The following is a concise narrative description.

In Chapter 1, characteristics of liner shipping operations are presented through scanning the external environment of the industry, and revenue management is introduced to this industry to overcome operational problems.

Chapter 2 reviews studies and applications regarding revenue management extensively, which includes research on the airline and air cargo industry, the liner shipping industry, the hotel industry and other industry. The methodology is also reviewed in this chapter, which includes dynamic programming, fuzzy multi-objective programming.

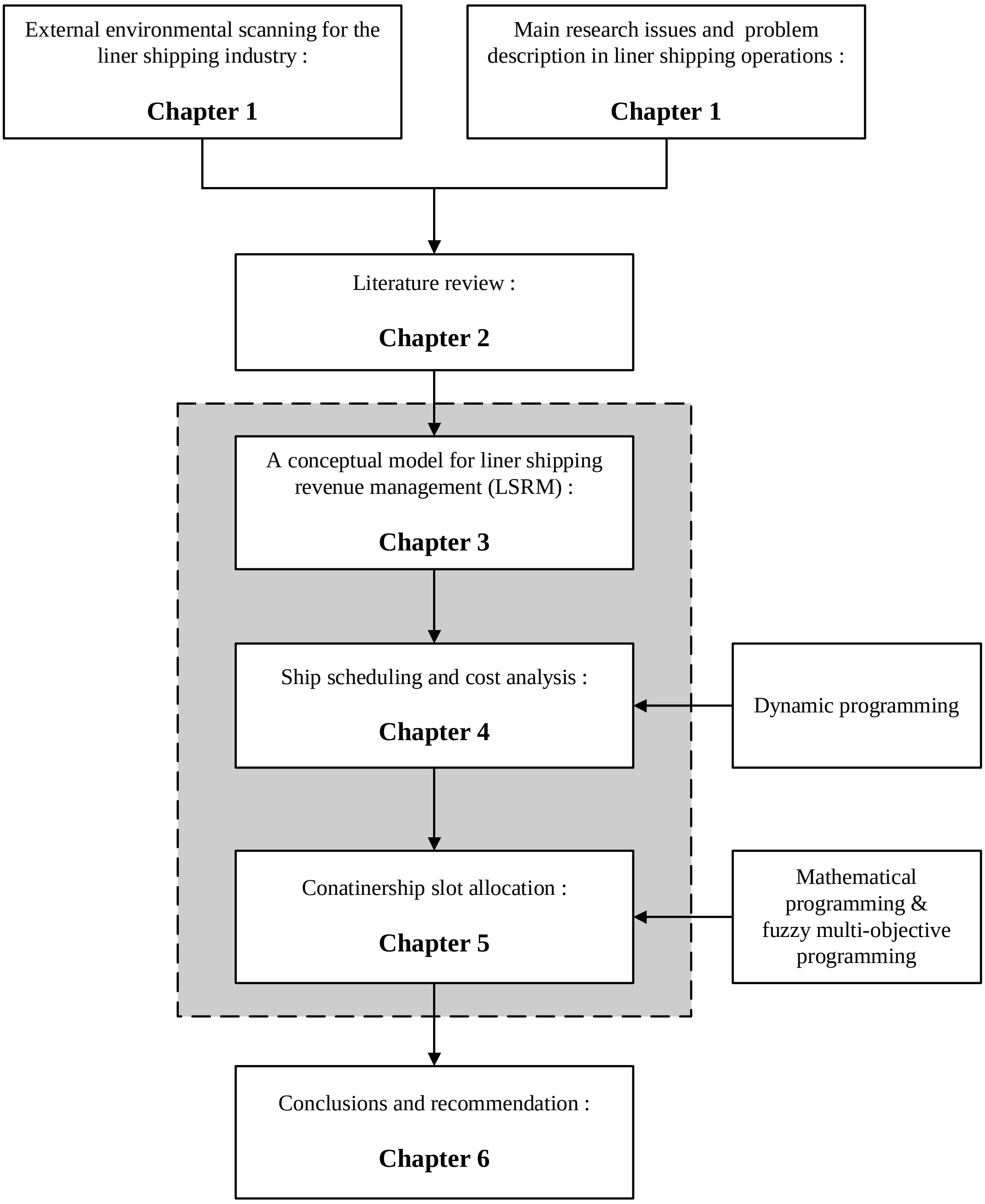


Figure 1.1 Research framework and overview of dissertation

Chapter 3, Chapter 4 and Chapter 5 are the core of this dissertation, in each chapter the problem will be described and the relevant models will be developed. In

Chapter 3, some major problems of the liner shipping industry are identified and a conceptual liner shipping revenue management (LSRM) model is proposed. LSRM is concerned with the integrated operations of long-term customer management, cost management, route planning and ship scheduling, as well as short-term cargo demand forecasting, container inventory control, slot allocation, pricing and dynamic space control.

Chapter 4 focuses on two stages: (1) ship scheduling; and (2) cost analysis of liner service route planning procedure and develop analytical models, that determine the sequences and timetables of calling ports, as well as clarify cost items of the planned routes. A dynamic programming (DP) model for ship scheduling will be proposed and cost items will be clarified, which can help planners make better scheduling decisions under berth time-window constraints, as well as estimate voyage fixed costs and freight variable costs more accurately in liner service route planning.

Containership capacity allocation is an important issue since liner companies must avoid unused space on a voyage to maximize their revenue. Therefore, in the face of uncertain cargo demand and fiercely competitive markets, liner carriers should build revenue management systems to maximize voyage profits through careful consideration of slot allocation and pricing. In Chapter 5, two containership slot allocation models are proposed, of which the first one is to deal with single objective and deterministic parameters. The second one is bi-criteria optimization model to deal with two conflicting objectives: carrier's freight contribution and agents' degree of satisfaction, as well as fuzzy constraints, i.e. uncertainties of cargo transportation demand and weight.

In addition to an effort to provide a general overview and major problems of liner shipping, relevant models are developed to solve the problems. Furthermore, we illustrate these models with case study of a Taiwan liner shipping company and compare the results to current practices in order to test the models' applicability and performance. Finally, some conclusions and recommendations are presented in Chapter 6.

Chapter 2

Literature Review

This chapter reviews studies and applications regarding revenue management extensively, which include research on the airline and air cargo industry, the liner shipping industry, the hotel industry and other industries. The needed methodology is also reviewed in this chapter, which includes dynamic programming, fuzzy multi-objective programming. These techniques will be utilized to formulate models and to resolve solutions. Additionally, as to the liner shipping operations, this chapter focuses on fleet deployment and ship scheduling, which mainly occupied the attention of researchers in recent years.

2.1 Revenue management (RM) and yield management (YM)

Revenue management (RM), alternatively known as yield management (YM), can be defined as the integrated management of price and inventory to maximize a company's profitability. RM research and a list of the industries in which it has been undertaken are shown in Table 2.1. Most RM research has dealt with airline revenue management because airlines have the longest history of developing and implementing RM systems. RM research on airlines focuses on some main areas: seat allocation, seat inventory control, pricing and overbooking control.

Table 2.1 Revenue management research and applications

Applied industries	RM issues and problems	References
Overview Concepts	Research overview	Weatherford and Bodily (1992), Donaghy et al. (1995), McGill and Van Ryzin (1999)
	Basic concepts	Kimes (1989), Gallego and Van Ryzin (1994)
	Core concepts, implementing steps	Cross (1997a) , Cross (1997b)
Airline	Seat inventory control Seat allocation	Belobaba (1987), Belobaba (1989), Brumelle and McGill (1990), Curry (1990), Wollmer (1992) Wong et al. (1993), Belobaba (1998a), Narayanan and Yuen (1998), Teodorovic (1998), Yuen and Irrgang (1998), Yuen (1998), Lautenbacher and Stidham (1999), Subramanian et al. (1999), Tajima and Misono (1999), Kuyumcu and Garcia-Diaz (2000)
	Pricing	Bodily and Weatherford (1995), Belobaba (1998b), Bergt et al. (1997), Garvett and Michaels (1998), You (1999), Wu (2002)
	Overbooking / booking control	Bodily and Pfeifer (1992), Robinson (1995), Belobaba and Farkas (1999), Chatwin (1999), Liang (1999), Wong and Tsai (2001)
	System construction	Smith et al. (1992)
	Economic efficiency	Botimer (1996)
	Impact analysis	Belobaba and Wilson (1997)
	Pricing and seat inventory control	Garcia-Diaz and Kuyumcu (1997)
	New directions and technology	Holloway (1997)
	Introduction, history and trends	Cross (1998), Kaps (2000)
	Pricing and seat allocation	Talluri and Van Ryzin (1999)

Source: collated and tabled by the author

Table 2.1 Revenue management research and applications (continued)

Applied industries	RM issues and problems	References
Air cargo	Forecasting, overbooking and bucket allocation	Kasilingam (1996)
	Pricing management	Herrmann et al. (1998)
Liner shipping	Pricing	Brook and Button (1996)
	Concepts	Kadar and Proost (1997a, 1997b)
	Slot allocation	Lee (1995), Chen and Lee (2001)
	Container reposition	Chiu et al. (2002)
Railway	Seat allocation	Ciancimino et al. (1999)
Hotel	Critical success factors for LYM	Griffin (1995)
	Human resource management HYM	Rodger and MacVicar (1996)
	Rate and reservation control	Bitran and Gilbert (1996), Norman and Mayer (1997), Quain et al. (1999), Badinelli (2000)
	Knowledge discovery framework	Choi and Cho (2000)
Manufacturer	Booking control, pricing of ATO	Harris and Pinder (1995)
Sales	Pricing	Feng and Gallego (1995), Feng and Xiao (1999), Zhao and Zheng (2000), Feng and Xiao (2000)
Restaurant	Implementing steps for RRM	Kimes et al. (1998), Kimes (1999)
Golf-course	Application	Kimes (2000)
Semiconductor	Application	Kang et al. (1998)

Source: collated and tabled by the author

2.1.1 Definition, core concepts and characteristics of RM

Weatherford and Bodily (1992) define yield management as the optimal revenue management of perishable assets through price segmentation and propose to replace the term yield management with perishable-asset revenue management (PARM). Gallego and Van Ryzin (1994) define yield management as an attempt to synthesize a range of optimal prices from a small, static set of prices in response to a shifting demand function. According to Weatherford and Bodily (1992), perishability of the product, fixed capacity, and possibility to segment customers are three common characteristics for yield management problems. Despite differences in the definition of revenue management, most researchers agree its primary goal is to maximize revenues.

Kimes (1989) suggests that RM practices are applicable where the following conditions predominate: (1) capacity is relatively fixed; (2) demand can be separated into distinct market segments; (3) inventory is perishable; (4) product is sold well in advance of consumption; (5) marginal sales costs are low and marginal production costs are high. Cross (1997) discusses core concepts, uncertainties of market and implementing steps (see Table 2.2) for RM in a non-technical fashion.

Table 2.2 Core concepts and implementing steps for RM

Seven core concepts of RM	Nine steps to RM
1. Focus on price rather than costs when balancing supply and demand.	1. Evaluate your market needs
2. Replace cost-based pricing with market-based pricing.	2. Evaluate your organization and process
3. Sell to segmented micro-markets, not to mass markets.	3. Quantify the benefits
4. Reserve sufficient product for your most valuable customers.	4. Enlist technology
5. Make decisions based on knowledge, not suppositions.	5. Implement forecasting
6. Exploit each product’s value cycle. (i.e., price it according to its freshness and the urgency with which customers wish to purchase it.)	6. Apply optimization
7. Continually reevaluate your revenue opportunities.	7. Create teams
	8. Execute, execute, execute, and
	9. Evaluate success.

Source: Cross, 1997

2.1.2 RM for airlines

Belobaba (1987) asserts that yield is a function of price together with the number of seats sold at each price. Belobaba (1987, 1989) develops a stochastic seat inventory control model with multiple fares. This model generalizes the marginal seat revenue concept to the expected marginal seat revenue principle (EMSR). The multiple-fare-class problem is further studied by Brumelle and McGill (1990), Curry (1990), Wollmer (1992), Wong et al. (1993) and Robinson (1995).

Botimer (1996) assesses airline revenue management techniques on the basis of economic efficiency and demonstrates that a differentiated fare product structure with a range of price levels coupled with effective yield management techniques can provide airline seats to those consumers who value them most when demand exceeds supply. Belobaba and Wilson (1997) present the impacts of airline yield management under competitive market conditions, taking into account the RM capabilities of competing airlines. This study makes use of a simulation model that includes both passenger choice behavior and the actual functions of airline yield management systems. Garcia-Diaz and Kuyumcu (1997) develop a graph-theory approach for allocating and setting optimal prices in an origin-destination network. Holloway's (1997), Straight and Level-Practice Airline Economics, includes one chapter to introduce the new directions and technology for airline RM system.

Teodorovic (1998) considers airline network seat inventory control problem and investigates the possibilities of using fuzzy set theory because uncertainty is one of the basic characteristics of future demand. Butler and Keller's (1998), Handbook of Airline Marketing, includes several chapters to introduce the airline RM system, Belobaba (1998a) proposes an example of the third generation yield management system (see Figure 2.1); Cross (1998) makes a detailed introduction to airline RM history and trends; Belobaba (1998b), Garvett and Michaels (1998) discuss issues related to pricing; Yuen and Irrgang (1998), Yuen (1998), Narayanan and Yuen (1998) discuss the issues related to seat allocation and booking control.

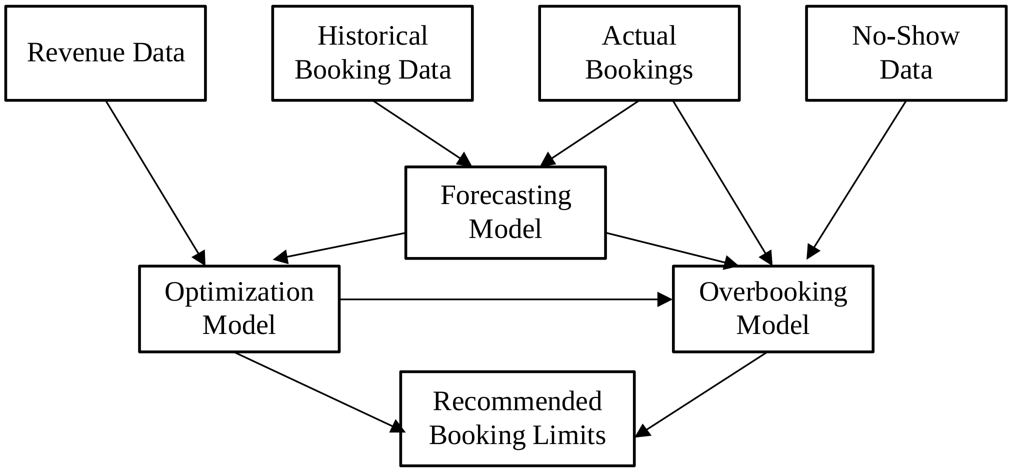


Figure 2.1 An example of third-generation YM system (Belobaba, 1998a)

Chatwin (1999) discusses a continuous-time airline-overbooking model with time-dependent fares and refunds. Talluri and Van Ryzin (1999) analyze a randomized version of the deterministic linear programming (DLP) method for computing network bid prices. Using the dynamic programming approach, Liang (1999) shows that a threshold control policy is optimal for a continuous-time dynamic yield management model. Lautenbacher and Stidham (1999) introduce dynamic and static models to identify approaches to the single-leg airline yield-management problem. Subramanian et al. (1999) formulate an overbooking control problem on a single-leg flight into a Markov decision process. Tajima and Misono (1999) report their experience in developing prototype solutions for seat allocation/reallocation problems. Kuyumcu and Garcia-Diaz (2000) propose a polyhedral graph theoretical approach utilizing split graphs and achieve significant computer time saving for solving seat allocation and pricing problems.

The correct spill estimation, or passenger demand turned away, is an integral part of the determination of optimal aircraft capacities in the fleet assignment process. While making advances in the solution of the large-scale fleet assignment optimization problem, airlines have continued to use an aggregate approach to spill estimation. Belobaba and Farkas (1999) illustrate the importance of incorporating the effects of yield management booking limits into the methodology used to estimate both the number of passengers spilled at a given aircraft capacity and their associated revenue value.

To consider a multiple booking class seat inventory control problem that relates to either a single flight leg or to multiple flight legs, You (1999) develops a dynamic pricing model to deal with two problems: (1) what are the suitable prices for the opened booking classes, and (2) when to close those opened booking classes. Kaps (2000) discusses what airline yield management is and what it is designed to accomplish and examines three components of modern airline yield management systems: (1) air traffic demand and capacity supply characteristics, (2) national and international business and economic conditions and trends, and (3) competitive forces. Wong and Tsai (2001, in Chinese) develop an optimal boundary concept for one-time decision airline overbooking problem in the cases of single-fare class and two-fare class. Wu (2002, in Chinese) creates a model to demonstrate that Taiwan domestic airlines might set a more aggressive pricing strategy when the over-capacity condition is serious, under a less over-capacity condition while airlines might resort to a more peaceful price strategy.

2.1.3 RM for air cargo

Kasilingam (1996) highlights the major differences between air cargo revenue management (CRM) and passenger yield management (PYM), and discusses the complexities involved in developing and implementing a CRM model. Hermann et al. (1998) provide a very detailed RM introduction to the air cargo business and other industries, including the influencing parameters, key success factors and pricing management.

2.1.4 RM for the liner shipping industry

In the shipping industry, Lee (1995, in Chinese) suggests a RM structure (see Figure 2.2) and formulates an optimal slot allocation model using fuzzy liner programming.

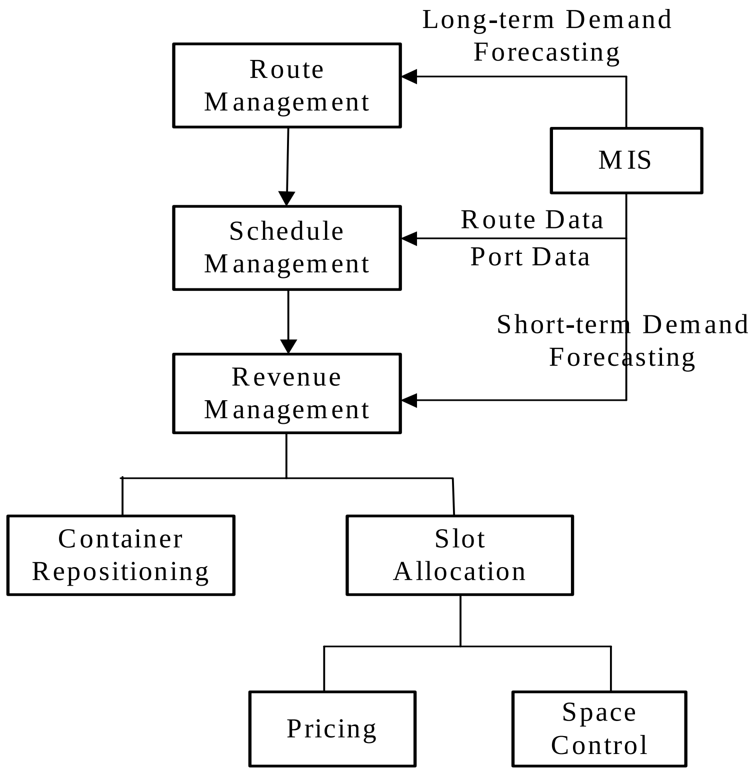


Figure 2.2 Structure of liner shipping operational strategy (Lee, 1995)

Brook and Button (1996) explore factors influencing the rates charged by liner shipping firms. Kadar and Proost (1997a, 1997b) introduce RM systems to the liner shipping industry to overcome the fiercely competitive market environment. Compared to the theoretical range of yield management systems illustrated in Figure 2.3, most liner companies are still using systems that are far from comprehensive, dynamic and integrated.

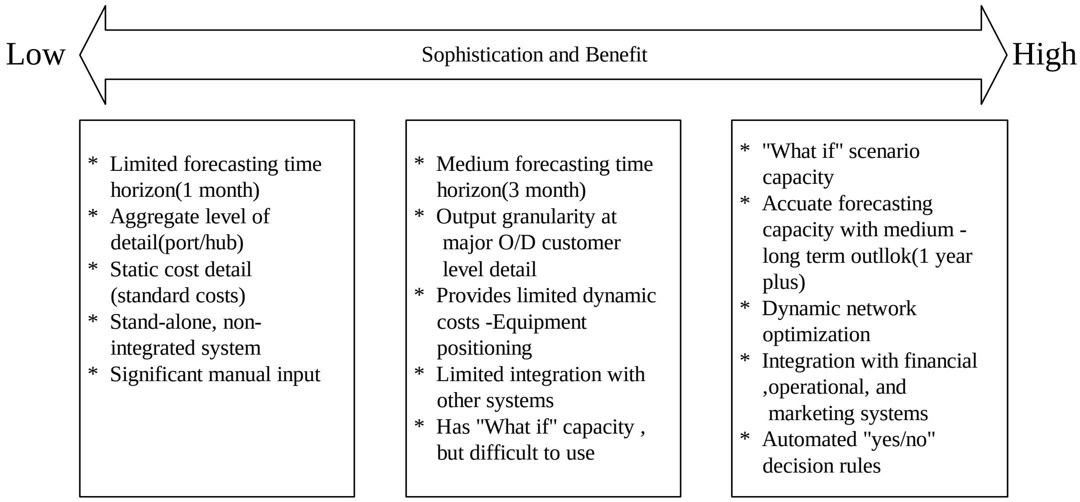


Figure 2.3 Yield management systems (Kadar and Proost, 1997b)

Chen and Lee (2001, in Chinese) deal with containership capacity allocation and formulate a multi-commodity network flow model to assign slots to each origin-destination legs. Chiu et al. (2002, in Chinese) formulates a container routing model to determine optimal paths for each set of containers with the same origin and destination, under the available capacities offered by service routes and at the minimum total costs.

2.1.5 RM for the hotel industry

In the hotel industry, hotel mangers have long been using pricing and reservation control strategies to deal with seasonal demand for room capacity constraint and to maximize the revenue. Multiple-rate pricing and reservation control problems are formulated by Bitran and Gilbert (1996), Norman and Mayer (1997), Quain et al. (1999) and Badinelli (2000). In addition, Griffin (1995) introduces the critical success factors for lodging yield management (LYM), Rodger and MacVicar (1996) discuss the human resource management issues involved in the implementation of hotel yield management. Choi and Cho (2000) develop a yield management technique to maximize revenue using probabilistic rule-based framework in knowledge discovery technique.

2.1.6 RM for other industries

Harris and Pinder (1995) apply revenue management concepts and techniques to assemble-to-order (ATO) manufacturing environments and present models for optimal pricing and capacity decisions. Ciancimino et al. (1999) were the first to apply RM to the railway industry, considering a deterministic linear programming model and a probabilistic nonlinear programming model for the network problem with non-nested seat allocation. Kimes (1999) applies yield management to restaurant and Kimes (1999) suggests a five-step approach to implement restaurant revenue management (RRM), and Kimes (2000) applies yield management to the golf course industry. Kang et al. (1998) provides a framework for implementing such an integrated yield management system in semiconductor manufacturing.

Recently there have been various studies of pricing policies in the continuous-time yield management framework. In a two-price model that allows a single price change, Feng and Gallego (1995) obtain an optimal threshold control policy. Feng and Xiao (1999) generalize these results by incorporating risk analysis and multiple price changes. Zhao and Zheng (2000) consider a dynamic pricing model for selling a given stock of a perishable product over a finite time horizon. Customers, whose reservation price distribution changes over time, arrive according to a non-homogeneous Poisson process. Feng and Xiao (2000) study a continuous-time yield management model in which reversible price changes are allowed, and formulate the problem into an intensity control model.

2.2 Fleet deployment and ship scheduling

There have been some studies on optimization models for fleet deployment problems, including fleet size and mix, cruising speed, routing or scheduling problems in sea transportation. However, most studies have been on industrial carriers, bulk carriers, or tankers. On liner fleet deployment, heuristic approaches rather than analytic optimization models have been dominant. A more detailed discussion and a survey of many relevant studies can be found in the papers of Ronen (1983, 1993). The available literature offers a comprehensive coverage of the various optimization problems that can be found in the shipping industry.

As for studies on ship scheduling or routing problems of the liner shipping, a few analytic optimization models have been proposed to solve routing and scheduling problems for liner fleets. Lane et al. (1987) tried to determine the most cost-effective size and mix for a fleet on one fixed route, and applied the model to the Australia-North America west coast route. Perakis and Jaramillo (1991), Jaramillo and Perakis (1991) developed a linear programming model for a routing strategy to minimize total fleet operating and lay-up cost and to assign each ship to some mix of the predetermined routes during a planning horizon.

Rana and Vickson (1988, 1991) addressed some problems in liner shipping and developed nonlinear programming models to maximize total profit by finding an optimal sequence of calling ports for each ship. Cho and Perakis (1996) suggested two models, one of which is a linear programming model to maximize profit. This model provides an optimal routing mix for each ship and optimal service frequencies for each candidate route. The other model is a mixed integer programming model to minimize cost, providing optimal routing mixes and frequencies, as well as best capital investment alternatives to expand fleet capacity. Powell and Perakis (1997) developed an integer programming model to minimize the operating and lay-up costs for a fleet of liner ships operating on various routes. Xie et al. (2000) presented an algorithm, which combines linear programming with dynamic programming to improve the solution for a linear model of fleet planning.

Fagerholt and Christiansen (2000) considers a traveling salesman problem with allocation, time window and precedence constraints (TSP-ATWPC) to optimize sequencing a given set of port visits in a real bulk ship scheduling problem, which is a combined multi-ship pickup and delivery problem with time windows and multi-allocation problem. The algorithm is a forward dynamic programming algorithm. Lu (2002, in Chinese) proposes the procedure and contents of practical route planning and a mixed integer programming model for calling port routing decision, amounts of service vessel, period of round trip voyage, and capacity allocation between each origin-destination pair is proposed under the condition when the cargo transportation demand is given. Chen and Chiu (2002, in Chinese) make an attempt to develop an optimization model to assist shipping carriers to solve the containership routing problem. The model is formulated as a multi-commodity network design problem, which takes ship flows and container flows into account.

2.3 Dynamic programming

Dynamic programming is a useful mathematical technique for making a sequence of interrelated decisions. It provides a systematic procedure for determining the combination of decisions that maximizes overall effectiveness. In contrast to linear programming, there does not exist a standard mathematical formulation of dynamic programming problems. Rather, dynamic programming is a general type of approach to problem solving, and the particular equations used must be developed to fit each individual situation. Therefore, a certain degree of ingenuity and insight into the general structure of dynamic programming problems is required to recognize when a problem can be solved by dynamic programming procedures and how it can be done (Hiller and Lieberman, 1986). Some basic features that characterize dynamic programming problems are presented and discussed bellow:

1. The problem can be divided into stages, with a policy decision required at each stage. Dynamic programming problems require making a sequence of interrelated decisions, where each decision corresponds to one stage of the problem;

2. Each stage has a number of states associated with it. In general, the states are the various possible conditions in which the system might be at that stage of the problem. The number of states may be either finite or infinite;

3. The effect of the policy decision at each stage is to transform the current state

into a state associated with the next stage (possibly according to a probability distribution);

4. The solution procedure is designed to find an optimal policy for the overall problem, i.e., a prescription of the optimal policy decision at each stage for each of the possible states;

5. Given the current state, an optimal policy for the remaining stages is independent of the policy adopted in previous stages. For dynamic programming problems in general, knowledge of the current state of the system conveys all the information about its previous behavior necessary for determining the optimal policy henceforth. It is sometimes referred to as the principle of optimality for dynamic programming;

6. The solution procedure begins by finding the optimal policy for the last stage;

7. A recursive relationship that identifies the optimal policy for stage n, given the optimal policy for stage $(n + 1)$, is available. The precise form of the recursive relationship differs somewhat among dynamic programming problems;

8. When we use this recursive relationship, the solution procedure moves either backward or forward stage by stage each time finding the optimal policy for that stage until it finds the optimal policy starting at the initial stage.

Dynamic programming is a very useful technique, especially for making a sequence of interrelated decisions. It requires formulating an appropriate recursive relationship for each individual problem. However, it provides a great computational savings over using exhaustive enumeration to find the best combination of decisions, especially for large problems. For example, if a problem has 10 stages with 10 states and 10 possible decisions at each stage, then exhaustive enumeration must consider up to 10^{10} combinations, whereas dynamic programming need make no more than 10^{3} calculations (Hiller and Lieberman, 1986).

2.4 Fuzzy multiple objective decision making (FMODM)

Often, many practical problems are solved under different scopes of consideration. Since Kuhn and Tucker (1951) published one of earliest considerations of multiple objectives using vector optimization concept, and then Yu (1973) proposed compromise solution method to cope with multi-criteria decision-making problems, there have abundant work of multi-criteria decision making for applications such as in transportation investment and planning, economic development planning, financial planning, capital budgeting, and investment portfolio, health care planning, land-use planning, water resource management, forest management, public policy and environmental issues, and so on. The multiple objective decision making developed over recent three decades can help resolve multi-objective problems (Cohon, 1978; Chen and Hwang, 1992). Related studies aim at figuring out how decision-maker can effectively find an optimal and compromise solution if there are many conflicting objectives during optimization (Zeleny, 1982). Nowadays, the multiple objective decision making plays an important role in the domain of operational research and management science.

On the other hand, Zadeh (1965) originally proposed fuzzy set theory and Bellman and Zadeh (1970) presented the concepts of decision-making in a fuzzy environment, as well as related heuristic approaches were developed increasingly, which consider the nature of fuzzy and conflicting decision making in practice. There are many distinguished studies to help us study and apply in this field. As to multi-attribute decision making (MADM), Hwang and Yoon (1981) developed TOPSIS for solving MADM problems, and Zimmermann (1978) first used max-min operator proposed fuzzy programming method to solve conflicts between objectives. Additionally, Sakawa (1983, 1984, 1993) developed interactive fuzzy linear, nonlinear and goal programming models. Lee and Li (1993) proposed FMODM method based on compromise programming and fuzzy set theory. Till now, many studies related to methodology and applications still devote to crisp or fuzzy MODM problems.

The common characteristics of MODM methods are that they possess: (1) a set of quantifiable objectives; (2) a set of well defined constraints; (3) a process of obtaining some trade-off information, implicit or explicit, between the stated quantifiable objectives and also between stated or unstated non-quantifiable objectives (Hwang and Yoon, 1981). In fuzzy set theory, there is a membership function $\mu(x)$ indicating each element x the degree of membership for x to belong to a set. Fuzzy multiple objective linear programming formulates the objectives and the constraints as fuzzy sets, characterized by their individual linear membership functions. The decision set is defined as the intersection of all fuzzy set and crisp set constraints. A crisp solution generated by selecting the optimal solution, such that it has the highest degree of membership in the decision set. Fuzzy linear programming is most widely used for the resolution of problems for the reason that this method accommodates the decision-making procedures of decision-makers most. Related studies include Hamacher (1978), Zimmermann (1978), Dubois and Prade (1980), Chanas et al. (1983), Werners (1987), Lai and Hwang (1992a, 1992b, 1994), and Cli'maco et al. (1993), Martinson (1993), Lee and Li (1993).

2.4.1 Fuzzy multi-objective linear programming (FMOLP)

The general concept of fuzzy multi-objective linear programming was first introduced by Tanaka et al. (1984) in the framework of the fuzzy decision of Bellman and Zadeh (1970). Following the fuzzy decision or the minimum operator introduced by Bellman and Zadeh (1970) together with any type of membership function respectively, they proved that there exist equivalent linear programming problems. Since then, fuzzy multi-objective programming has been rapidly developed and drew a great deal of attention. Fuzzy multiple objectives linear programming (FMOLP) usually can be represented as follows:

$$Max\ \tilde{z}_k = \sum_{j=1}^{n} \tilde{c}_{kj} x_j,\ k = 1, 2, \ldots, q_1 \tag{2.1}$$

$$Min\ \tilde{w}_k = \sum_{j=1}^{n} \tilde{c}_{kj} x_j,\ k = q_1 + 1, \ldots, q \tag{2.2}$$

$$s.t.\ \ \sum_{j=1}^{n} \tilde{a}_{ij} x_j \le \tilde{b}_i,\ i = 1, 2, \ldots, m_1 \tag{2.3}$$

$$\sum_{j=1}^{n} \tilde{a}_{ij} x_j \ge \tilde{b}_i,\ i = m_1 + 1, \ldots, m_2 \tag{2.4}$$

$$\sum_{j=1}^{n} \tilde{a}_{ij} x_j = \tilde{b}_i,\ i = m_2 + 1, \ldots, m \tag{2.5}$$

$$x_j \geq 0,\ j = 1, 2, \ldots, n \tag{2.6}$$

where $\tilde{c}_{kj}$ is the j-th coefficient of the k-th objective, $\tilde{a}_{ij}$ is the j-th coefficient of the i-th constraint and $\tilde{b}_i$ is the right hand side (RHS) of the i-th constraint in which $\tilde{c}_{kj}$, $\tilde{a}_{ij}$ and $\tilde{b}_i$ are fuzzy numbers.

The above FMOLP problem can be solved by transforming it into a crisp MOLP problem shown as follows:

$$Max\ (z_k)_\alpha = \sum_{j=1}^{n} (c_{kj})_\alpha^U x_j,\ k = 1, 2, \ldots, q_1 \tag{2.7}$$

$$Min\ (w_k)_\alpha = \sum_{j=1}^{n} (c_{kj})_\alpha^L x_j,\ k = q_1 + 1, \ldots, q \tag{2.8}$$

$$s.t.\ \ \sum_{j=1}^{n} (a_{ij})_\alpha^L x_j \leq (b_i)_\alpha^U,\ i = 1, 2, \ldots, m_1, m_2 + 1, \ldots, m \tag{2.9}$$

$$\sum_{j=1}^{n} (a_{ij})_\alpha^U x_j \geq (b_i)_\alpha^L,\ i = m_1 + 1, \ldots, m \tag{2.10}$$

$$x_j \geq 0,\ j = 1, 2, \ldots, n \tag{2.11}$$

where $(c_{kj})_\alpha^U$ and $(c_{kj})_\alpha^L$, $(a_{ij})_\alpha^U$ and $(a_{ij})_\alpha^L$, $(b_i)_\alpha^U$ and $(b_i)_\alpha^L$ are upper and lower bound of fuzzy number $\tilde{c}_{kj}$, $\tilde{a}_{ij}$ and $\tilde{b}_i$ respectively, which are derived from α-level cut. This crisp MOLP problem can be solved by fuzzy algorithm interactively. For details, see Zimmermann 1978, Lee and Li 1993.

Zimmermann's fuzzy linear programming with i linear objective functions is introduced as follows (Sakawa, 1993):

$$Min \quad z(x) = (z_1(x), z_2(x), ..., z_i(x))^T \tag{2.12}$$

$$s.t. \quad Ax \leq b,\ x \geq 0 \tag{2.13}$$

where

$z_i(x)$: the objective function, $z_i(x) = c_i x$, i =1,2,…,p;

x: the decision variable, $x = (x_1, x_2, ..., x_n)^T$;

b: the RHS value, $b = (b_1, b_2, ..., b_m)^T$;

A: the coefficient matrix, $A = [a_{ij}]_{m\times n}$.

For each of the objective function $z_i(x) = c_i x$, i =1,2,…,p; of this problem, assume that the decision maker has a fuzzy goal – the objective $z_i(x)$ should be substantially less than or equal to some value p_i. Thus, the corresponding linear membership function $\mu_i^L(z_i(x))$ is defined as:

$$\mu_i^L(z_i(x)) = \begin{cases} 0 & ;\ z_i(x) \geq z_i^- \\ \dfrac{z_i(x) - z_i^-}{z_i^+ - z_i^-} & ;\ z_i^+ \leq z_i(x) < z_i^- \\ 1 & ;\ z_i(x) \leq z_i^+ \end{cases} \tag{2.14}$$

where z_i^- denotes the objective value of pessimistic expectation by a decision maker, and z_i^+ denotes the objective value of optimistic expectation by a decision maker. This is shown in Figure 2.4.

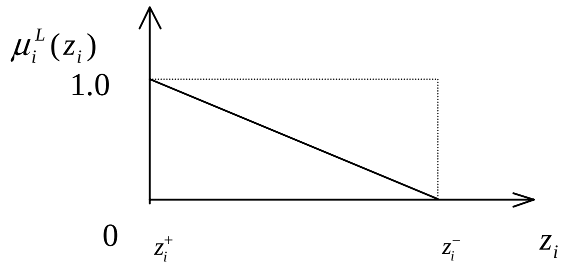


Figure 2.4 The achievement level for fuzzy objectives

Using such linear membership function $\mu_i^L(z_i(x))$, i =1,2,…,k; and apply the operator of Bellman and Zadeh (1970), the original problem can be changed as:

$$\underset{i}{Min} \quad \mu_i^L(z_i(x)) \tag{2.15}$$

$$s.t. \quad Ax \le b,\ x \ge 0 \tag{2.16}$$

Interpreting the auxiliary variable λ, the above formulation can be rewritten as follows:

$$Max \quad \lambda \tag{2.17}$$

$$s.t. \quad \lambda \le \mu_i^L(z_i(x)), \quad i=1,2,\ldots,p; \tag{2.18}$$

$$Ax \le b,\ x \ge 0. \tag{2.19}$$

2.4.2 Interactive multi-objective linear programming with fuzzy parameters (MOLP-FP)

In practice, it would certainly be more appropriate to consider that the possible values of the parameters in the description of the objective functions and the constraints usually involve the ambiguity of the experts' and decision makers' understanding of the real system. In contrast to the multi-objective linear programming problems discussed above, by considering the experts' imprecise or fuzzy understanding of the nature of the parameters in the problem-formulation process, multi-objective linear programming problems involving fuzzy parameters are introduced and solved through interactive algorithm. The interactive fuzzy multi-objective linear programming can be used to derive the satisfying solution of the decision maker (DM) efficiently from a Pareto optimal solution set (Sakawa, 1993).

When formulating a multi-objective linear programming problem, which closely describes and represents the real-world decision situation, various factors of the real-world system should be reflected in the description of the objective functions and the constraints. Therefore, these objective functions and constraints involve many parameters whose possible values may be assigned by the experts or decision makers. In the conventional approaches, such parameters are required to fix some values in an experimental and/or subjective manner through their understanding of the nature of the parameters in the problem-formulation process.

In most real-world situations, the possible values of these parameters are often only imprecisely or ambiguously known to the experts or decision makers. With this observation, it would be certainly more appropriate to interpret their understanding of the parameters as fuzzy numerical data, which can be represented by means of fuzzy sets known as fuzzy numbers. The resulting multi-objective linear programming problem involving fuzzy parameters would be viewed as a more realistic version than the conventional one. The interactive algorithm plays an important role in finding out satisfying solutions, which is addressed as follows:

The DM must select a compromise or satisfying solution from an α-Pareto optimal solution set based on a subjective value judgment. Thus, an interactive programming approach to the MOLP-FP (Sakawa, 1993) is constructed to derive the satisfying solution of the DM from the α-Pareto optimal solution set, in which the steps marked with an asterisk involve interaction with the DM.

Step 0: Individual minimum and maximum

Calculate the individual minimum and maximum of each objective function under the given constraints for $\alpha = 0$ and $\alpha = 1$.

Step 1: Initialization*

Ask the DM to select the initial value of α $(0 \le \alpha \le 1)$ and the initial reference levels $\overline{Z}_i$, $i = 1,\ldots, k$.

Step 2: α-Pareto optimal solution

For the degree α and the reference levels specified by the DM, solve the corresponding minimax problem and perform the α-Pareto optimality test to obtain the α-Pareto optimal solution together with the trade-off rates between the objective functions and the degree α.

Step 3: Termination or updating*

The DM is supplied with the corresponding α-Pareto optimal solution and the trade-off rates between the objective functions and the degree α. If the DM is satisfied with the current objective function values of the α-Pareto optimal solution, stop. Otherwise, the DM must update the reference levels and/or the degree α by considering the current values of the objective functions and α together with the trade-off rates between the objective functions and the degree α and return to step 2.

At Step 1, to generate a candidate for the satisfying solution which is also α-Pareto optimal, in this interactive decision-making method, not considering the fuzzy goals of the DM for each of the objective functions of the α-MOLP, the DM is asked to specify the degree α of the α-level set and the reference levels of achievement of the objective functions, called reference levels.

At Step 2, the minimax problem is simply used as a means of generating an α-Pareto optimal solution, and if the DM is not satisfied with the current α-Pareto optimal solution, it is possible to improve the solution by updating the reference levels and/or the degree α.

At Step 3, given the α-Pareto optimal solution for the degree α and the reference levels specified by the DM by solving the corresponding minimax problem, the DM must either be satisfied with the current α-Pareto optimal solution or act on this solution by updating the reference levels and/or the degree α. To help the DM express a degree of preference, trade-off information between a standing objective function and each of the other objective functions as well as between the degree α and the objective functions is very useful.

2.5 Concluding Remarks

In transportation industries revenue management has been introduced and shown to successfully solve problems related to perishability, fixed capacity, high capacity, variable costs, demand and market segmentation, advance sales and bookings, stochastic demand, historical sales data, and also assist forecasting capabilities. The aforementioned characteristics are also found in liner shipping operations. Proven to be an effective tool in the airline industry, revenue management has considerable potential for the liner shipping industry.

The volume of publications on liner shipping is fairly limited, especially in cost and revenue analysis, because of the confidentiality that often shrouds highly commercial information such as fleet-deployment, costs, freight revenue, rates and marketing strategies. In addition to the literature related to ship scheduling problems, studies aimed at the costs and profitability analysis for liner shipping service route planning due are also limited due to lack of the data.

The interactive algorithm plays an important role in finding out satisfying solutions, since in most real-world situations, the possible values of parameters are often imprecisely or ambiguously known to the experts or decision makers. With this observation, it would be certainly more appropriate to interpret their understanding of the parameters as fuzzy numerical data, which can be represented by means of fuzzy sets known as fuzzy numbers. The multi-objective linear programming involving fuzzy parameters can be viewed as a more realistic version than the conventional one.

Chapter 3

Liner Service Revenue Management (LSRM)

In this chapter, some major problems of the liner shipping industry are identified and a conceptual liner shipping revenue management (LSRM) model is proposed. LSRM is concerned with the integrated operations of long-term customer management, cost management, route planning and ship scheduling, as well as short-term cargo demand forecasting, container inventory control, slot allocation, pricing and dynamic space control.

3.1 Major problems of the liner shipping industry

Viewing this industry overall, some major problems regarding cost and revenue issues are summarized as follows:

1. Cost-reduction and freight rate competition

The business of this industry is now entirely cost-reduction, which in turn depends upon generating supply. Increasing the vessel capacity supply helps carriers' lower ceilings by forcing down per-unit costs. The problem is that to attract more cargo, individual carriers must provide additional capacity. So it is hardly surprising that many trades are plagued with overcapacity, fierce competition and low rates. The result is a vicious circle: cutting costs - increasing space supply - building bigger ships - creating overcapacity - competing by reducing freight rates -

suffering from low rates - cutting costs. Moreover, this vicious circle speeds up because of some additional factors: (a) undifferentiated services; (b) fuzzy brand recognition; (c) low switching costs and weak loyalty; and (d) break-up of conferences.

2. Improper marketing and pricing strategy

Kadar and Proost (1997) tracked the ships allocated to the nine main routes and calculated TEU miles deployed. The results show that between 1990 and 1995 average capacity utilization was fairly stable at about 75%, with fluctuations in seasonal demand producing peak utilization figures near 80%. Actual effective capacity utilization was higher at 85%~89%, when some additional factors are taken into account. This indicates the main problem of this industry, capacity utilization better than other industries but carriers still struggle with low return operations.

Agents, sales representative and persons in charge of pricing at headquarters know instinctively about the dependency among supply, demand and price. Agents or sales representatives lower the prices on the spot market and to attract needed cargo tonnage, when every time demand goes down in a market. Many liner companies focus short-term performance improvement by trying to control load factors. An increase in capacity utilization is usually viewed as a remedy for declining yields. A downward spiral of lower and lower yields is triggered by lowering prices to generate more demand.

Clearly pricing and revenue management are directly linked: revenue equals price times lifts, which means that price determines revenue. If the price is set too high, demand will be low; if too low, demand will be much higher than capacity. When we look at the price-demand relation (see Figure 3.1), assuming that we are acting in a very simple market model, there are principally two ways to react in the market: either we change the price and cope with the reaction in terms of more or less demand by adjusting the capacity availability; or we influence the capacity availability and have to assess the necessary reaction in terms of prices. Most carriers simply use the low rate policy to assure space utilization, which is illustrated as the point A of Figure 3.1. This resulted in the space supply increase and lower rates.

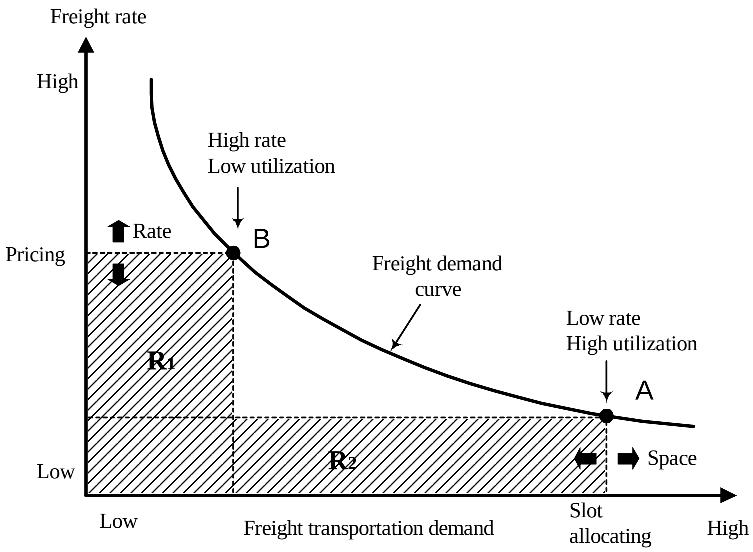


Figure 3.1 Low rate/high utilization vs. high rate/low utilization

3. Empty container repositioning problems

Repositioning empty containers is costly for liner carriers, and recent increases in container flow imbalances in the main trades, especially the transpacific and

Asia/Europe trades, have highlighted this problem. A detailed analysis of the world container flow (see Table 3.1) shows a continuously worsening situation. Storing and repositioning such massive and increasing volumes of empty containers is growing more costly, and the need for empty repositioning remains one of the container carriers' biggest problems. The problems not only result in losing revenue opportunities and increasing container handling and storage costs, but bring some negative effects on marketing strategies, e.g. low rates, container one-way free use, that erode revenue even further.

Table 3.1 World container movements (in million TEUs)

Year	Loaded	Empty	Total	Empty/Total
1990	66	17	83	20.5%
1992	80	20	100	20.0%
1994	100	24	124	19.4%
1996	119	28	147	19.0%
1998	134	33	167	19.8%
2000*	152	38	190	20.0%
2002*	162	41	203	20.0%

Source: Containerisation International Yearbook 1999; notes: * = estimates.

4. Global alliances

Liner carrier alliances are developing at least two different types: (i) core alliances with a set of global partners, (ii) multi-consortia networks of slot exchanges covering individual traders (Damas, 1996). Through this kind of global alliance arrangement, a lot of scale benefits can be achieved: more frequent services, shorter transit times, wider port coverage, lower slot costs and a stronger bargaining position in negotiating with terminal operators, container depots and inland/feeder transportation carriers. Liner alliances operational cooperation are listed as follows:

- Joint terminals or terminal contracts,
- Joint services,
- Joint feeder services,
- Joint purchase or ownership of ships,
- Joint purchase and usage of containers,
- Joint intermodal, rail or trucking operations,
- Joint container depots,
- Jointly-managed pools of containers and equipments,
- Joint EDI systems,
- Joint bunker purchase,
- Interchange of empty containers.

In addition, there are some trends critically influencing the development of this industry, such as fewer and larger carriers, continuous overcapacity, severe competition, low freight rates, post-Panamax ships, less transit time, hub-and-spoke operations, pendulum services, network integration, total logistics services, and carriers' developing the internet electronic business.

3.2 Characteristics of LSRM environments

There are five characteristics of LSRM environments, as follows:

1. Perishability

All container transportation services are perishable; and vessel capacity is also perishable. Just like airlines, freight revenue from an empty slot is zero at departure from the last loading port in the origin area, unused capacity is lost and represents potential revenue loss in liner shipping environments.

2. Fixed capacity and high capacity change costs

RM is most applicable to environments with short-term fixed capacity, and LSRM faces the same situation. Although slot chartering in/out is sometimes available to increase or decrease capacity, there are still limits to these temporary capacity extensions or deductions and unit costs of the additional capacity will cost a lot more than regular ones.

3. Segmenting demand

RM is most effective when demand can be segmented and price sensitivity varies from market segments. Segmenting cargo transportation demand may be difficult and carriers have made few efforts for it. But there are still many options, similar to the airline industry, which relies primarily on time-sensitive and destination-sensitive fencing restrictions to segment demand. So in principle, liner shipping operations can segment the cargo transportation demand in a similar manner.

4. Advance bookings and stochastic demand

Another key element of liner shipping operation is the advance booking process. Advance sales assure some space utilization and allow updating of long-term and medium-term demand forecasts and pricing strategy. While fluctuations in demand create problems for efficient vessel space management, these same fluctuations create revenue opportunities. Thus, demand fluctuations enhance the value of change order responsiveness.

5. Historical lifting data and forecasting capability

To realize the potential of RM requires customer, market and revenue data. This information is used for both demand forecasting and segmenting between time sensitive and price sensitive cargoes. Capturing the useful historical data and making it accessible to LSRM systems is crucial to the implementation of RM.

In light of the above characteristics, liner shipping companies may soon find RM techniques indispensable for refining their operation. This industry is ripe for the application of RM and expects great profits from RM.

3.3 Components and functions of LSRM

Liner carriers require dramatic changes in operational practices to face this tough and fluctuating market. To provide them with a good solution to build RM systems, a conceptual liner shipping revenue management (LSRM) model is proposed. LSRM is concerned with the integrated operation of long-term customer management, cost management, route planning and ship scheduling, as well as short-term cargo demand forecasting, container inventory control, slot allocation, pricing and dynamic space control.

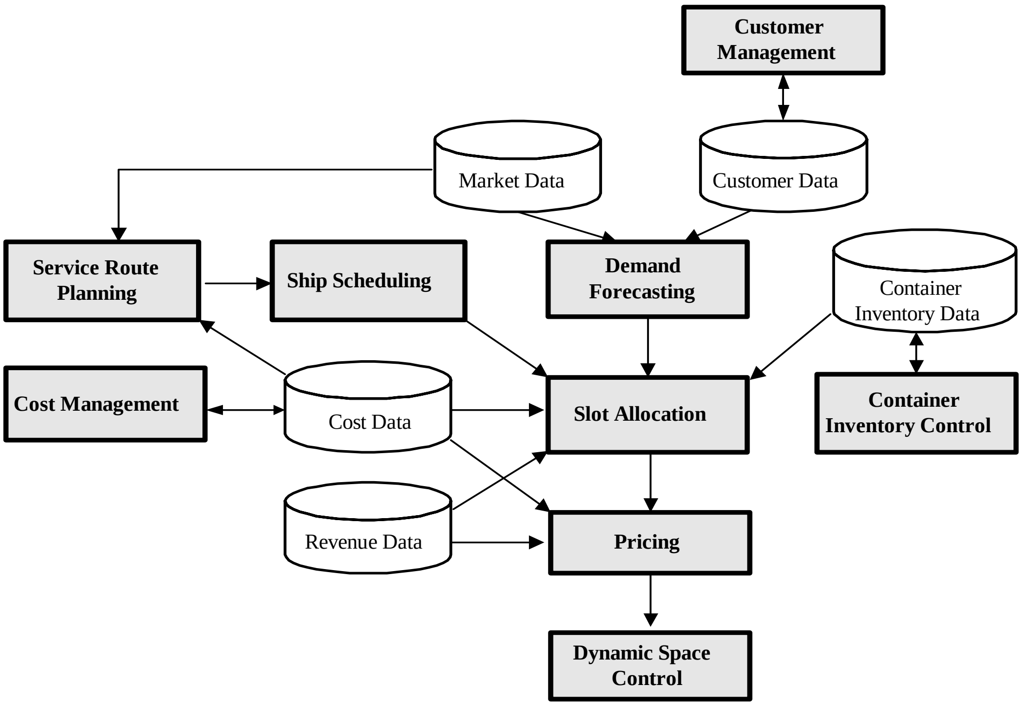


Figure 3.2 A conceptual model for liner shipping revenue management system

The proposed LSRM system is shown in Figure 3.2. There are two major components: (1) long-term planning, which can assist with longer term customer management, cost management, market monitoring, service route planning and ship scheduling; and (2) short-term operations, which can assist with voyage revenue optimization in terms of demand forecasting, slot allocation, pricing, container inventory control and dynamic space control. Ideally such a system should be integrated with freight revenue, cost, container inventory database and accounting systems.

Computerized liner shipping operations frequently have a critical start on RM implementation because its computerized information can be incorporated into the RM system to provide decision support information regarding market, customer, container inventory, cost and revenue. A complete LSRM system would provide operational functions as follows:

3.3.1 Long-term planning

1. Customer management

A customer database records the customers' basic data, booking data, cargo distribution and volume. This provides the information necessary to maintain service contracts and to forecast demand.

2. Cost management

There must be a powerful database recording every item of costs including fixed and variable costs. Variable costs, in particular, should be tracked with detailed records of every shipment including truck, feeder and railway costs, container handling costs, terminal and depot stowage costs, commission, tally costs and cargo claim costs. The variable costs of all service point pairs are needed to accurately calculate the freight's marginal contribution.

3. Service route planning and ship scheduling

This function provides the decision support to plan new service routes and to modify or integrate the current service network so that the company can maximize the shipment potential. To choose the calling ports and rotation, market information is required, including global/regional economic and trade development, as well as container flow between port pairs. Meanwhile, the personnel in charge of operation or planning can deploy the fleet by the terminal/berth windows and maintain punctuality of schedule.

3.3.2 Short-term operations

1. Demand forecasting

By means of the data on market, customers and historical booking, this subsystem can provide estimates of advance sales and report exceptions for each demand segment to analysts or decision-makers.

2. Container inventory control

In this subsystem, there is a container inventory database, which records and provides all the locations and numbers of containers, both owned and leased. It provides support for making right decisions to handle container reposition, on-hire and off-hire, so as to provide customers with the containers they need and decrease container-holding costs.

3. Slot allocation

Slot allocation is the process of determining the space to be allocated to different legs, markets and customers on a given voyage, based on their demand, cargo marginal contribution, containership capacity, container inventory and profitability. This subsystem supports the right slot allocation decision to maximize freight contribution.

4. Pricing

Based on information related to costs, local market sales, demand pattern (e.g. distribution, time, volume, delivery condition), this subsystem provides tactical pricing decision support to make the space sell at the right price, to the right customer and at the right loading port, as well as maximize the contribution and utilization of the vessel capacity.

5. Dynamic space control

From a voyage's commencement, space usage is dynamic, and there will be differences from pre-allocation. This subsystem provides functions to monitor the booking and lifting situation, and to dynamically reallocate space to prevent unused space.

3.4 Concluding remarks

The implementation of LSRM systems needs a lot of work, for example, integration with related databases and pricing, as well as container inventory and dynamic slot control. In addition, computerization is a critical element in LSRM implementation because computerized information can be incorporated into RM systems to provide decision support information related to markets, customers, container inventory, costs and revenue.

There are some components of the proposed LSRM systems to be modeled, computerized and integrated. To build and solve a model optimizing space utilization, which covers the decisions of all the components, fully utilizes historical data to forecast cargo demand, and dynamically adjusts its pricing and allocation decisions with the evolving booking data is out of the question. Referring to the literature, most airlines and researchers deal with the seat allocation problem flight by flight. Since pricing, container invetory and dynmic space controls are based on slot allocation decision. Slot allocation is deemed to be the core element of the LSRM system and long-term service route planning affects service scope and quality. Thus, ship scheduling and slot allocation problems are chosen for this study to be the first approach to build the LSRM systems.

Chapter 4

Ship Scheduling and Cost Analysis for Liner Service Route Planning

Liner shipping companies can benefit greatly from using systematic methods to improve ship scheduling and cost analysis on service route planning. This chapter proposes a dynamic programming (DP) model for ship scheduling and clarifies cost items. This can help planners make better scheduling decisions under berth time-window constraints, as well as to estimate voyage fixed costs and freight variable costs more accurately in liner service route planning.

4.1 Liner service route planning

Liner shipping provides regular services between specified ports according to timetables advertised in advance. The services are, in principle, open to all shippers and seem like public transport services. The provision of such services, often offering global or regional coverage, requires extensive infrastructure in terms of ships, equipment (e.g. containers, chassis, trailers) and assigns agencies. Since a service route of one containership fleet, once determined, is hard to alter for a certain period of time, the initial route planning and scheduling decisions should be made carefully after thorough study and planning. It is highly desirable to plan new routes and rearrange service networks by analytical methods, since improvement of ship scheduling and cost estimates can yield additional profits or cost savings. In liner shipping long-term operations, there are five key functions, customer relationship management, market monitoring, cost management, service route planning and ship scheduling. The latter two functions are for providing decision support to plan new service routes and modify or integrate the current service network so that companies can maximize their shipment potential.

Generally, a liner company may follow the procedure shown in Figure 4.1 to plan a new service route and/or to integrate current service routes.

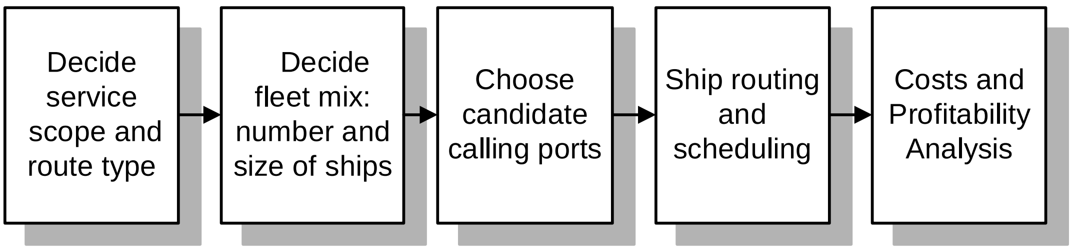


Figure 4.1 Procedure of liner service route planning

The first stage in this process is to decide service scope and route types according to either cargo flow distribution and growth or service coverage requirements. Currently, shipping lines operate three general types of deep-sea itineraries: end to end, pendulum and round the world service routes (Lim, 1996), which are shown in Figure 4.2. End to end services schedule vessels back and forth between two continents. Pendulum services schedule vessels back and forth between three continents with one of these continents as a fulcrum, with the points at either end of the pendulum swing linked only through the fulcrum. This type of service offers a way to fill container slots four times on the same voyage and to eliminate certain overlapping port calls in the fulcrum area. The merging of separate end-to-end services into a pendulum or round the world service serves the two main purposes of broadening the range of through services and reducing the number of ships required to provide the same coverage. This gives a major cost saving by merging the previously duplicated port calls in the central region of the pendulum. Also round the world services can overcome the problems of end-to-end operations, by accommodating the needs of global corporations. The world's three principal trade corridors are tied together into one and this type of service can move in either direction, moving westward or eastward or in both directions.

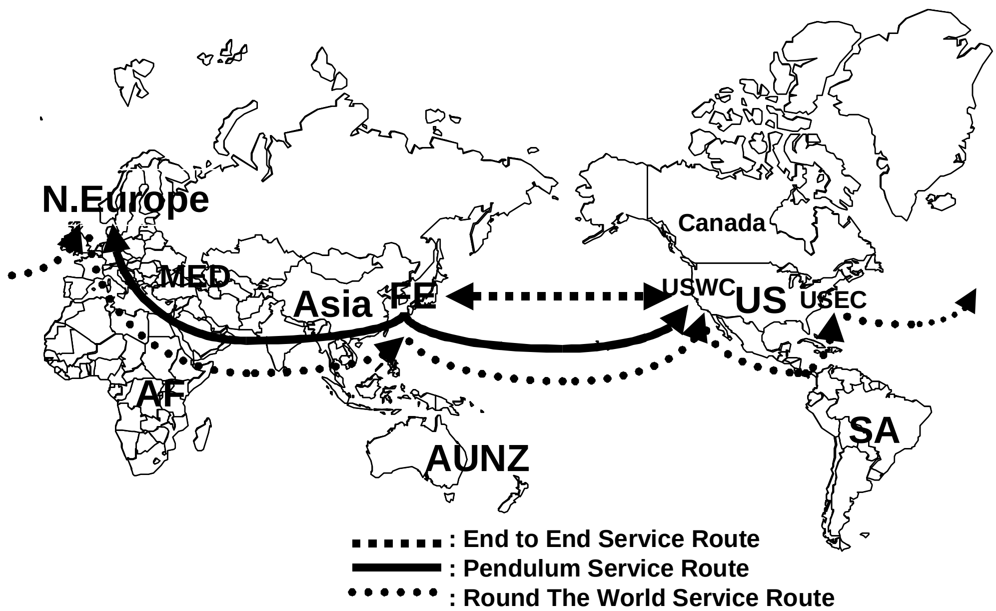


Figure 4.2 Three types of liner service routes

At the second stage, planners may consider trade scale (i.e. cargo transport demand) of the planned route and the available owned/chartered-in fleet to determine fleet mix. At the same time, regularity and frequency of service are considered to determine number and size of ships, which are important factors for ship routing and scheduling decisions. At this stage, planners might determine approximate service frequencies on the planned route. Additionally, they might also decide which ships to add to the fleet, i.e. among a finite set of capital investment options which ships to reallocate, which ships to charter in for the planning horizon, which ships to build or purchase. Deploying improper size containerships, can easily lead to low capacity utilization for carriers who decide to operate independently, so carriers often develop cooperative partnerships or strategic alliances with other carriers. Alliances have emerged in order to exploit economies of scope among otherwise competing operators, using strategies such as the individual service network integration, vessel sharing, slot chartering, slot exchange, joint ownership and/or utilization of equipment and terminals.

Choosing candidate calling ports at the third stage is to maximize the shipment potential on the planned route; and for this market information is required, including global/regional economic, trade development. Uncertainty of cargo demand plays a major role in liner operations. Therefore, planners need, as important preliminary data for the second stage, the cargo demand forecasts and port-pair cargo flows for the markets the shipping company plans to serve. According to the demand forecasts of each port pair for the planning horizon, they can suggest a finite set of candidate calling ports, which are derived from their common sense, past experience, or view of future main cargo flows.

The first three stages as mentioned above are less structural problems and are difficult to formulate using analytical models. In this chapter, we focus on issues regarding the latter two stages of the planning procedure and develop analytical models, which determine the sequences and timetables of calling ports, as well clarify cost items of the planned routes. Liner shipping companies can benefit greatly from improving ship scheduling for service route planning by systematic methods. This chapter proposes a dynamic programming (DP) model for ship scheduling and clarifies cost items. This can help planners make better scheduling decisions under berth time-window constraints, as well as estimate voyage fixed costs and freight variable costs more accurately in liner service route planning.

4.2 Ship scheduling

Scheduling is a fairly common problem in transport but, nevertheless, liner shipping has certain intrinsic features that make the design of scheduling models particularly difficult. Ship scheduling is the most detailed level of planning liner fleet operations. In service route planning, ship scheduling concerns the assignment of arrival and departure times to ships operating on a route. It includes determining estimated time to berth (ETB), and estimated time to departure (ETD) when the ships will call at ports, as well cruising speeds between two sequential ports and quay crane dispatching, buffer time arrangement decisions (see Figure 4.3). Usually a given set of candidate calling ports' available time windows has to be determined in advance, and some congested ports' available berth time-windows are extremely limited. We deem these hard time windows. On the other hand, there may be flexibility in the available time windows, called soft time windows. Dynamic programming is a very useful technique for making a sequence of interrelated decisions, providing a systematic procedure for determining the combination of decisions that maximizes overall effectiveness. The proposed ship scheduling model is formulated through dynamic programming.

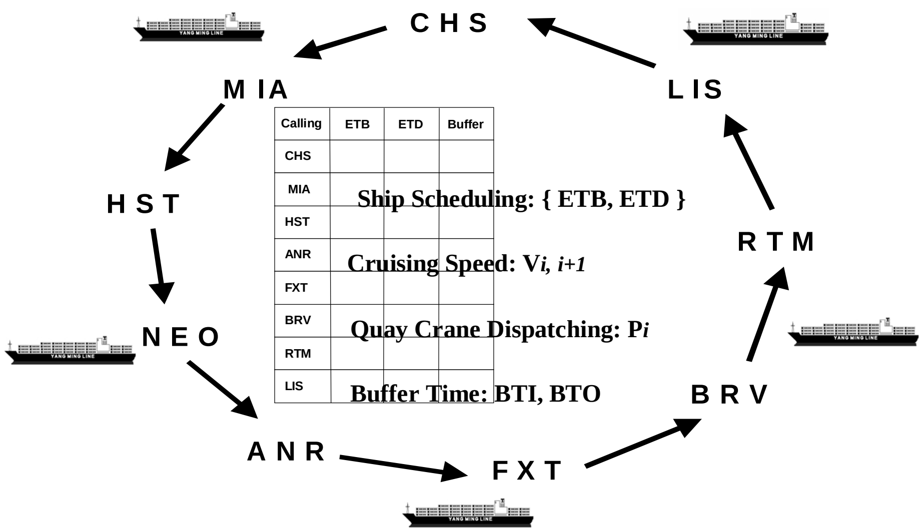


Figure 4.3 Ship scheduling problems of the liner shipping

4.2.1 Model formulation: dynamic programming

Using dynamic programming, discrete stages are defined for the original problem, and states are defined for individual stages. In this case, the stages of the dynamic programming solution procedure are the sequential candidate ports where the route is planned to call. There are n candidate calling ports, so the dynamic programming solution procedure has n stages. We use index i to denote the candidate calling ports; i = 1, 2, ...n. The dynamic programming problem of optimal ship scheduling is formulated as follows.

The following assumptions are imposed for the model:

(1) The available birth time windows at each candidate calling port have been provided by the terminal operators.

(2) The cruising speed can be adjusted to a certain extent depending on the ships' design.

(3) The volume of each port cargo movement including way-port cargo can be

estimated approximately.

(4) The container handling productivity of terminals as each calling port can be adjusted to a certain extent to accommodate the carrier's requirements.

Based on the assumptions as mentioned above, the states of each stage are defined as a set associated with the major factors that affect estimated schedules at the very next calling port. The problem is divided into n stages with an action of cruising speed, quay crane dispatching and buffer time decisions at each stage *i*. Each stage has some factors associated with the next stage. The state at each stage *i* is defined as follows:

$$S_i = \left\{ P_i, BTO_i, V_{i,i+1}, BTI_{i+1} \right\} \tag{4.1}$$

where,

P_i = Gantry crane productivity at calling port *i* (unit: moves per hour), which is in the set **Pi** of available crane productivity offered by the terminal operators at port **i**, i.e. $P_i \in \mathbf{Pi}$.

BTO_i = Buffer time for departuring from calling port *i* (unit: hour).

$V_{i,i+1}$ = Cruising speed from calling port *i* to the next calling port *i* +1 (unit: knot, nautical miles per hour), which is in the interval between minimum critical speed, $V_{\min}$ and maximum critical speed, $V_{\max}$, i.e. $V_{i,i+1} \in \mathbf{V}[V_{\min}, V_{\max}]$.

BTI_{i+1} = Buffer time for arriving at the very next calling port *i* +1 (unit: hour).

ETW_i, the estimated time windows at port *i* (i.e. stage *i*) is represented as follows:

$$ETW_i = \{ETB_i, ETD_i\}. \tag{4.2}$$

where,

ETB_i = Estimated time to arrival at the assigned berth (ETB) of calling port *i*.

ETD_i = Estimated time to departure (ETD) from calling port *i*.

The voyage time of each leg (i.e. one-trip voyage from port *i* to the next port *i* +1) for scheduling is illustrated by Figure 4.4 and explained below.

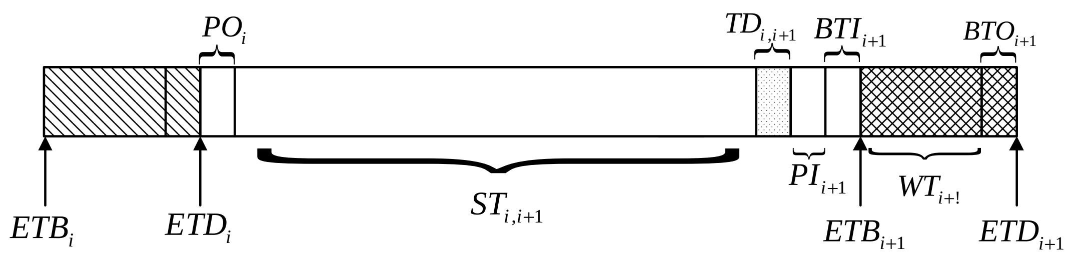


Figure 4.4 Voyage time from port *i* to the next port *i* +1

ETB_{i+1}, estimated time to berth at the very next calling port can be derived from Equation (4.3).

$$ETB_{i+1} = ETD_i + PO_i + ST_{i,i+1} + TD_{i,i+1} + PI_{i+1} + BTI_{i+1}. \tag{4.3}$$

where,

PO_i = Pilot-out time at calling port *i* (unit: hour).

$ST_{i,i+1}$ = Steaming time from calling port *i* to the next calling port *i* +1 (unit: hour).

$TD_{i,i+1}$ = Time zone difference between calling port *i* and the next calling port *i* +1 (unit: hour).

PI_{i+1} = Pilot-in time at calling port *i* +1 (unit: hour).

The pilot in/out time at a calling port can be estimated by experienced captains. Time zone differences are tabulated in world port time zone tables. The steaming time from calling port *i* to the next calling port *i* +1 can be calculated by Equation (4.4).

$$ST_{i,i+1} = D_{i,i+1} / V_{i,i+1} \tag{4.4}$$

where,

$D_{i,\,i+1}$ = Distance from calling port *i* to the next calling port *i* +1 (unit: nautical mile).

ETD_i , estimated time to departure from the very next calling port can be derived from Equation (4.5).

$$ETD_i = ETB_i + WT_i + BTO_i \tag{4.5}$$

where,

WT_i = Working time for unloading and loading containers at calling port *i* (unit: hour).

Working time to unload and load containers can be calculated by Equation (4.6),

$$WT_i = (TM \times M_i) / P_i \tag{4.6}$$

where,

TM = Total expected container moves on the round-trip voyage (unit: move),

M_i = Expected cargo proportion at calling port *i* (unit: %).

Total expected container moves can be calculated by Equation (4.7),

$$TM = N \times CP \times U \times (TF/2 + 0.5) \tag{4.7}$$

where,

N = 4, when the planned route type is end-to-end service,

N = 6, when the planned route type is pendulumn service,

N = 8, when the planned route type is round-the-world service,

CP = Average vessel operational capacity of the fleet (unit: TEU, Twenty-foot equivalent unit),

U = Expected capacity utilization (unit: %),

TF = 20’ container proportion on this trade (unit: %).

Once ETB_i is determined, ETD_i, ETB_{i+1} and ETD_{i+1} can be derived from Equation (4.3) ~ (4.7) above; and P_i, BTO_i, $V_{i,i+1}$ and BTI_{i+1} are factors to determine estimated time windows, of which P_i and $V_{i,i+1}$ are two key factors. The action of the dynamic programming is defined as the decisions for cruising speed, quay crane dispatching, and buffer time chosen at any stage *i* to minimize the total expected variations in time from available berth time windows to estimated berth time windows for the planned voyage. We illustrate the optimal ship scheduling policy with Figure 4.5, in which each voyage leg is arranged to meet terminal time-window constraints as closely as possible.

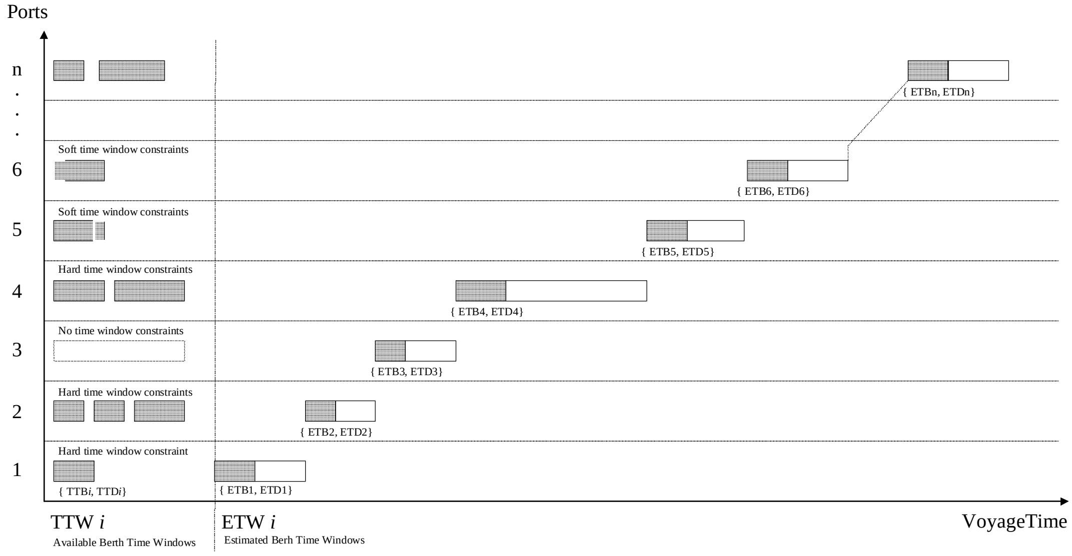


Figure 4.5 Ship scheduling with berth time-window constraints

Let $TTW_i = \{ TTB_i, TTD_i \}$, available terminal time window at calling port *i*, where,

TTB_i = Available berthing time at calling port *i* terminal.

TTD_i = Available departuring time at calling port *i* terminal.

The terminal operators at calling ports might offer single or multiple time windows with hard or soft constraints. There are some patterns with respect to time-window conditions offered by terminal operators or port authorities, which can be categorized into three types, as follows:

(1) $\{\hat{TTB}_i, \hat{TTD}_i\}$: both-side hard time-window constraints,

(2) $\{\hat{TTB}_i, \tilde{TTD}_i\}, \{\tilde{TTB}_i, \hat{TTD}_i\}$: single-side hard time-window constraints, i.e. one-side soft time window constraints,

(3) $\{\tilde{TTB}_i, \tilde{TTD}_i\}$: no time-window constraints, i.e. both-side soft time window

constraints.

An appropriate recursive relationship for ship scheduling problem must be formulated, one which is divided into n stages that correspond to the n voyage legs of the rotation. This recursive relationship minimizes the total expected variations in time from available berth time windows to estimated berth time windows, as represented in Equation (4.8),

$$Z_{i+1}^{*} = Z_{i}^{*} + \underset{P_i \in \mathbf{Pi},\, BTO_i}{Min} (ETD_i - TTD_i)^2 + \underset{V_{i,i+1} \in \mathbf{V},\, BTI_{i+1}}{Min} (ETB_{i+1} - TTB_{i+1})^2 \tag{4.8}$$

When we use this recursive relationship, the solution procedure moves forward (or backward) stage by stage, each time finding the optimal policy for that stage until it finds the optimal policy stopping at the last (or first) stage. The algorithm for ship scheduling is shown as Figure 4.6 and explained as follows:

Step 1. Input the needed data including distance, pilot in/out time, time zone difference, cargo movement, available terminal time windows, service speed, and quay crane capacity.

Step 2. Assign one of the ports with single hard time windows to i =1 and ETB_1 = TTB_1. Adjust P_1 to meet ETD_1 = TTD_1. Set all the initial buffer time = 0.

Step 3. Adjust cruising speed $V_{i,\,i+1}$ and buffer time to minimize the variation from ETB_{i+1} to TTB_{i+1}. Adjust quay crane dispatching P_{i+1} and buffer time to minimize the variation from ETD_{i+1} to TTD_{i+1}.

Step 4. Check if the assigned time windows meet terminal time windows with hard constraints. If no, try to change the sequence of calling ports in the same service continent and go back to Step 3; if yes, output ship scheduling results i.e. proforma schedules.

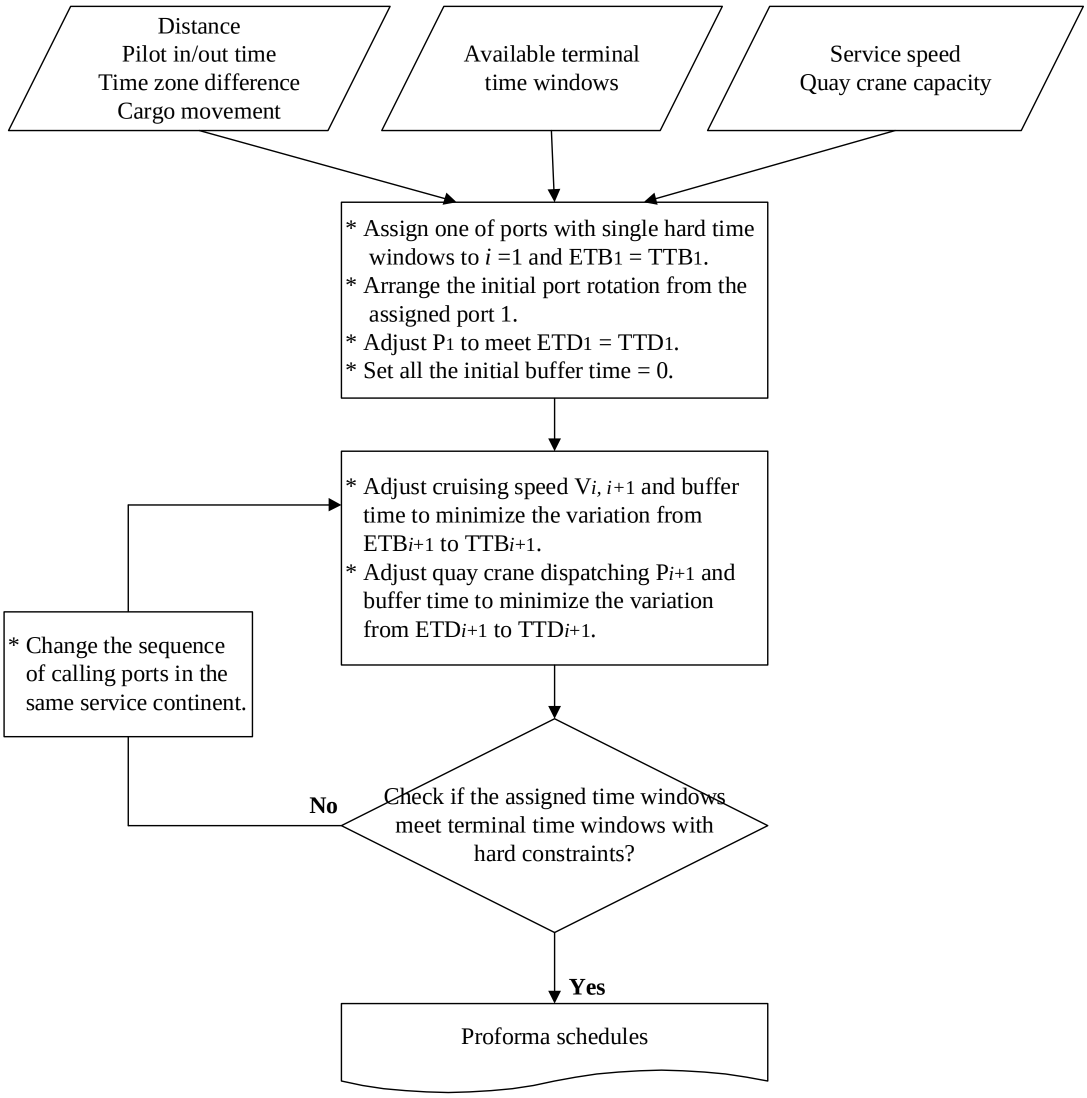


Figure 4.6 Solution procedure for ship scheduling

4.2.2 Computational results and model implementation

A new trans-Atlantic service route planning for a Taiwan liner company is used as a case study. The company plans to deploy 5 full-container vessels with 19-knot service speed on this service route to provide weekly services. The candidate calling ports and initial rotation are shown in Figure 4.3, planned to call at Charleston (CHS), Miami (MIA), Houston (HST), New Orleans (NEO) on the U.S. East Coast and Gulf of Mexico, as well as Antwerp (ANR), Felixstowe (FXT), Bremerhaven (BRV), Rotterdam (RTM) and Lisbon (LIS) in Europe.

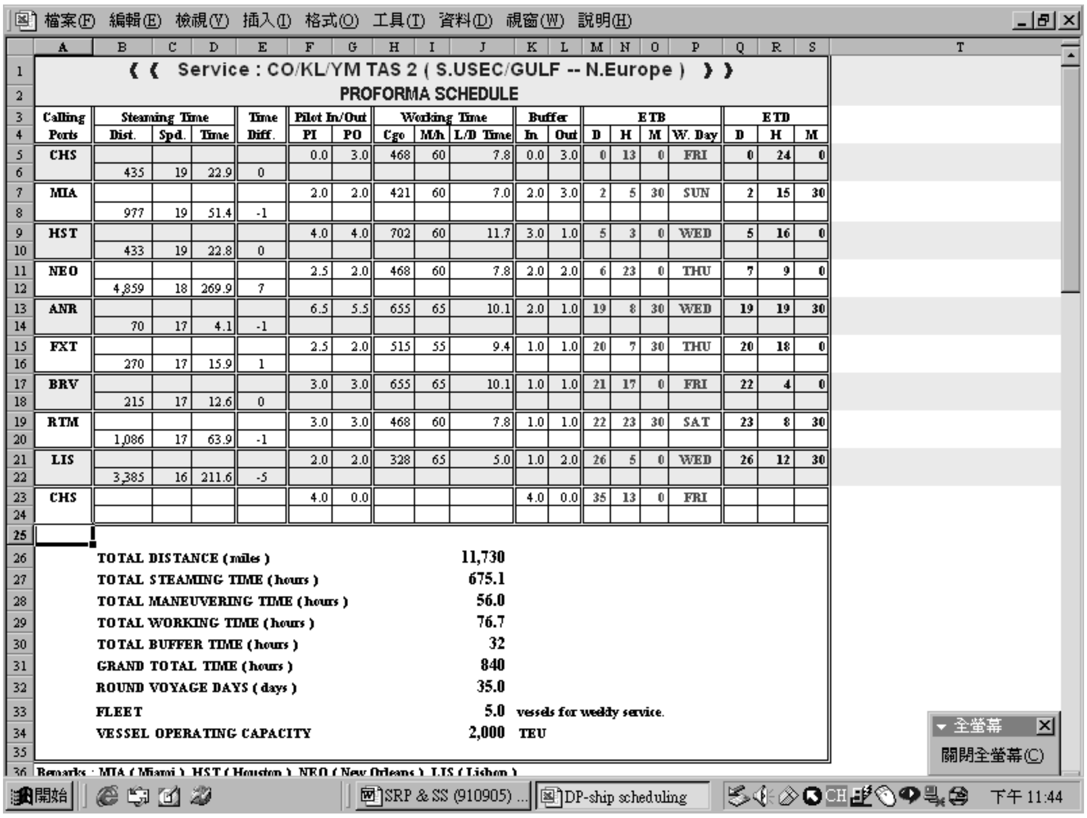
By applying Microsoft Excel working sheets (see Figure 4.7) with solution procedure, the available berth time window, distance, time zone difference, pilot in/out time and cargo distribution proportion data are manually input into the relevant cells, and the volume of containers handled at each port is generated by automatic calculation. Estimated time windows to berth will be calculated and output in relevant cells. It should be emphasized that in this system port rotation exchange and the buffer time must be adjusted by human estimation.

For weekly service routes, the total voyage time must not exceed the maximum fleet round voyage time, which can be represented as Equation (4.9):

$$\sum_{i=1}^{n}(ST_i + WT_i + PI_i + PO_i + BTI_i + BTO_i) \le 24 \times F \times 7 , \qquad (4.9)$$

where,

F = number of vessels deployed on the route.



《《 Service : CO/KL/YM TAS 2 (S.USEC/GULF -- N.Europe) 》》

PROFORMA SCHEDULE

Calling Ports	Steaming Time Dist.	Spd.	Time	Time Diff.	Pilot In/Out PI	PO	Working Time Cgo	M/h	L/D Time	Buffer In	Out	ETB D	H	M	W. Day	ETD D	H	M
CHS					0.0	3.0	468	60	7.8	0.0	3.0	0	13	0	FRI	0	24	0
	435	19	22.9	0														
MIA					2.0	2.0	421	60	7.0	2.0	3.0	2	5	30	SUN	2	15	30
	977	19	51.4	-1														
HST					4.0	4.0	702	60	11.7	3.0	1.0	5	3	0	WED	5	16	0
	433	19	22.8	0														
NEO					2.5	2.0	468	60	7.8	2.0	2.0	6	23	0	THU	7	9	0
	4,859	18	269.9	7														
ANR					6.5	5.5	655	65	10.1	2.0	1.0	19	8	30	WED	19	19	30
	70	17	4.1	-1														
FXT					2.5	2.0	515	55	9.4	1.0	1.0	20	7	30	THU	20	18	0
	270	17	15.9	1														
BRV					3.0	3.0	655	65	10.1	1.0	1.0	21	17	0	FRI	22	4	0
	215	17	12.6	0														
RTM					3.0	3.0	468	60	7.8	1.0	1.0	22	23	30	SAT	23	8	30
	1,086	17	63.9	-1														
LIS					2.0	2.0	328	65	5.0	1.0	2.0	26	5	0	WED	26	12	30
	3,385	16	211.6	-5														
CHS					4.0	0.0				4.0	0.0	35	13	0	FRI			

TOTAL DISTANCE (miles)	11,730	
TOTAL STEAMING TIME (hours)	675.1	
TOTAL MANEUVERING TIME (hours)	56.0	
TOTAL WORKING TIME (hours)	76.7	
TOTAL BUFFER TIME (hours)	32	
GRAND TOTAL TIME (hours)	840	
ROUND VOYAGE DAYS (days)	35.0	
FLEET	5.0	vessels for weekly service.
VESSEL OPERATING CAPACITY	2,000	TEU

Remarks : MIA (Miami) HST (Houston) NEO (New Orleans) LIS (Lisbon)

Figure 4.7 Microsoft Excel working sheets for ship scheduling

$TT_{i,i+1}$, the transit time from calling port *i* to the next calling port *i*+1 can be derived from Equation (4.10), which will be needed by marketing and pricing personnel to provide shippers with transit time information and to compare their own strengths and weaknesses with other competitors for pricing strategies at each market. The transit time for trans-Atlantic service (see Table 4.2 and Table 4.3) is calculated by working sheets when the proforma schedule is adjusted and finalized.

$$TT_{i,i+1} = ETB_{i+1} - ETD_i \tag{4.10}$$

There are some marketing implications for the transit time. The shorter transit time can provide shippers with better service. In general, carriers arrange shorter transit time to ports where there is large container throughput or niche markets. The transit time also indicates the competitive advantage compared with other competitors.

Table 4.1 Proforma schedule for trans-Atlantic service

Calling Ports	Steaming Time			Time Diff.	Pilot In/Out		Working Time			Buffer		ETB				ETD		
	Dist.	Spd.	Time		PI	PO	Cgo	M/h	Time	In	Out	D	H	M	W. Day	D	H	M
CHS					0.0	3.0	468	60	7.8	0.0	3.0	**0**	**13**	**0**	**FRI**	**0**	**24**	**0**
	435	19	22.9	0														
MIA					2.0	2.0	421	60	7.0	2.0	3.0	**2**	**5**	**30**	**SUN**	**2**	**15**	**30**
	977	19	51.4	-1														
HST					4.0	4.0	702	60	11.7	3.0	1.0	**5**	**3**	**0**	**WED**	**5**	**16**	**0**
	433	19	22.8	0														
NEO					2.5	2.0	468	60	7.8	2.0	2.0	**6**	**23**	**0**	**THU**	**7**	**9**	**0**
	4,859	18	269.9	7														
ANR					6.5	5.5	655	65	10.1	2.0	1.0	**19**	**8**	**30**	**WED**	**19**	**19**	**30**
	70	17	4.1	-1														
FXT					2.5	2.0	515	55	9.4	1.0	1.0	**20**	**7**	**30**	**THU**	**20**	**18**	**0**
	270	17	15.9	1														
BRV					3.0	3.0	655	65	10.1	1.0	1.0	**21**	**17**	**0**	**FRI**	**22**	**4**	**0**
	215	17	12.6	0														
RTM					3.0	3.0	468	60	7.8	1.0	1.0	**22**	**23**	**30**	**SAT**	**23**	**8**	**30**
	1,086	17	63.9	-1														
LIS					2.0	2.0	328	65	5.0	1.0	2.0	**26**	**5**	**0**	**WED**	**26**	**12**	**30**
	3,385	16	211.6	-5														
CHS					4.0	0.0				4.0	0.0	**35**	**13**	**0**	**FRI**			

TOTAL DISTANCE (miles)	**11,730**	
TOTAL STEAMING TIME (hours)	**675.1**	
TOTAL MANEUVERING TIME (hours)	**56.0**	
TOTAL WORKING TIME (hours)	**76.7**	
TOTAL BUFFER TIME (hours)	**32**	
GRAND TOTAL TIME (hours)	**840**	
ROUND VOYAGE DAYS (days)	**35.0**	
FLEET	**5.0**	**vessels for weekly service.**
VESSEL OPERATING CAPACITY	**2,000**	**TEU**

Table 4.2 Transit time for trans-Atlantic eastbound service

Ports	ANR	FXT	BRV	RTM	LIS
CHS	19	20	21	22	26
MIA	17	18	19	20	24
HST	14	15	16	17	21
NEO	12	13	14	15	19

Unit: days

Table 4.3 Transit time for trans-Atlantic westbound service

Ports	ANR	FXT	BRV	RTM	LIS
CHS	16	15	13	12	9
MIA	18	17	15	14	11
HST	21	20	18	17	14
NEO	22	21	19	18	15

Unit: days

4.3 Cost analysis

Cost items and categories for liner shipping service route planning are different from accounting costs or pricing costs. The trans-Atlantic service planning case as mentioned above is used to clarify fixed costs and variable costs and carry cost calculations on this route.

4.3.1 Fixed costs

Voyage fixed costs are constant regardless of the freight volume. When a fleet launches a route and provides a new service, fixed costs will occur constantly. These can be analyzed on a single round-trip voyage basis, which includes four major items, i.e. vessel costs, port charges, bunker costs and equipment costs, as explained below.

Vessel costs for the carriers own vessels include (1) Crew costs: crew wages, provisions, health insurance and other crew related expenses; (2) Vessel maintenance costs: inspection, repair, extraordinary dry-dock repair and classification survey costs; (3) Insurance costs: hull insurance and P&I; (4) Vessel depreciation and interest costs; (5) Fleet management fees. The above five cost items are included in the carriers own vessel daily costs. However, vessels are chartered in on time-charter basis, instead, the vessel daily costs include daily hire, P&I insurance, and management fees.

Bunker costs include marine diesel oil (A oil), heavy fuel oil (C oil), cylinder oil, engine system oil and lubrication oil consumption, although the latter three items can be estimated approximately and included in A oil daily consumption.

Port charge includes wharfage, tonnage dues, light dues, pilotage, towage, mooring/unmooring fees, oil pollution levy, quarantine fees, electricity/utility charge, port state inspection fees, garbage removal charge and government duties. Additionally, if the vessels pass through a canal (e.g. Suez canal, Panama canal), canal transit tolls and booking fees must be included.

The above three cost items are attributed to fleet operations. In addition, the provision of services requires equipment for freight business. Equipment costs include hiring, depreciation, insurance, maintenance and repair expenses occurred by equipped containers and chassis.

The four major cost items and voyage fixed cost of this trans-Atlantic service route are shown as Table 4.4, obtained form the Microsoft Excel working sheets. Five charter-in containerships are planned to be deployed on the route and to provide a weekly service, for which total voyage time is 35 days.

Table 4.4 Fixed cost items for trans-Atlantic service route planning

1. Fleet costs	
Fleet : 5 vessels (2,000 TEU)	
Vessel hire (USD/day)	12,000
Voyage days	35
Total fleet cost per voyage	**420,000**

2. Container and chassis costs	
Hire	111,810
Depreciation	54,493
Insurance	3,361
Repair and maintenance	49,105
Container and chassis cost per voyage =	**218,769**

3. Bunker costs	
Distance (nautical miles)	11,730
Average speed (knots)	17
Total steaming time (hours)	643
Total steaming time (days)	26.8
A oil	
A oil price (USD/ton)	143
A oil consumption (ton/day)	3.5
A oil consumption cost (USD)	17,518
C oil	
C oil price (USD/ton)	102
C oil consumption (ton/day)	74
C oil consumption cost	202,085
Total bunker cost per voyage	**219,603**

4. Port charge	
Charleston	11,500
Miami	11,500
Houston	11,500
New Orleans	11,500
Antwerp	30,000
Felixstowe	30,000
Bremerhaven	38,000
Rotterdam	30,000
Lisbon	25,000
Total port charge per voyage	**199,000**

Total fix cost per voyage (1+2+3+4)	**1,057,372**	USD

4.3.2 Variable costs

Variable costs are directly related to the volume of freight, which includes six major items: (1) feeder costs, (2) trailer/railway costs, (3) container handling costs, (4) tally costs, (5) container management and repositioning costs, and (6) terminal stowage costs. The major cost items for trans-Atlantic service route are shown as Table 4.5. Due to transshipment pattern differences between east bound and west bound voyages, the variable costs should be estimated separately for the two directions.

Table 4.5 Variable cost items for trans-Atlantic service route planning

Variable cost items	East bound	West bound
Feeder costs	130	75
Trailer/railway costs	186	185
Container handling costs	160	198
Tally costs	78	82
Container management and repositioning costs	48	55
Terminal stowage costs	22	22
Another costs	4	4
Unit variable costs (USD/TEU)	628	621

The proposed cost items and estimated amounts may work well for the route under investigation. Since the planned service route in this study has not yet been implemented yet, no actual amounts are available, so no cost comparisons between the estimated numbers and actual numbers can be performed.

4.4 Concluding remarks

Planners of liner shipping companies typically respond to service route planning by using insights acquired through experience, without any help from analytical models for ship scheduling problems. However, as terminal berth time-window constraints increase, the scheduling problems must consider increasingly more complex factors that humans alone cannot process simultaneously. To provide planners with better methods, this chapter proposes a DP ship scheduling model and clarifies cost items. This can help planners make better scheduling decisions under berth time-window constraints, as well estimate voyage fixed costs and freight variable costs in liner service route planning. Further conclusions are listed below:

1. Compared with the traditional methods, the proposed DP ship scheduling model pursues an optimal scheduling strategy including cruising speed and

quay crane dispatching decisions, rather than a tentative and rough schedule arrangement. This improvement not only gives this new mathematical model, but also could yield cost savings due to decreases of vessel fuel consumption and port time.

2. The computational results presented in this chapter are based on a specific trans-Atlantic service route planning. However, the proposed model, with similar solution algorithm and cost analysis should be applicable to other route planning. Additionally, this model is flexible in its use, and the Microsoft Excel working sheets with VBA (Visual Basic Application) can be utilized for other cases with some slight adjustments.

3. The proposed model has several advantages over current practice. The solution procedure is relatively easy to implement and flexibly handles a large number of time-window constraints that may arise in many real life routing and scheduling applications. However, the major drawback of the proposed model and solution algorithm is that regional port rotation changes and buffer time decisions must be by means of human observations and manual modifications.

4. The DP ship scheduling model can be extended to cases of integrating one company's service networks or integrating individual service networks between strategic alliance partners. It also can be useful for rescheduling berth time windows to cope with feeder schedules, inland transport schedules and partners' route schedules, so as to gain more efficient hub-and-spoke operations, tighter transshipment processes and better level-of-service.

5. Cost items and categories for liner shipping service route planning are different from accounting costs. The cost items have been clarified, and both voyage fixed costs and freight variable costs can be estimated more accurately according to the proposed items. This understanding can be useful for the follow-up profitability analysis.

Chapter 5

Containership Slot Allocation

In the competitive liner shipping market, carriers may utilize revenue management systems to increase profits by using slot allocation and pricing. Containership capacity allocation is an important issue since liner companies must avoid unused space on a voyage to maximize their revenue. Therefore, in the face of uncertain cargo demand and fiercely competitive markets, liner carriers should build revenue management systems to maximize voyage profits through careful consideration of slot allocation and pricing. Two containership slot allocation models are proposed in this chapter, of which the first one is to deal with single objective and deterministic parameters. The second one is bi-criteria optimization model to deal with two conflicting objectives: carrier's freight contribution and agents' degree of satisfaction, as well as fuzzy constraints, i.e. uncertainties of cargo transportation demand and weight.

5.1 Problem description

Since liner shipping is a capital-intensive industry, liner companies must invest large sums on vessels and containers. In the current fiercely competitive market, freight rates cannot be increased easily, and it is costly to reposition empty containers due to trade imbalance. Therefore, liner companies have difficulty generating reasonable profits and even incur deficits. Thus, carriers should enhance service route planning and ship scheduling to achieve long-term benefits. In addition, they should build a revenue management model to maximize voyage profits by means of slot allocation and pricing.

In the liner shipping industry containership capacity is a vitally important consideration since there is no revenue derived form unused space. Thus, liner companies should avoid unused space on a voyage in order to derive the highest possible revenue from containership capacity. Interviews with persons in charge of slot allocation and pricing in liner companies in Taiwan indicate that most liner companies are still using RM systems that are far from comprehensive, dynamic, computerized and integrated. Therefore, a concerted effort is needed to improve liner shipping revenue management by more effectively utilizing RM techniques to enhance operations.

For pricing, container invetory and dynmic space controls are based on slot allocation decision. Slot allocation is deemed to be the core element of the LSRM system. To build and solve a model optimizing space utilization, which covers the decisions of all the components of LSRM systems, fully utilizes historical data to forecast cargo demand, and dynamically adjusts its pricing and allocation decisions with the evolving booking data is out of the question. Most airlines and researchers approach revenue management for the first step by dealing with seat allocation problem flight by flight. In this chapter, the slot allocation problem is chosen to be the first approach to build the LSRM systems. RM concepts and mathematical programming techniques are applied to formulate an optimal containership slot allocation model. The other components are left for further research and being integrated with the proposed slot allocation model.

Most liner carriers usually allocate available space according to agents' space requests and cargo demands, with less consideration being given to marginal contribution, storage and repositioning costs for empty containers caused by trade imbalances, cargo weight and values. Therefore, available space cannot be effectively allocated to maximize the freight contribution.

Even for a single voyage leg, the slot allocation problem is very complex. On the same voyage, there may be a lot of different cargo demand with varying origin-destination (O-D) legs, each of which will generate a different contribution amount. For major liner carriers practicing hub-port operations, every voyage to the hub-port can have containers destined to almost all of its side ports and inland points; every voyage from the hub-port can have containers departing from almost all of its side ports and inland points. In addition, every O-D leg has several different freight rates. Therefore, there can be hundreds of rate/O-D combinations for each voyage, each having its contribution to the carrier.

Figure 5.1 shows a Far East - Europe route rotation, calling at Singapore (SIN), Hongkong (HKG), Keelung (KEL), Tokyo (TYO), Nagoya (NGO), Kobe (UKB) and Kaohsiung (KHH) in Asia, as well as Rotterdam (RTM), Felixstowe (FXT), Bremerhaven (BRV) and Le Havre (LEH) in Europe. The company deploys eight full-container vessels on this service route to provide a weekly service for every calling port. The slot allocation problem is how decision-makers can allocate the available vessel space (i.e. slots) to every origin (i.e. loading port) to destination (i.e. discharging port) pair leg efficiently and effectively to maximize the total freight contribution and total agents' degree of satisfaction from the whole voyage.

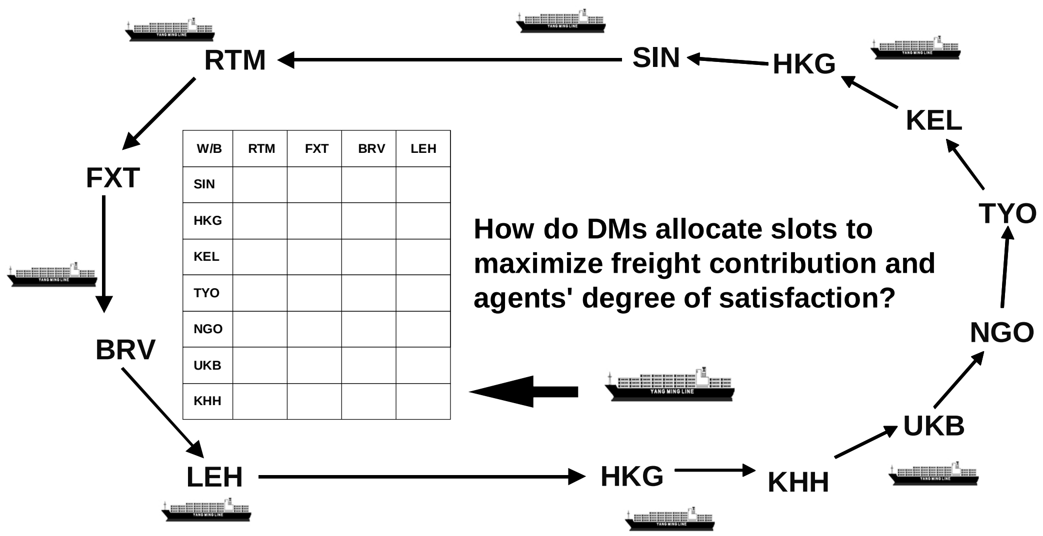


Figure 5.1 Service route rotation and slot allocation problem

5.2 Basic slot allocation model (SA1)

Two containership slot allocation models are proposed in this chapter, of which the first one is to deal with single objective and deterministic parameters to maximize the total freight contribution from the whole voyage.

The following assumptions are imposed for the model:

(1) The average freight rates of each origin-destination port pair have been estimated,

(2) The average variable cost of each origin-destination port pair has been accurately estimated,

(3) The minimum/maximum cargo demand of each origin-destination port pair has been estimated,

(4) There are four major types of containers (i.e. 20’ dry container, 20’ reefer container, 40’ dry container and 40’ reefer container),

(5) The inter-port cargo demand will not be taken into account (i.e. the model is

formulated for deep-sea liner services). Slots for loading inter-port cargo (i.e. so-called short voyage leg cargo in liner practice) cannot occupy slots for loading long voyage cargo because contributions from inter-port cargo are much less than those from long voyage leg cargo.

5.2.1 SA1 model formulation

1. Notation

Indices:

i = Index of loading port, $i = 1,2,...,m$.

j = Index of discharging port, $j = 1,2,...,n$.

k = Index of container type, $k = 1$ for 20' dry container; $k = 2$ for 20' reefer container; $k = 3$ for 40' dry container; $k = 4$ for 40' reefer container.

f = Index of slots for loaded containers.

e = Index of slots for empty containers.

Decision variables:

x^{f}_{ijk} = Slot allocating number of k-type loaded containers shipped from loading port i to discharging port j.

x^{e}_{ijk} = Slot allocating number of k-type empty containers shipped from loading port i to discharging port j.

Parameters:

MC_{ijk} = Marginal contribution of each k-type container delivered from loading port i to discharging port j.

$$MC_{ijk} = FR_{ijk} - VC_{ijk} \tag{5.1}$$

FR_{ijk} = Freight revenue of each *k*-type container delivered from loading port *i* to discharging port *j*.

VC_{ijk} = Variable costs of each *k*-type container delivered from loading port *i* to discharging port *j*, the variable costs include truck, feeder and railway costs, container handling costs, terminal and depot stowage costs, commission, tally costs and cargo claim costs.

EC_{ijk} = Repositioning cost of each *k*-type empty container delivered between port *i* and port *j*, with costs including inland transport/feeder cost, handling cost and holding cost.

IF_{ijk} = Imbalance factors of *k*-type container flow from loading port *i* to discharging port *j*.

$$IF_{ijk} = \begin{cases} (F_{ijk} - F_{jik}) / F_{ijk} & if\ F_{ijk} > F_{jik}, \\ 0 & if\ F_{ijk} \le F_{jik}. \end{cases} \tag{5.2}$$

F_{ijk} = The *k*-type container flow from loading port *i* to discharging port *j* during a period of time.

CP = The operational capacity of the vessel (unit: TEU, Twenty-foot Equivalent Units).

DW = The deadweight tonnage of the vessel (unit: ton).

W^f_{ijk} = The average total weight (tons) of each *k*-type loaded container delivered from loading port *i* to discharging port *j*.

W^e_k = The tare weight (tons) of each *k*-type empty container.

RF = The maximun reefer plug number of the vessel.

FE = The maximun number of 40’ containers loaded by the vessel.

D_{ijk}^{L} = The minimun contracted k-type slot number of the agent at port i to port j.

D_{ijk}^{U} = The maximum k-type slot number of cargo demand at port i to port j.

CI_{jk} = The repositioning demand of k-type containers to be supplied port j.

2. Objective function

The objective function of the model is to maximize the total freight contribution (freight revenue minus variable cost) from the shippment. This is represented in equation (5.3).

$$Max \quad Z = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(MC_{ijk} - IF_{ijk}EC_{ijk})x_{ijk}^{f} - EC_{ijk}x_{ijk}^{e} \tag{5.3}$$

3. Constraints

(1) *Vessel capacity constraints*

There are two major restrictions on the vessel capacity, one represented in equation (5.4) so that all the allocated slots for loaded and empty containers cannot exceed the vessel operational capacity; and the other represented in equation (5.5) so that the total weight of loaded and empty containers cannot exceed the vessel deadweight tonnage.

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{2}(x_{ijk}^{f} + x_{ijk}^{e}) + 2\cdot\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3}^{4}(x_{ijk}^{f} + x_{ijk}^{e}) \le CP \tag{5.4}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(W_{ijk}^{f}x_{ijk}^{f} + W_{k}^{e}x_{ijk}^{e}) \le DW \tag{5.5}$$

(2) *Vessel specification constraints*

There are two major restrictions on the vessel specification, one represented in equation (5.6) so that all the slots for loaded reefer containers cannot exceed the number of the vessel equipped reefer plugs; and the other represented in equation (5.7) so that the total slots of 40' loaded and empty containers cannot exceed the designed 40' container space of the vessel.

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=2,4} x_{ijk}^{f} \leq RF \tag{5.6}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3,4} (x_{ijk}^{f} + x_{ijk}^{e}) \leq FE \tag{5.7}$$

(3) *Cargo demand constraints*

As the minimum contract volume with agents and pre-booking accounts, and maximum cargo demand, the slots allocated to each O-D leg must be set between the interval of lower bound and upper bound of cargo demand. These are represented in equation (5.8) and (5.9).

$$x_{ijk}^{f} \geq D_{ijk}^{L} \quad \text{for all } i, j \text{ and } k. \tag{5.8}$$

$$x_{ijk}^{f} \leq D_{ijk}^{U} \quad \text{for all } i, j \text{ and } k. \tag{5.9}$$

(4) *Repositioning container demand constraints*

Represented as equation (5.10), the total slots for loading empty containers must be greater than the repositioning demand of *k* type containers to be supplied port *j*.

$$\sum_{i=1}^{m} x_{ijk}^{e} \geq CI_{jk} \quad \text{for all } j \text{ and } k. \tag{5.10}$$

(5) *Variable integer constraints*

The final constraint is integrality restrictions on the decision variables, as represented in equation (5.11).

$$x_{ijk}^{f},\ x_{ijk}^{e} \quad \text{integer} \quad \text{for all } i, j \text{ and } k. \qquad (5.11)$$

5.2.2 Case study and discussions on SA1 model

An Asia - Europe service route of a liner company in Taiwan (see Figure 5.1) is used as a case study. The company deployed eight full-container vessels on this service route to provided weekly service for every calling port. The specification of the vessels is 3350 TEU operational capacity, 36,510 ton deadweight, equipped with 200 reefer plugs and 1,135 40’ maximum container slots. Cost, revenue and container inventory databases were imported to calculate the needed related model parameter data, freight revenue, variable costs, repositioning costs, container flow, repositioning demand and container inventory. The optimization software LINGO 6.0 is utilized to solve the model. For designing user-friendly input and output interfaces with LINGO 6.0, the indices of the model is reduced from three dimensions to two dimensions to import/export data from a Microsoft Excel file and make allocation results understood easily by the persons in charge.

The optimal slot allocation of one westbound voyage is shown as Table 5.1 and Table 5.2. In comparison with the pre-allocated slot and the past lifting and revenue data, the optimal slot allocation is quite different from those of the previous O-D allocation pattern. However, this expected contribution is a lot greater than the average of the latest four voyages allocated by the current practice. The repositioning slots are allocated to O-D combination with the least repositioning cost. The results show the applicability and better performances than the previous allocation used in the current practice.

The total numbers of slot allocation are 2,956 TEUs for loaded containers and 167 TEUs for empty containers respectively. The expected space utilization is 93.2% (3,123 TEUs divided by the vessel's operational capacity 3,350 TEUs), that represents the space is not fully utilized. The expected deadweight utilization is almost 100%, which means the vessel capacity utilization is "down but not full." To improve this situation, the marketing strategy to attract more lower weight cargo is proposed, e.g., offering preferable freight rates to the accounts which shipped more lower weight cargo.

The results of sensitivity analysis show that IF_{ijk} (imbalance factors) are relatively sensitive parameters because they affect empty container repositioning costs and real marginal contribution of loaded slot allocation. When deadweight tonnage of the vessel is not sufficient to load all conatiners, the parameters, W_{ijk}^{f} (loaded container weight) are sensitive and result in a new optimal solution that allocates less slots to load heavier containers. This means the aim of fully utilizing capacity and high contribution can be improved by attracting more lower weight cargo demand.

Table 5.1 Slot allocation table (for loaded containers)

Type	20'DC				20'RF				40'DC				40'RF			
O/D	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH
SIN	25	80	115	15	0	0	0	0	35	29	36	20	1	3	3	3
HKG	45	55	75	10	9	8	6	0	41	50	70	18	9	10	9	8
KEL	4	24	41	1	0	0	0	0	27	29	45	19	5	2	1	2
TYO	10	15	19	10	3	8	0	0	29	26	31	23	5	5	5	5
NGO	4	21	18	11	0	0	0	0	37	25	36	20	5	5	5	5
UKB	10	19	17	15	0	0	0	0	29	26	30	30	5	5	5	5
KHH	25	41	60	13	6	5	8	7	45	28	50	25	6	6	6	6

Notes: DC (Dry Container), RF (Reefer Container)

Table 5.2 Slot allocation table (for empty containers)

Type	20'DC				20'RF				40'DC				40'RF			
O/D	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH	RTM	FXT	BRV	LEH
SIN	20	10	30	5	3	2	4	1	0	0	0	0	0	0	0	0
HKG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KEL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TYO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NGO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UKB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KHH	0	0	0	0	0	0	0	0	10	10	15	3	3	1	3	1

Notes: DC (Dry Container), RF (Reefer Container).

5.3 Bi-criteria slot allocation model (SA2)

However, for real world practice, the complex slot allocation process requires explicit consideration of another factor, namely, agents' degree of satisfaction. Thus, carrier's freight contribution and agents' degree of satisfaction will both be considered. Since the essential factor in determining slot allocation is cargo demand and weight, cargo demand and weight are not deterministic but their trend is reflected in past records, so they can be defined as fuzzy numbers. An optimal slot allocation model will be formualted through fuzzy multi-objective programming

(FMOP) to deal with fuzzy constraints, i.e. uncertainties of cargo weight and transportation demand. Interactive fuzzy multi-objective linear programming with fuzzy parameters is applied to solve this problem.

The following assumptions are imposed for the model:

(1) The average freight rates of each origin-destination port pair have been estimated,

(2) The average variable cost of each origin-destination port pair has been accurately estimated,

(3) The minimum/maximum cargo demand and weight of each origin-destination port pair has been estimated and defined as fuzzy numbers,

(4) There are four major types of containers (i.e., 20' dry container, 20' reefer container, 40' dry container and 40' reefer container),

(5) The inter-port cargo demand will not be taken into account (i.e. the model is formulated for deep-sea liner services). Slots for loading inter-port cargo (i.e. so-called short voyage leg cargo in liner practice) cannot occupy slots for loading long voyage cargo because contributions from inter-port cargo are much less than those from long voyage leg cargo.

5.3.1 SA2 model formulation

1. Notation

Fuzzy parameters:

$\tilde{D}^{U}_{ijk}$ = The maximum k-type slot number (TEUs) of cargo demand at port i to port j.

$\tilde{W}^{f}_{ijk}$ = The average total weight (tons) of each k-type loaded container delivered from loading port i to discharging port j.

The maximum cargo demand and maximum/minimum weight of k-type slots at each port pair can be estimated from the past booking data and approximate upper bound, lower bound and mean values can be obtained to define their membership functions shown in Figure 5.2 and Figure 5.3.

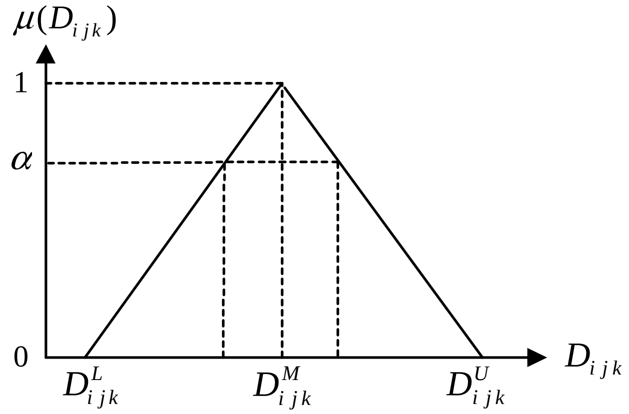


Figure 5.2 Fuzzy numbers of cargo demand

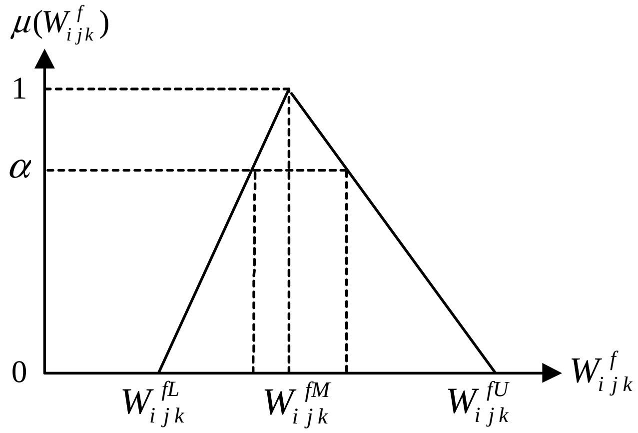


Figure 5.3 Fuzzy numbers of cargo weight

The μ represents degree of membership and α denotes the α level cut. The

α-level set of a fuzzy set A is defined as an ordinary set A_α for which the degree of its membership function exceeds the level α:

$$A_\alpha = \{ \ x \mid \mu_A(x) \geq \alpha \ \}, \quad \alpha \in [0,1] \tag{5.12}$$

The membership functions of cargo demand and weight are as follows:

$$\mu\ (D_{ijk}) = \begin{cases} (D_{ijk} - D^L_{ijk})/(D^M_{ijk} - D^L_{ijk}) & for\ D^L_{ijk} \leq D_{ijk} \leq D^M_{ijk}\ , \\ (D_{ijk} - D^U_{ijk})/(D^M_{ijk} - D^U_{ijk}) & for\ D^M_{ijk} \leq D_{ijk} \leq D^U_{ijk}\ , \\ 0 & otherwise\ . \end{cases} \tag{5.13}$$

$$\mu\ (W^f_{ijk}) = \begin{cases} (W^f_{ijk} - W^{fL}_{ijk})/(W^{fM}_{ijk} - W^{fL}_{ijk}) & for\ W^{fL}_{ijk} \leq W^f_{ijk} \leq W^{fM}_{ijk}\ , \\ (W^f_{ijk} - W^{fU}_{ijk})/(W^{fM}_{ijk} - W^{fU}_{ijk}) & for\ W^{fM}_{ijk} \leq W^f_{ijk} \leq W^{fU}_{ijk}\ , \\ 0 & otherwise\ . \end{cases} \tag{5.14}$$

2. Objective functions

(1) *Maximum total freight contribution*

The first objective function of the model is to maximize total freight contribution (freight revenue minus variable cost) from the shipment. This is represented in Eq.(5.15).

$$Max \quad Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{4} (MC_{ijk} - IF_{ijk} EC_{ijk}) x^f_{ijk} - EC_{ijk} x^e_{ijk} \tag{5.15}$$

(2) *Maximum total satisfaction level of slot allocation*

The second objective function of the model is to maximize total shippers and agents' degree of satisfaction with their slot allocation. This is represented in Eq.(5.16).

$$Max \quad Z_2 = \sum_{i=1}^{m} U_i(TS_i) \tag{5.16}$$

where TS_i denotes total slots (unit: TEU) allocated to shippers and agents at loading port *i* and they can be derived from Eq.(5.17).

$$TS_i = \sum_{j=1}^{n}\sum_{k=1}^{2} x_{ijk}^{f} + 2\times\sum_{j=1}^{n}\sum_{k=3}^{4} x_{ijk}^{f} \qquad (5.17)$$

$U_i(TS_i)$ denotes the satisfaction functions. Since degree of satisfaction depends on agents' subjective perception of differences bwtween their slot requests and given slot allocation, the sales behavior of agents at each loading ports is analyzed to define the functions. Through reviewing statistics of historial voyage booking data and inspecting agents' sales power, we categorize into three types of slot requests (see Figure 5.4, 5.5 and 5.6) and formulate three fuzzy satisfaction functions as follows:

(a) *Moderate type*

Most agents belong to this type. They consider the cargo quantity they can get and make appropriate slot requests (i.e. mean value). Further, they can accept more slot allocation to a certain extent (i.e. allowance). If the total slots allocated to them are between their requests and allowance, they will feel "satisfied". If the total slots are less than their requests to a certain extent (i.e. lower bound) or more than allowances to a certain extent (i.e. upper bound), they will feel "less satisfied". This fuzzy satisfaction function is represented as Eq.(5.18):

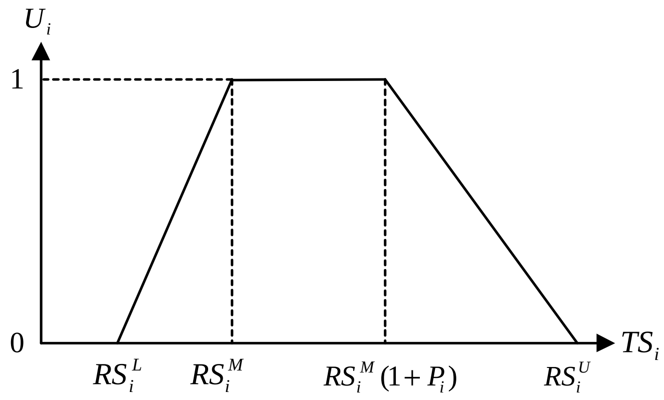


Figure 5.4 Fuzzy satisfaction functions of moderate type

$$U_i(TS_i) = \begin{cases} (TS_i - RS_i^L)/(RS_i^M - RS_i^L) & for\ RS_i^L \le TS_i \le RS_i^M\ , \\ 1 & for\ RS_i^M \le TS_i \le RS_i^M(1+P_i)\ , \\ (TS_i - RS_i^U)/[RS_i^M(1+P_i) - RS_i^U] & for\ RS_i^M(1+P_i) \le TS_i \le RS_i^U\ , \\ 0 & otherwise\ . \end{cases} \quad (5.18)$$

where RS_i^L, RS_i^U and RS_i^M denote lower bound, upper bound and mean values of requested slots by the agent at port *i* respectively, which can be obtained by past booking data. P_i denotes allowance percentage of the agent at port *i*, which can be obtained by inspecting the agent's sales power and behavior and asking about their allowances.

(b) *Conservative type*

Some agents consider the cargo quantity they can get, and make precise slot requests carefully, but cannot accept any allowance. This fuzzy satisfaction function is represented as Eq.(5.19):

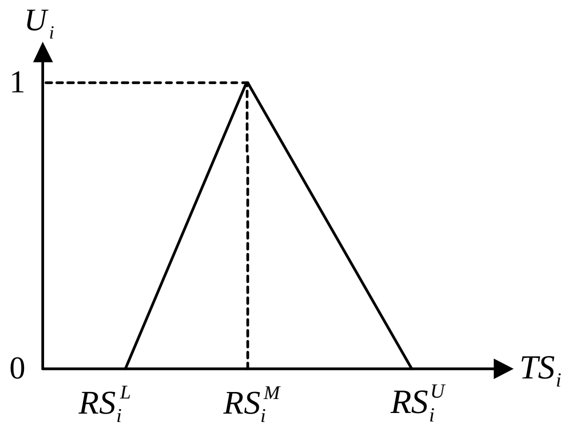


Figure 5.5 Fuzzy satisfaction functions of conservative type

$$U_i(TS_i) = \begin{cases} (TS_i - RS_i^L)/(RS_i^M - RS_i^L) & \text{for } RS_i^L \le TS_i \le RS_i^M \text{ ,} \\ (TS_i - RS_i^U)/(RS_i^M - RS_i^U) & \text{for } RS_i^M \le TS_i \le RS_i^U \text{ ,} \\ 0 & \text{otherwise .} \end{cases} \tag{5.19}$$

(c) *Aggressive type*

Some agents make slot requests more than the cargo quantity they can get, in other words, they rquest “the more, the better”. This fuzzy satisfaction function is represented as Eq.(5.20):

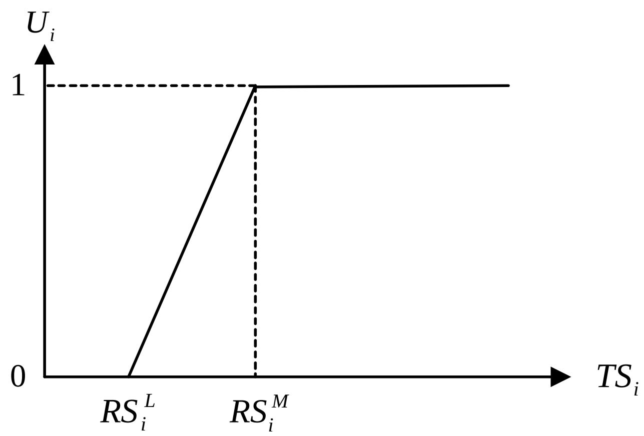


Figure 5.6 Fuzzy satisfaction functions of aggressive type

$$U_i(TS_i)=\begin{cases}(TS_i - RS_i^L)/(RS_i^M - RS_i^L) & \text{for } RS_i^L \le TS_i \le RS_i^M \text{ ,}\\ 1 & \text{for } RS_i^M \le TS_i \text{ ,}\\ 0 & \text{otherwise .}\end{cases} \tag{5.20}$$

3. Constraints

(1) *Vessel capacity constraints*

There are two major restrictions on vessel capacity: all the allocated slots for loaded and empty containers cannot exceed the vessel operational capacity, represented in Eq.(5.21); and the total weight of loaded and empty containers cannot exceed the vessel deadweight tonnage, represented in Eq.(5.22). Due to the uncertainty of loaded container weight, the weight is formulated as fuzzy numbers:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{2}(x_{ijk}^{f}+x_{ijk}^{e})+2\cdot\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3}^{4}(x_{ijk}^{f}+x_{ijk}^{e})\le CP \tag{5.21}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{4}(\tilde{W}_{ijk}^{f}x_{ijk}^{f}+W_{k}^{e}x_{ijk}^{e})\le DW \tag{5.22}$$

(2) *Vessel specification constraints*

There are two major restrictions on vessel specification: all the slots for loaded reefer containers cannot exceed the number of the vessel equipped reefer plugs, represented in Eq.(5.23); and total slots for 40’ loaded and empty containers cannot exceed the designed 40’ container space of the vessel, represented in Eq.(5.24):

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=2,4}x_{ijk}^{f}\le RF \tag{5.23}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=3,4}(x_{ijk}^{f}+x_{ijk}^{e})\le FE \tag{5.24}$$

(3) *Cargo demand constraints*

Due to minimum contract volume with agents and pre-booking accounts, and maximum cargo demand defined as fuzzy numbers, the slots allocated to each O-D leg must be set between the interval of lower bound and upper bound (fuzzy constraints) of cargo demand. These are represented in Eq.(5.25) and (5.26).

$$x_{ijk}^{f} \geq D_{ijk}^{L} \quad \text{for all } i, j \text{ and } k. \tag{5.25}$$

$$x_{ijk}^{f} \leq \tilde{D}_{ijk}^{U} \quad \text{for all } i, j \text{ and } k. \tag{5.26}$$

(4) *Repositioning container demand constraints*

Represented as Eq. (5.27), the total slots for loading empty containers must be greater than the repositioning demand of *k* type containers to be supplied to port *j*.

$$\sum_{i=1}^{m} x_{ijk}^{e} \geq CI_{jk} \quad \text{for all } j \text{ and } k. \tag{5.27}$$

(5) *Variable integer constraints*

The final constraint is integrality restrictions on the decision variables, as represented in Eq. (5.28).

$$x_{ijk}^{f},\ x_{ijk}^{e} \quad \text{integer} \quad \text{for all } i, j \text{ and } k. \tag{5.28}$$

5.3.2 Solution procedures

The interactive fuzzy multi-objective programming with fuzzy parameters (Sakawa, 1993) method are utilized in this study to solve it. The algorithm with some adjustments is shown as follows and illustrated in Figure 5.7:

Step 0: Individual minimum and maximum

Calculate the individual minimum and maximum of each objective function under the given constraints for $\alpha = 0$ and $\alpha = 1$. In this model, the first objective of slot allocation problems is solved under the constraints for $\alpha = 0$ and $\alpha = 1$.

Step 1: Initialization

Ask the DM to select the initial value of α ($0 \le \alpha \le 1$) and the initial reference levels $\overline{Z}_1$ and $\overline{Z}_2$.

Step 2: α-Pareto optimal solution

For the degree α and the reference levels specified by the DM, solve the single objective Z_1(total freight contribution) of the slot allocation problems under the initial α level cut. Then, the DM considers the trade-off between Z_1 and Z_2 (total agents' degree of satisfaction). If the DM satisfies the result of the outcome, this solution is referred to as the α-Pareto optimal solution; otherwise, the DM adjusts the result of the agent's slot allocation to obtain a higher degree of satisfaction.

Step 3: Termination or updating

The DM is supplied with the corresponding α-Pareto optimal solution and the trade-off rates between the objective functions and the degree α. If the DM is satisfied with the current objective function values of the α-Pareto optimal solution, stop. Otherwise, the DM must update the reference levels and/or the degree α by considering the current values of the objective functions and the degree α together with the trade-off rates between the objective functions and the degree α and return to step 2.

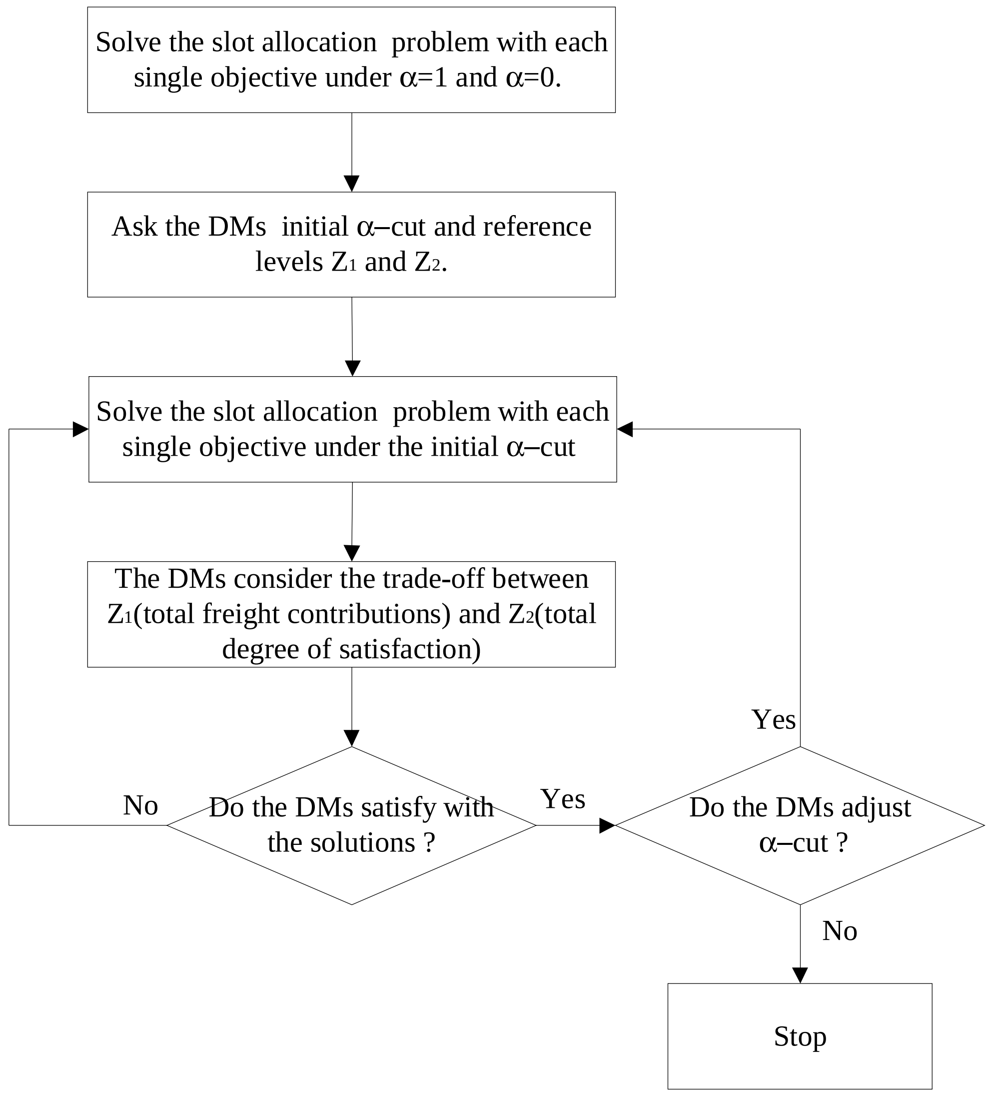


Figure 5.7 The interactive fuzzy multi-objective programming with fuzzy parameters

5.3.3 Case study and discussions on SA2 model

The optimal slot allocation to maximize the objective Z_1 and the two objectives Z_1 and Z_2 simultaneously for one westbound voyage are illustrated as Table 5.3,

Figure 5.8, Figure 5.9 and Table 5.4, Figure 5.10, Figure 5.11 respectively. In comparison with the pre-allocated slots and historical lifting and revenue data, the optimal slot allocation is clearly different from these in the O-D distribution pattern. Further, freight contribution, agents' degree of satisfaction and capacity utilization (total allocated slots divided by vessel operational capacity) are much better than in past practice. The repositioning slots are allocated to the O-D combination with the least repositioning cost. The results show the applicability of the proposed model and excellent performance in practice.

Table 5.3 Optimal allocation results according to different α-cut values to maximize Z_1

	Lower weight of loaded containers			Upper weight of loaded containers		
α-cut	Z^*_1	Z_2	Expected Utilization	Z^*_1	Z_2	Expected Utilization
0.0	2,955,172	2.7	100%	2,388,918	6.1	78%
0.1	2,949,388	2.9	100%	2,403,789	6.1	79%
0.2	2,942,167	3.2	100%	2,454,899	6.2	81%
0.3	2,914,267	4.2	99%	2,455,935	6.1	81%
0.4	2,854,395	4.8	97%	2,472,563	5.9	82%
0.5	2,799,913	5.1	95%	2,481,900	5.8	82%
0.6	2,766,259	5.5	93%	2,522,694	5.9	84%
0.7	2,722,047	6.1	92%	2,523,819	5.7	84%
0.8	2,657,819	6.5	91%	2,527,053	6.1	85%
0.9	2,618,499	6.6	89%	2,548,744	6.4	87%
1.0	2,549,875	6.7	87%	2,549,875	6.7	87%

As indicated in Table 3, Figure 5.8 and Figure 5.9, to maximize the single objective Z_1 results in agents' lowest degree of satisfaction because of focusing solely on freight contribution to allocate slots. As regards lower cargo weight, this is achieved by a smaller α-cut value, suggesting that decision-makers should request agents to attract more low weight cargo to increase capacity utilization and revenue. With regard to upper weight, heavier weight is derived from a larger α-cut value, thus freight contribution and capacity utilization are much lower, indicating that too much heavy cargo will result in low revenue.

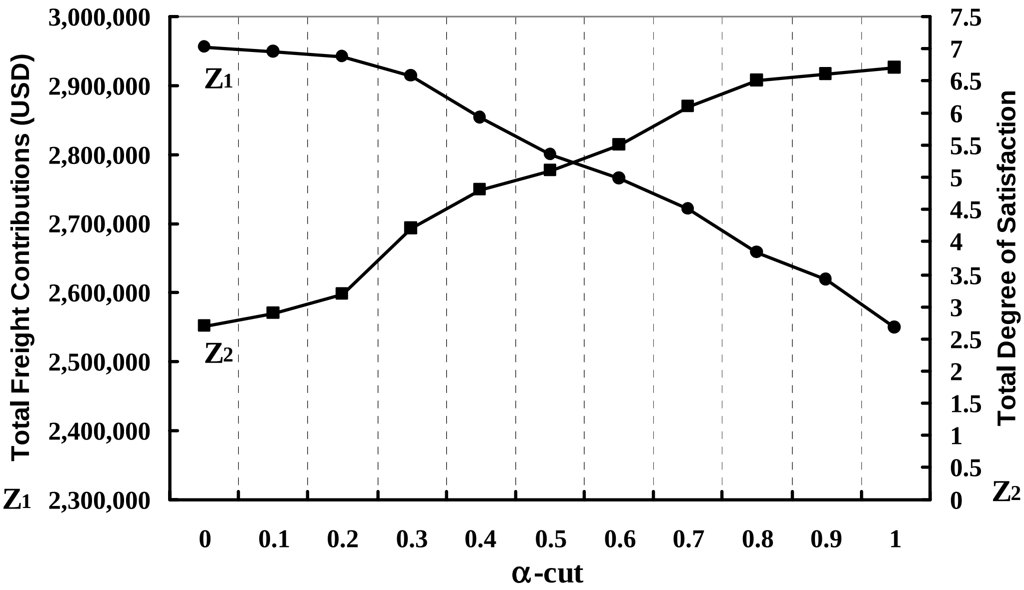


Figure 5.8 Results derived from lower cargo weight according to different α-cut values to maximize Z_1

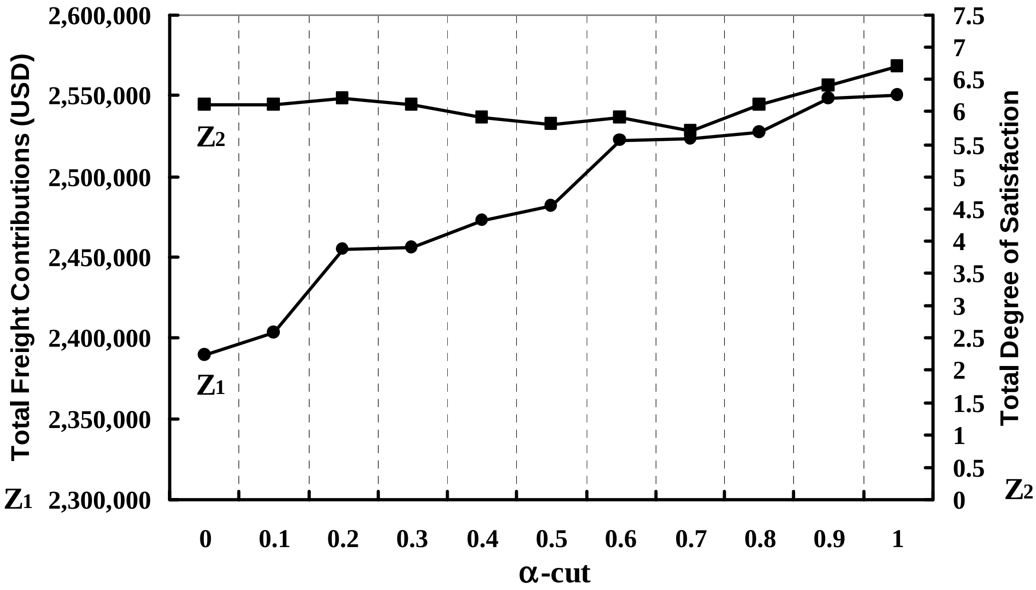


Figure 5.9 Results derived from upper cargo weight according to different α-cut values to maximize Z_1

Table 5.4 Optimal allocation results according to different α-cut values to maximize Z_1 and Z_2

	Lower weight of loaded containers			Upper weight of loaded containers		
α-cut	Z^*_1	Z^*_2	Expected Utilization	Z^*_1	Z^*_2	Expected Utilization
0.0	2,924,028	7.0	100%	--	--	--
0.1	2,918,039	7.0	100%	--	--	--
0.2	2,911,020	7.0	100%	--	--	--
0.3	2,883,918	7.0	99%	--	--	--
0.4	2,835,691	7.0	97%	2,466,163	7.0	82%
0.5	2,788,891	7.0	95%	2,475,203	7.0	82%
0.6	2,751,102	7.0	93%	2,496,758	7.0	83%
0.7	2,720,738	7.0	92%	2,520,738	7.0	84%
0.8	2,655,984	7.0	91%	2,524,181	7.0	85%
0.9	2,617,884	7.0	89%	2,546,608	7.0	86%
1.0	2,567,752	7.0	87%	2,567,752	7.0	87%

-- denotes no feasible solutions.

As shown in Table 5.4, Figure 5.10 and Figure 5.11, to maximize objectives Z_1 and Z_2 simultaneously, more low weight cargo is necessary to increase capacity utilization and revenue, but, at the same time, agents must be satisfied that their slot requests have all or largely been met, i.e. slots allocated to them should be between their requests and allowance. Further, a cooperative, flexible relationship between carriers and agents is necessary to promote and maintain agents' continued satisfaction with slot allocation. This can be achieved using the proposed interactive fuzzy multi-objective slot allocation model. Decision-makers will thereby achieved higher long-term revenue, but should monitor aggressive-type agents because of the higher risk of unused slot allocation.

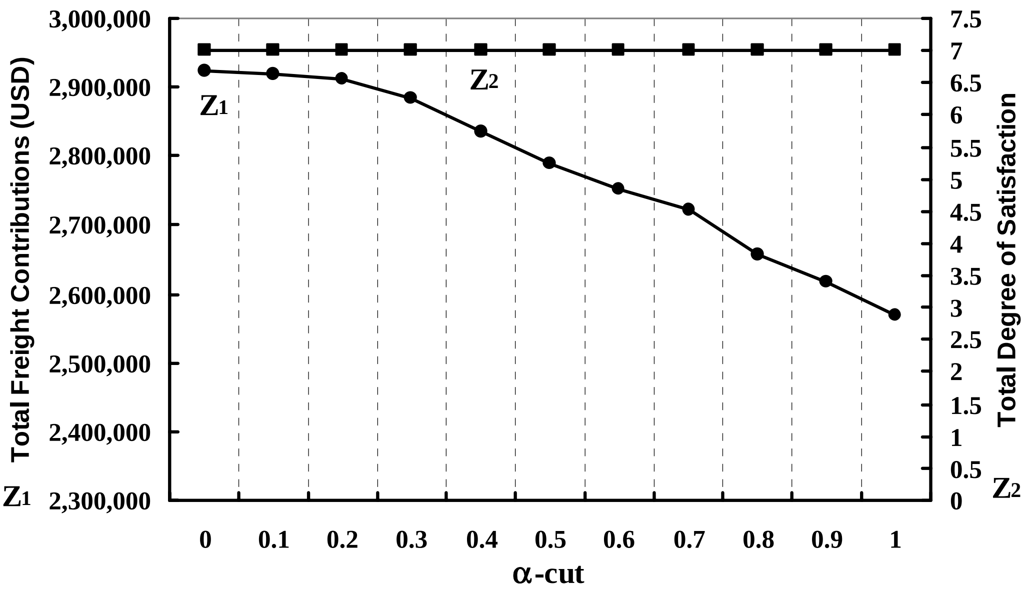


Figure 5.10 Results derived from lower cargo weight according to different α-cut values to maximize Z_1 and Z_2

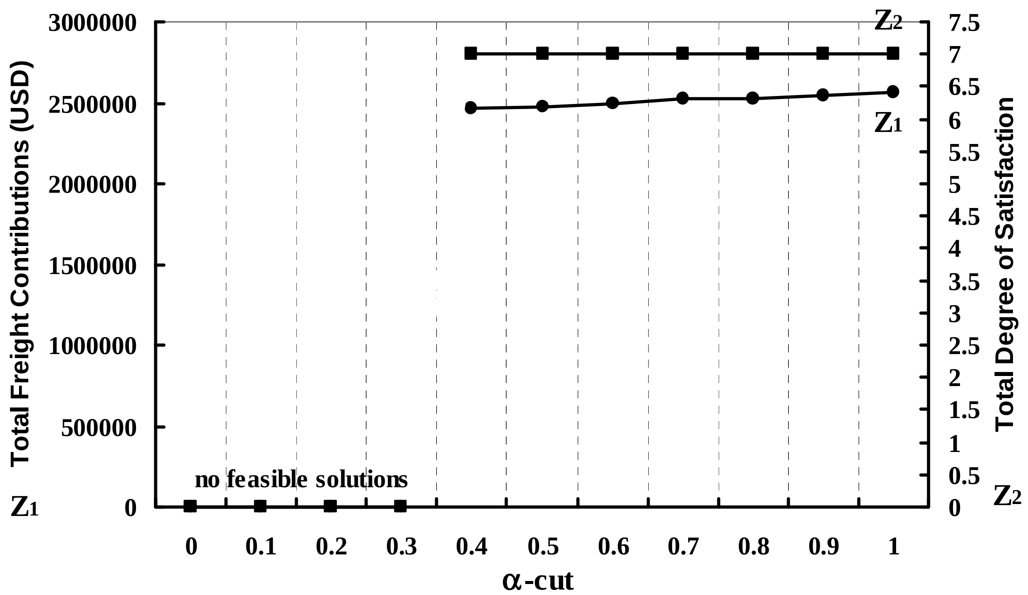


Figure 5.11 Results derived from upper cargo weight according to different α-cut values to maximize Z_1 and Z_2

5.4 Concluding remarks

The objective of the proposed slot allocation model SA1 is to maximize the total freight contribution instead of freight revenue, due to high variable costs in the liner shipping. The SA2 model is formulated through fuzzy multi-objective programming. The two objectives of SA2 model are to maximize the total freight contribution and to maximize agents' degree of satisfaction, rather than focus primarily on total freight revenue. Taking into account likely continuous worsening trade imbalances, repositioning costs should be included in the first objective function. Further issues are listed below:

1. The optimal slot allocation can be a guideline for allocating space to every calling port to achieve the most expected contribution, however, the persons in charge should keep watching space usage and adjust allocation to avoid unused space. According the above discussions, cargo weight is the crucial factor to achieve better capacity utilization.

2. In real business practice in liner companies, decision-makers face slot allocation problems due to uncertainties of cargo weight and demand, agents' slot requests, various O-D freight contribution and trade imbalances, which make decision making very complex. The proposed interactive fuzzy multi-objective slot allocation model is suitable to meet the actual situations of slot allocation and decision-makers' needs.

3. Due to uncertainties of cargo demand and weight, allocation results from the application of fuzzy theory indicate that the interactive fuzzy multi-objective

programming method can provide decision-makers with more precise information to achieve more freight contribution and to increase capacity utilization. Using different α-cut values to obtain the required information, decision-makers will achieve more satisfactory solutions and thereby develop a more cooperative, long-term relationship with agents.

4. The concepts of this model have been applied to a liner company in Taiwan and the results show its applicability and better performance compared to previous practice. Although we expect some changes to occur in the current marketing strategy of only emphasizing space utilization, through applying the proposed model, liner carriers will be able to focus both on freight contribution and agents' degree of satisfaction, and also consider the impact on repositioning costs due to trade imbalance. However, change takes time and top management support is required to implement the LSRM system and this new slot allocation, method and concept.

Chapter 6

Conclusions and Recommendations

The liner shipping companies require a dramatic change in their operation and business practices. Carriers and alliances can benefit greatly from using systematic methods to streamline ship scheduling on service route planning and to integrate their service networks by analytical models. Additionally, carriers may utilize revenue management systems to increase profits by using slot allocation and pricing. In this study, a lot of efforts have been devoted to developing a conceptual liner shipping revenue management (LSRM) model and formulating ship scheduling and slot allocation models. Several conclusions and study contributions are summarized as below. In addition, some further research issues and suggestions to this industry are listed for recommendations.

6.1 Conclusions

1. In this study, related research on revenue management for transportation industries is reviewed. A conceptual model of liner shipping revenue management (LSRM) is proposed to provide carriers with better reference solutions to build their RM systems.

2. Planners of liner shipping companies typically respond to service route planning by using insights acquired through experience, without any help from

analytical models for ship scheduling problems. However, as terminal berth time-window constraints increase, more complex factors that humans alone cannot process simultaneously should be taken into account. To provide planners with better methods, this study proposes a DP ship scheduling model and clarifies cost items. This can help planners make better scheduling decisions under berth time-window constraints, as well as estimate voyage fixed costs and freight variable costs in liner service route planning.

3. The proposed DP ship scheduling model pursues an optimal scheduling strategy including cruising speed and quay crane dispatching decisions instead of a tentative and rough schedule arrangement. This improvement not only gives this new mathematical model, but also could yield cost savings due to decreases of vessel fuel consumption and port time.

4. The proposed DP ship scheduling model has several advantages over current practice. The solution proposed is relatively easy to implement and flexibly handles a large number of time-window constraints that may arise in many real life routing and scheduling applications. However, the major drawback of the proposed model and solution algorithm is that regional port rotation changes and buffer time decisions must be by means of human observations and manual adjustments.

5. The objective of the proposed slot allocation model (SA1) is to maximize the total freight contribution instead of freight revenue, due to high variable costs in the liner shipping. We considering the possibility of a continuous worsening

situation of trade imbalances, so trade imbalance factors and repositioning costs are included in the objective function.

6. In real business practice in liner companies, decision-makers face slot allocation problems due to uncertainties of cargo weight and demand, agents' slot requests, various O-D freight contribution and trade imbalances, which make decision making very complex. The proposed interactive fuzzy multi-objective slot allocation model (SA2) is suitable to meet the actual situations of slot allocation and decision-makers' needs. The two objectives of SA2 model are to maximize the total freight contribution and to maximize agents' degree of satisfaction, rather than to focus primarily on total freight revenue.

7. Due to uncertainties of cargo demand and weight, allocation results from the application of fuzzy theory indicate that the interactive fuzzy multi-objective programming method can provide decision-makers with more precise information to achieve more freight contribution and to increase capacity utilization. Using different α-cut values to obtain the required information, decision-makers will achieve more satisfactory solutions and thereby develop a more cooperative, long-term relationship with agents.

8. The concepts of this model have been applied to a liner company in Taiwan and the results show its applicability and better performance compared to previous practice. We expect some changes to occur in the current marketing strategy of only emphasizing space utilization through applying the proposed

model. Liner carriers will be able to focus both on freight contribution and agents' degree of satisfaction, and also consider the impact on repositioning costs due to trade imbalances. However, change takes time and top management support is required to implement the LSRM system and this new slot allocation method and concept.

6.2 Recommendations

1. A comprehensive liner shipping revenue management (LSRM) system should be set up and phased in as an enterprise resource planning (ERP) to integrate a liner company's resources, e.g. vessels, capacity (slots), containers, customers, agents…etc. Two major components are proposed to be included in an LSRM system: (1) long-term planning, which can assist with longer term customer management, cost management, market monitoring, service route planning and ship scheduling; and (2) short-term operations, which can assist with voyage revenue optimization in terms of demand forecasting, slot allocation, pricing, container inventory control and dynamic space control. Such a system should be integrated with freight revenue, cost, container inventory database and accounting systems.

2. The implementation of LSRM systems still needs a lot work, for example, integration with related databases and pricing, as well as container inventory and dynamic slot control. In addition, computerization is a critical element in LSRM implementation because computerized information can be incorporated into RM systems to provide decision support information related to markets,

customers, container inventory, costs and revenue.

3. Liner shipping revenue management (LSRM) is an excellent research area with a high potential for developing new models and procedures to improve revenue, and provide decision support to liner shipping companies. Long-term customer relation management (CRM), service route planning and ship scheduling, as well as short-term pricing, dynamic space control and container inventory control problems provide the greatest opportunities in terms of future research.

4. The optimal slot allocation derived from the proposed models (SA1 or SA2) can be a guideline for allocating space to every calling port to achieve maximum expected contribution. However, the persons in charge should keep watching space usage and adjust allocation to avoid unused space. Additionally, cargo weight is the crucial factor to achieve better capacity utilization, therefore cargo weight of loaded containers should be controlled to achieve better dead weight loading factors.

5. Cost items and categories for liner shipping service route planning are different from accounting costs. The cost items have been clarified, and both voyage fixed costs and freight variable costs can be estimated more accurately according to the proposed items. This understanding can be useful for the follow-up profitability analysis to new service routes, or for cost management to booking pricing and profit center transfer pricing.

6. The DP ship scheduling model can be extended to cases of integrating one

company's service networks or integrating individual service networks between strategic alliance partners. It also can be useful for rescheduling berth time windows to cope with feeder schedules, inland transport schedules and partners' route schedules, so as to gain more efficient hub-and-spoke operations, tighter transshipment processes and better level-of-service.

Bibliography

Ashar, A., 1999. The fourth revolution. Containerisation International 32(12), 57-61.

Ashar, A., 2000. 2020 vision. Containerisation International 33(1), 35-39.

Bausch, D. O., Brown, G. G., Ronen, D., 1998. Scheduling short-term marine transport of bulk products. Maritime Policy and Management 25(4), 335-348.

Bellman, R. E., Zadeh, L. A., 1970. Decision-making in a fuzzy environment. Management Science 17(1), 141-164.

Belobaba, P. P., 1987. Airline yield management: an overview of seat inventory control. Transportation Science 21(1), 63-73.

Belobaba, P. P., 1989. Application of a probabilistic decision model to airline seat inventory control. Operations Research 37(2), 183-197.

Belobaba, P. P., Wilson, J. L., 1997. Impacts of yield management in competitive airline markets. Journal of Air Transport Management 3(1), 3-9.

Belobaba, P. P., 1998a. The evolution of airline yield management: fare class to origin-destination seat inventory control. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 285-302.

Belobaba, P. P., 1998b. Airline differential for effective yield management. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 349-361.

Belobaba, P. P., Farkas, A., 1999. Yield management impacts on airline spill estimation. Transportation Science 33(2), 217-232.

Bellman, R. E., Zadeh, L. A., 1970. Decision making in a fuzzy environment, Management Science 17(4), 141-164.

Bendall, H. B., Stent, A. F., 1999. Long-haul feeder services in an era of changing technology: an Asia-Pacific perspective. Maritime Policy and Management 26(2), 145-159.

Bergt, N., Dean, V., Carty, D., 1997. Chapter 6. The price: revenue and inventory management. In: Dempsey, P. S., Gesell, L. E. (Eds.), Airline Management: Strategies for the 21st Century. Coast Aire Publications, U.S.A., pp. 279-315.

Bodily, S., Pfeifer, P. E., 1992. Overbooking decision rules. Omega 20(1), 129-133.

Bodily, S., Weatherford, L., 1995. Perishable-asset revenue management: generic and multiple-price yield management with diversion. Omega 23(2), 173-185.

Botimer, T. C., 1996. Efficiency considerations in airline pricing and yield management. Transportation Research A 30(4), 307-317.

Brook, M. R., Button, K. J., 1996. The determinants of shipping rates: a north Atlantic case study. Transport Logistics 1(1), 21-30.

Brumelle, S. L., McGill, J. I., 1990. Allocation of airline seats between stochastically dependent demand. Transportation Science 24(2), 183-192.

Butler, G. F., Keller, M. R. (Ed.), 1998. Handbook of Airline Marketing. McGraw-Hill, U.S.A..

Chanas, S., 1983. The use of parametric programming in fuzzy linear programming. Fuzzy Sets and Systems 11(3), 243-251.

Chatwin, R. E., 1999. Continuous-time airline overbooking with time-dependent fares and refunds. Transportation Science 33(2), 182-191.

Chen, S. J., Hwang, C. L., 1992. Fuzzy Multiple Attribute Decision Making: Methods and Application. Spring-Verlag, New York.

Cho, S. C., Perakis, A. N., 1996. Optimal liner fleet routeing strategies. Maritime Policy and Management 23(3), 249-259.

Christiansen, M., 1999. Decomposition of a combined inventory and time constrained ship routing problem. Transportation Science 33(1), 3-16.

Ciancimino, A., Inzerillo, G., Lucidi, S., Palagi, L., 1999. A mathematical programming approach for the solution of the railway yield management problem. Transportation Science 33(2), 168-181.

Cl'umaco, J. N., Antunes, C. H., Alves, M. J., 1993. Interactive decision support for multi-objective transportation problems. European Journal of Operational Research 65(1), 58-67.

Cohon, J. L., 1978. Multiobjective Programming and Planning. Kluwer Academic Press, New York.

Crichton, J., 1998. The trend mill. Containerisation International 31(1), 57-59.

Cross, R. G., 1997a. Revenue Management -Hard-core Tactics for Market Domination. Broadway books, U.S.A..

Cross, R. G., 1997b. Launching the revenue rocket – how revenue management can work for your business. Cornell Hotel and Restaurant Administration Quarterly 38(2), 32-43.

Cross, R. G., 1998. Trends in airline revenue management. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 303-318.

Curry, R., 1990. Optimal seat allocation with fare classes nested by origins and destinations. Transportation Science 24(2), 193-204.

Damas, P., 1996. Alliances and webs. American Shipper 38(10), 37-48.

Davies, J. E., 1990. Destructive competition and market sustainability in the liner shipping industry. International Journal of Transport Economics 27(3), 227—245.

Deris, S., Omatu, S., Ohta, H., Kutar, L. C. S., Samat, P. A., 1999. Ship maintenance scheduling by genetic algorithm and constraint-based reasoning. European Journal of Operational Research 112(4), 489-502.

Donaghy, K., McMahon, U., McDowell, D., 1995. Yield management: an overview. International Journal of Hospitality Management 14(2), 139-150.

Dubois, D., Prade, H., 1980. Systems of linear fuzzy constraints. Fuzzy Sets and Systems 3(1), 37-48.

Evans, J., Marlow, P. (Ed.), 1990. Quantitative methods in maritime economics, Fairplay Publications Ltd., U.K..

Fagerholt, K., 1999. Optimal fleet design in a ship routing problem. International Transactions in Operational Research 6(4), 453-464.

Fagerholt, K., 2000. Evaluating the trade-off between the level of customer service and transportation costs in a ship scheduling problem. Maritime Policy and Management 27(2), 145-153.

Fagerholt, K., Christiansen, M., 2000. A traveling salesman problem with allocation, time window and precedence constraints – an application to ship scheduling. International Transactions in Operational Research 7(3), 231-244.

Fossey, J., 1997a. Transpacific turmoil. Containerisation International 30(8), 45-49.

Fossey, J., 1997b. Suicidal tendencies. Containerisation International 30(5), 37-41.

Frannkel, E. G. (Ed.), 1982. Management and Operations of American Shipping. Auburn House Publishing Company, U.S.A..

Gallego, G., Van Ryzin, G. J., 1994. Optimal dynamic pricing of inventories with stochastic demand over finite horizons. Management Science 40(8), 999-1020.

Garcia-Diaz, A., Kuyumcu, A., 1997. A cutting-plane procedure for maximizing revenue in yield management. Computers Industry Engineering 33(1-2), 51-54.

Garvett, D., Michaels, L., 1998. Pricing parrying: a direction for quick, decisive, and profit-maximizing pricing. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 333-348.

Hamacher, H., Leberling, H., Zimmerman, H.-J., 1978. Sensitivity analysis in fuzzy linear programming. Fuzzy Sets and Systems 1(3), 269-281.

Haralambides, H. E., Veenstra, A. W., 2000. Modeling performance in liner shipping. In: Hensher, D. A., Button, K. J. (Eds.), Handbook of Transport Modelling. Elaevier Science Ltd., UK, pp. 643-658.

Herrmann, N., Muller, M., Crux, A., 1998. Pricing and revenue management can reshape your competitive position in today's air cargo business. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 387-410.

Hiller, F. S., Lieberman, G. J., 1986. Introduction to Operations Research. Holden-Day, Inc., Oakland.

Holloway, S. (Ed.), 1997. Straight and Level: Practical Airline Economics. Ashgate Publishing Company, U.S.A..

Hwang, C. L., Yoon, K., 1981. Multiple Attribute Decision Making, Lecture Notes in Economics and Mathematical Systems. Springer-Verlag, Berlin.

Jaramillo, D. I., Perakis, A. N., 1991. Fleet deployment optimisation for liner shipping Part 2: Implementation and results. Maritime Policy and Management 18(4), 235-262.

Jansson, J. O., Shneerson D. (Ed.), 1987. Liner Shipping Economics. Chapman and Hall, New York.

Kadar, M. H., Proost, D. D., 1997a. Supply and demand in liner shipping. Containerisation International 30(6), 61-65.

Kadar, M. H., Proost, D. D., 1997b. Back to the basics for marketing, pricing, and selling. Containerisation International 30(7), 49-51.

Kaps, R. W., 2000. Air transport yield management system. In: Kaps, R. W. (Eds.), Fiscal Aspect of Aviation Management. Southern Illinois University, U.S.A., pp. 220-232.

Kasilingam, R. G., 1996. Air cargo revenue management: characteristics and complexities. European Journal of Operational Research 96(1), 36-44.

Kim, S. H., Lee, K. K., 1997. An optimization-based decision support system for ship scheduling. Computers Industry Engineering 33(3), 689-692.

Kimes, S. E., 1989. The basics of yield management. Cornell Hotel and Restaurant Administration Quarterly 30(2), 14-19.

Kuhn, H. W., Tucker, A. W., 1951. Nonlinear programming. In: Neyman, J. (Eds.), Proceedings of 2nd Berkeley Symposium on Mathematical Statistics and Probability, University of California Press, Berkeley, pp. 481-491.

Kuyumcu, A., Garcia-Diaz, A., 2000. A polyhedral graph theory approach to revenue management in the airline industry. Computer and Industrial Engineering 38(3), 375-396.

Lai, Y. J., Hwang, C. L., 1992a. Interactive fuzzy linear programming. Fuzzy Sets and Systems 45(2), 168-183.

Lai, Y. J., Hwang, C. L., 1992b. Fuzzy Mathematical Programming. Springer-Verlag, Berlin.

Lai, Y. J., Hwang, C. L., 1994. Fuzzy Multiple Objective Decision Making. Springer-Verlag, Berlin.

Lane, D. E., Heaver, T. D., Uyeno, D., 1987. Planning and scheduling for efficiency in liner shipping. Maritime Policy and Management 14(2), 109-125.

Lautenbacher, C. J., Stidham, JR. S., 1999. The underlying markov decision process in the single-leg airline yield-management problem. Transportation Science 33(2), 136-146.

Lee, E. S., Li, R. J., 1993. Fuzzy multiple objective programming and compromise programming with Pareto optimum. Fuzzy Sets and Systems 53(2), 275-288.

Liang, Y., 1999. Solution to the continuous time dynamic yield management model. Transportation Science 33(1), 117-123.

Lim, S. M., 1996. Round-the-world service: The rise of Evergreen and the fall of U.S. Lines. Maritime Policy and Management 23(2), 119-144.

Martin-Clark, D., 2000. The quiet revolution. Containerisation International 33(1), 71-73.

Martinson, F. K., 1993. Fuzzy vs. minmax weighted-multiobjective linear programming illustrative comparisons. Decision Sciences 24(5), 809-824.

McGill, J. I., Van Ryzin, G. J., 1999. Revenue management: research overview and prospects. Transportation Science 33(2), 233-256.

Narayanan, P. R., Yuen, B. B., 1998. Point of sale: an alternative form of O&D control. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 377-385.

Perakis, A. N., Jaramillo, D. I., 1991. Fleet deployment optimisation for liner shipping Part 1: Background, problem formulation and solution approaches. Maritime Policy and Management 18(3), 183-200.

Powell, B. J., Perakis, A. N., 1997. Fleet deployment optimization for liner shipping: an integer programming model. Maritime Policy and Management 24(2), 183-192.

Rana, K., Vickson, R. G., 1988. A model and solution algorithm for optimal routing of a time-chartered containership. Transportation Science 22(1), 83-95.

Rana, K., Vickson, R. G., 1991. Routing containerships using Lagrangean relaxation and decomposition. Transportation Science 25(2), 201-214.

Robinson, L. W., 1995. Optimal and approximate control polices for airline booking with sequential fare classes. Operations Research 43(3), 252-263.

Rommelfanger, H., Slowinski, R., 1998. Fuzzy linear programming with single or multiple objective functions. In: Slowinski, R. (Eds.), Fuzzy Set in Decision Analysis, Operations Research and Statistics. Kluwer Academic Publishers, U.S.A., pp. 179-213.

Ronen, D., 1983. Cargo ships routing and scheduling: Survey of models and problems. European Journal of Operational Research 12(1), 119-126.

Ronen, D., 1993. Ship scheduling: The last decade. European Journal of Operational Research 71(3), 325-333.

Sakawa, M., 1983. Interactive computer programs for fuzzy linear programming with multiple objectives. International Journal of Man-Machine Studies 18(4), 489-503.

Sakawa, M., 1984. Interactive fuzzy goal programming for multiobjective nonlinear problems and its application to water quality management. Control and Cybernetics 13(2), 217-228.

Sakawa, M., 1993. Fuzzy Sets and Interactive Multiobjective Optimization. Plenum Press, New York.

Smith, B., Leimkuhler, R., Darrow, R., Samules J., 1992. Yield management at American airlines. Interfaces 1(1), 8-31.

Subramanian, J., Stidham, JR. S., Lautenbacher C. J., 1999. Airline yield management with overbooking, cancellations, and no-shows. Transportation Science 33(2), 147-167.

Tajima, A., Misono, S., 1999. Using a set packing formulation to solve airline seat allocation/reallocation problems. Journal of the Operations Research Society of Japan 42(1), 32-44.

Talluri, K., Van Ryzin, G., 1999. A randomized linear programming method for computing network bid prices. Transportation Science 33(2), 207-216.

Tanaka, H., Ichihashi, M., Asai, K., 1984. A formulation of fuzzy linear programming problem based on comparison of fuzzy numbers. Control and Cybernetics 13(2), 185-194.

Teodorovic, D., 1998. Airline network seat inventory control: a fuzzy set theory approach. Transportation Planning and Technology 22(1), 47-72.

Wan, K., Levary, R. R., 1995. A linear programming based price negotiation procedure for contracting shipping companies. Transportation Research Part A 29(3), 173-186.

Weatherford, L. R., Bodily, S. E., 1992. A taxonomy and research overview of perishable-asset revenue management: yield management, overbooking, and pricing. Operations Research 40(5), 831-844.

Werners, B., 1987. An interactive fuzzy programming system. Fuzzy Sets and Systems 23(2), 131-147.

Wollmer, R. D., 1992. An airline seat management model for a single leg route when lower fare classes book first. Operations Research 40(5), 26-37.

Wong, J. T., Koppelman, F. S., Daskin, M. S., 1993. Flexible assignment approach to itinerary seat allocation. Transportation Research B 27(1), 33-48.

Xie, X., Wang, T., Chen, D., 2000. A dynamic model and algorithm for fleet planning. Maritime Policy and Management 27(1), 53-63.

Yan, S., Bernstein, D., Sheffi, Y., 1995, Intermodal pricing using network flow techniques. Transportation Research Part B 29(3), 171-180.

You, P. S., 1999. Dynamic pricing in airline seat management for flights with multiple flight legs. Transportation Science 33(2), 192-206.

Yu, P. L., 1973. A class of solutions for group decision problems. Management

Science 19(8), 936-946.

Yu, G., Yang, J., 1998. Optimization applications in the airline industry. In: Du, D.-Z., Pardalos, P. M. (Eds.), Handbook of Combinatorial Optimization Vol. 2. Kluwer Academic Publishers, U.S.A., pp. 635-726.

Yuen, B. B., 1998. Group revenue management: redefining the business process. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 363-375.

Yuen, B. B., Irrgang, M. E., 1998. The new generation of revenue management: a network perspective. In: Butler, G. F., Keller, M. R. (Eds.), Handbook of Airline Marketing. McGraw-Hill, U.S.A., pp. 319-331.

Zadeh, L.A., 1965. Fuzzy sets. Information and Control 8(2), 338-353.

Zeleny, M., 1985, Multiple Criteria Decision Making. McGraw-Hill, New York.

Zheng Y. S., Zhao, W., 2000. Optimal dynamic pricing for perishable assets with nonhomogeneous demand. Management Science 46(3), 375-388.

Zimmermann, H. J., 1978. Fuzzy programming and linear programming with several objective functions. Fuzzy Sets and Systems 1(1), 45-55.

李高彥(1995)，定期貨櫃海運業應用收益管理之研究，國立交通大學管理科學研究所碩士論文。

汪進財、葉文健(1998)，「超額訂位問題之最佳控制策略」，中華民國運輸學會第 13 屆論文研討會，頁 51 - 60。

汪進財、蔡言宏(2001)，「航空公司超額定位控制策略之研究」，運輸計畫季刊，第 30 卷第 1 期，頁 135 - 164。

吳偉銘(2002)，「超額容量對國內線航空定價行為影響之研究」，運輸計畫季刊，

第 31 卷第 2 期，頁 429 - 450。

邱明琦、陳春益、林佐鼎(2002)，「海運貨櫃排程模式之研究」，運輸計畫季刊，第 31 卷第 3 期，頁 495 - 522。

許文娟(1998)，Ksilingam 航空貨運收益管理模式之研究，國立交通大學交通運輸研究所碩士論文。

陳茂南(1997)，「競爭環境中航空公司應變之道 – 生益管理」，中華民國運輸學會第 6 屆校際運輸學術聯誼研討會，頁 58 - 73。

陳春益、張永昌(1997)，「航商選擇定期貨櫃航線泊靠港之探討」，國家科學委員會研究彙刊：人文及社會科學，第 7 卷第 3 期，頁 438 - 444。

陳春益、李啟安(2001)，「貨櫃航商收益管理之研究 – 以艙位分配為例」，中華民國運輸學會第 16 屆論文研討會，頁 851 - 859。

陳春益、邱明琦(2002)，「貨櫃航線網路設計之研究」，運輸計畫季刊，第 31 卷第 2 期，頁 267 - 298。

陳昭宏(1997)，「航空公司營收管理模式之研究 – 整合艙位配置與超額訂位之動態策略」，中華民國運輸學會第 6 屆校際運輸學術聯誼研討會，頁 25 - 42。

盧華安、劉中平、徐育彰(1998)，「貨櫃船船隊部署問題之探討」，中華民國運輸學會第 13 屆論文研討會，頁 165 - 173。

盧華安(2002)，「定期貨櫃航線設計之研究」，運輸計畫季刊，第 31 卷第 1 期，頁 121 - 142。

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Publications:

Journal Papers

1. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2003. Ship scheduling and cost analysis for liner shipping service route planning. International Journal of Maritime Economics & Logistics (received in September, 2002 and accepted in May, 2003, to appear in Vol. V, No.4).
2. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2003. Ship scheduling and service network integration for liner shipping companies and strategic alliances. Journal of Eastern Asia Society for Transportation Studies (received in February, 2003 and accepted in June, 2003, to appear in October, 2003).
3. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2003. An optimal containership slot

allocation for liner shipping revenue management. Maritime Policy and Management (received in May, 2002).

4. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2003. Revenue management for liner shipping companies: a containership slot allocation model. International Journal of Transport Management (received in March, 2003).
5. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2002. Container slot allocation using fuzzy multi-objective programming techniques. Traffic and Transportation 21, 39-56.
6. Ting, Shin-Chan, Tzeng, Gwo-Hshiung, 2001. Liner shipping revenue management: optimal slot allocation model. Traffic and Transportation 20, 53-77.
7. 丁士展(民國 87 年),「定期航運產業生態之合縱連橫」,航貿週刊，第 9847 期，頁 58 - 63。
8. 邱盛生、陳志鶴、康照宗、丁士展、李宏生、方志文、林秋錦(民國 85 年)，「台北市棋盤式幹線便捷公車規劃」,都市交通。
9. Tzeng, Gwo-Hshiung, Hwang, Ming-Jiu, Ting, Shih-Chan, 1995. Coal logistics system: allocation planning and bulk fleet development for Taipower. International Journal of Physical Distribution & Logistics Management 25(8), 26-49. (**SCI**)
10. 曾國雄、黄明居、丁士展(民國 84 年),「專用散裝船隊最適調配之研究」,運輸計劃季刊，第 24 卷第 4 期，頁 447 - 480。(**TSSCI**) 曾國雄、黄明居、丁士展(民國 83 年),「台電最適燃煤調配計劃之研究」,台電工程月刊，第 556 期，頁 35 - 46。

Conference Proceedings

1. Ting, Shih-Chan, Tzeng, Gwo-Hshiung, 2002. Fuzzy multi-objective programming approach to allocating containership slots for liner shipping revenue management. The 16th MCDM (Multi-Criteria Decision Making) World Conference.
2. 丁士展(民國 90 年)，「定期航運航線規劃之成本分析」，第 9 屆校際運輸學術聯誼研討會。
3. 李樑堅、陳韜、丁士展(民國 89 年)，「我國港埠作業民營化後之航港管理之面對課題及解決對策 - 以高雄港為例」，中華民國運輸學會第 15 屆學術研討會。
4. 邱盛生、陳志鶴、康照宗、丁士展、李宏生、方志文、林秋錦(民國 84 年)，「台北市棋盤式幹線便捷公車規劃」，中華民國運輸學會第 10 屆學術研討會。
5. Tzeng, Gwo-Hshiung, Hwang, Ming-Jiu, Ting, Shih-Chan, 1995. Coal allocation using fuzzy multi-objective multi-index transportation problems for Taipower. The 13th MCDM (Multi-Criteria Decision Making) World Conference.
6. 曾國雄、黃明居、丁士展(民國 84 年)，「交談式模糊多指標運輸問題應用於台電燃煤調配計劃之研究」，中華民國第二屆模糊理論與應用研討會。

Books

1. 丁士展(民國 83 年)，專用散裝船隊最適調配之研究 - 以台電燃煤船運為例，交通大學交通運輸研究所碩士論文。

2. 丁士展(民國 92 年)，定期航運航線規劃與收益管理之研究，交通大學交通運輸研究所博士論文。

Reports

1. 船舶運送業國內航線別成本計算制度之研究，交通部運輸研究所，民國 91 年。
2. 如何加強港埠作業民營化後港埠經營監督之研究，交通部，民國 89 年。
3. 大眾運輸(海運部分)營運評鑑制度之研究，交通部中部辦公室，民國 88 年。
4. 路面管理系統資源最適規劃之研究，交通部公路局，民國 88 年。
5. 公共工程合理化期程之研究，行政院公共工程委員會，民國 88 年。
6. 2000 年造船計畫，陽明海運公司，民國 87 年。
7. 1998 年船隊調配計畫，陽明海運公司，民國 87 年。
8. 開闢越大西洋航線專案，陽明海運公司，民國 86 年。
9. 營業車輛使用年限之研究，交通部運輸研究所，民國 85 年。
10. 促進大眾運輸發展方案，交通部運輸研究所，民國 84 年。
11. 台北市棋盤式幹線便捷公車之研究，交通部運輸研究所，民國 84 年。
12. 台電公司燃煤最適調配之研究，台灣電力公司，民國 83 年。
13. 台北市公共設施設置標準之研究，台北市政府，民國 82 年。