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Research on liner shipping schedule recovery

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

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Abstract

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Liner shipping market has be under depressed situation in last few years due to the economic crisis, increasing bunker costs, and excessive capacity compared to demand. So that more focus has been put on cost control, which may highly related to operational disruptions in liner shipping. Disruptions can occur due to bad weather conditions, port congestion, and technical problems and so on. Common method for recovering a schedule is to either increase the speed at the cost of high bunker consumption. Advanced recovery options might exist by swapping two port calls or even omitting one.

This paper evaluated vessel schedule recovery by investigating disruption scenario. Select a recovery action balancing the trade-off between extra bunker cost, vessel schedule reliability and the impact on cargo (evaluate by punishment cost) in the remaining rotation. At first, make a analyzation and conclusion on the theory, scope, and the achievements of disruption management which used to be talked in aviation and logistic field, also those used on shipping field but put more focus on port side. Finally, take time deviation as main variable and make models. In this paper two cases are used to testify the model, and make a objective evaluation and analysis, and put forward my own idea about the future work.

Key word: liner shipping; uncertainties; disruption management; schedule recovery

1. Introduction

Liner shipping is highly efficient, standardized, international and informational, embodies the scale of economy in modern society. But since shipping industry is still under a depressed situation, how to maintain schedule accuracy under premise of cost leadership has already been the top issue of liner shipping companies.

Liner transportation is defined as liner-shipping company should provide repeated and regular container transportation service to different shippers with fixed schedule, port rotation according to operation regulation set beforehand, and freight is charged per transported unit. This is quite a simplified way for international trade. Since the port of call of whole rotation is published in advance. However, uncertainties happen during navigation may cause schedule deviation, sometimes even makes the published schedule unfeasible. Also, shipping industry's specialty is cost intensive, for example, high value of vessel itself, bunker cost, cost of going through canals, calling ports for cargo discharging and loading, once containers cannot be carried onboard or delivered on time, shipping company has to take these losses and get goodwill hurt. What customers/shippers ask for is a fast and reliable delivery, at mean time, shipping company keeps improving its daily operation work to save as much cost as possible [31], which are contradictory with each other. The research this paper brings out is about how to face uncertainties among the whole transportation network to recover those impacted schedule and find a balance between two contradictions.

Currently, most researches on liner-shipping schedule are about how to design or optimize on a pro-forma basis. To maintain competitiveness of certain service, research has been focused on designing the network to operate as efficiently as possible. For shipping companies, a division of the ports into hubs and spokes is common. The network is not a traditional hub and spoke network design with direct links between two hubs or a spoke and a hub. The motivation for this hub-and-spoke network design is to benefit from the economies of scale on container vessels.

Even though, pro-forma schedule made by liner shipping company cannot take all uncertainties which may happen in real situation into consideration. Once encounter with bad weather, mechanical failure, port congestion, port closure etc., no matter how much buffer has been reserved in case uncertainties happen, great loss would be caused if cannot be recovered in time. So how to deal with schedule recovery is very important for liner shipping company.

All these uncertainties we can call them disruptions. Currently once disruptions happen, measurements usually taken by ship operators based on their experience. So the operator needs to have a very clear understanding of the objective of recovery and have some unique thoughts of fleet and ship management. If take it as one-off case, it is good to make quick decision. But for big liner shipping company who has large number vessels, better to make decision according to where the delay happened, how much is the actualized time deviated from schedule, and then do the recovery through detailed analysis and well-calculated result. The aim of this paper is to test the border which can make balance between schedule reliability and extra cost.

2. Literature Review

As mentioned in chapter one, always have uncertainties happen and disturb scheduled liner-shipping network operation. We call them disruptions. And people started talking about disruption problem since 1960s', but the concept wasn't been defined until 1980s'.

2.1 Main Research on Liner Shipping Schedule Optimization

Nowadays, most of the researches in liner shipping schedule are about how to design or optimize a liner-shipping schedule on a pro-forma basis. Wu Wenyi (2004)[1] combined shortest path algorithm and theory of utilization, tried to make a routing selection model under optimized network. The effectiveness of this algorithm is verified by the sample application. Author mainly discussed about how to combine several related service of one company and to turn them into a transportation network, find out the shortest path and optimized the whole network. Baird (2006)[5] proposed a multi-objective model for liner shipping route design in order to reduce transportation and inventory cost. Firstly decide the function of transport and inventory cost by analysis, and then solve the problem by applying certain system, find out best-fitted type of vessels and transportation cycle. Optimized service route then be decided. Gelareh(2010)[3] proposed a mode of optimizing the network by choosing certain center hub port. Author suggest to reduce transportation cost by sizing the number of hub ports and designing the rotation with the premise of providing better service to customers. In this model, FLAC numerical calculation and heuristic method is combined to apply to solve the problem. Meng Qiang and Wang Tingsong(2010) [4] proposed a multi-stage fleet planning model , solved it by dynamic programming algorithm and applied shortest path method to acyclic network. This help to get effective and optimized solution. Hong Bo (2011) [2]find there has certain time lag for liner shipping company to react to increasing bunker price and take useful action by setting up a model to calculate the impact in voyage cost caused by bunker.

2.2 Main Research on Disruption Management in Transportation System

Yu Gang (2004) [9] first defined disruption management as at the beginning of planning job, use an optimization model and solving algorithm to find out a good operation plan; if any disruption event happened duo to both inside or outside uncertainty in process and make the plan infeasible, a real-time new plan has to be made, which need to take original optimization objective into consideration and try to reduce negative impact. Hu Xiangpei(2008) [10] outlined how disruption management concept formed and its development process; reviewed and analyzed graph model and the research progress of mathematical model, also the algorithm methodologies.

Study on schedule recovering from outside impact now is mainly applied to aviation, railway and highway transportation. But only recent years some researches start to involve liner shipping, which are taking reference on those researches regarding aviation and logistic. Firstly, we shall take a look into what people done in aviation and logistic field.

2.2.1 Aviation Field

In aviation field, disruption management is mainly focused on recovery of flight, crew and passenger. Yong Yean Yik (2005) [11] studied about multi-objective airline schedule recovery model: how to minimize the impact that would cause to passengers and how to maximize the ratio of ensuring passengers arrive on time. Meanwhile, also added the time need for maintaining. Edmund K. Burke(2010) [12] studied on multi-objective method of robust airline scheduling which enhanced reliability and flexibility of flight. Lavanya Maria (2010) [13] also used robust model to forecast the possible uncertain factors in future operation, combined disruption management and flight schedule to manage delay and disruption. Based on financial loss, Liu Yanhong et al. (2011) [14]studied on recovery model of delayed flight. This model not only considered how much time the flight delayed, but also considered the financial loss caused by different type of flights, solved by genetic algorithm.

Disruption management study in aviation is relatively mature; many concept models are proved to be effective by applying to practice. As airline is similar to liner shipping to some extent-plane and ship, passenger and cargo, it is very consultative to schedule recovery in liner shipping industry [27].

2.2.2 Logistic Field

In logistic field, mainly discuss about the truck, road condition and insufficient customer information. Potivn (2006) [26] studied about disruption caused by random driving time of trucks while collecting cargo. Set the integer programming model with objective of weighted sum of minimum driving time, delayed delivery time and delayed work finish time. Li Jing Quan et al. (2009) [25]

set up a mathematical model with objective of minimum operation cost and cancellation cost, which is solved by Lagrangian relaxation method. Wang Xuping (2010) [28] studied on disruption caused by delivery time changing, and solved the problem by genetic methodology.

Obviously, in recent year most research in logistics field are from single aspects, rarely has factor combined research.

2.3 Relative Research on Liner Shipping

However, although disruption control has been noticed in liner shipping industry, there has not a standard of how to handle disruptions based on scientific ways, usually by personal behavior and decision. Since liner shipping is similar to airline. And disruption management is well applied in airline industry. We believe that a mathematical support model would result in maintaining a cost saving policy, while schedule reliability of service would not be suffered.

Take a review on previous research on optimization of liner shipping schedule recovery, there has limited resource. Marielle Christiansen et al. (2007) [15] thought there has two main reasons for people do not write paper on this topic: 1) in contrast with inland transportation and logistic industry, shipping company is low in volume, although is much higher in value; 2) shipping is an industry with long history, way of management is kind of solicitation. But just as shown in Notteboom (2006) [7], shipping usually has more uncertainty. But from author's suggestion is that there has a fierce competition in liner shipping market, it is really possible that some companies may has their own system on how to optimize schedule recovery, but as trade secrets.

Currently, most of research about disruption problem is focused on terminal side. Wu Peijian (2010) [16] analyzed how disruption events happened randomly in terminal affect the operation of liner shipping network by applying sampling statistics theory and simulation methodology from service quality aspect. Author proposed a reliable simulation model to calculate the minimum time need for cargo commencement in the whole network and increase the reliability of whole schedule.

Yang Chunxia et al. (2011) [17] and Li Qiang et al. (2009) [18] supposed disruption management of the distribution of berth in container terminal, mainly focusing on how to recover berth schedule when vessel is delayed. As we know, for liner shipping, company usually fixed a certain window and berth with terminal side to ensure the schedule. Yang Chunxia et al. (2011) [17] suggest to use integer linear programming model and proposed an improvement on how to use genetic algorithm to solve the problem. However this is almost different from optimizing vessel schedule recovery problem, which makes the application range too narrow. Li Qiang et al.(2008) [19] take heuristic algorithm to study disruption management of berth availability. Zeng Qingcheng et al. (2007) [20] take simulation of local double berth allocation to solve disruption management of berth availability. Chen Qiushuang et al. (2010) [21] did research and discussion on the disruption management under container terminal's uncertainty environment. Suggested a system framework with robust allocation model. Sun Huijie (2010) [22] introduced the concept disruption management to study problem of berth window delay.

Judith Mulder (2009) [23] examined an optimal recovery policy in liner shipping network by using a Markov decision model. Author thought that, in order to study this problem, there have two questions need to be clarified: What kind of measure need to be taken to prevent further delay? How much buffer needed to make up for delay? Upon these two question, Markov Model is used to decide what measure to be taken in particular place for a certain delayed vessel. Jie Li (2009) [30] doing research based on simulation, add in penalty factor, take use of constraint and performance function to realize the optimization of random events. Thus get a solution closer to reality. Al-Yakoob S M, Sherali H D. (2012) [29] used a column approach and mix integer scheduling to design a model with minimum voyage cost to optimize the amount of fleet, schedule and the choice of transshipment port. Heuristic algorithm with fixed sequence is used to solve this problem.

Especially for liner shipping field, Jakob Dirksen (2013) [24] is the first person who take reference of airline disruption problem and set up a MIP model for handling. Also Jakob take the use of actual case from Maersk to prove this model is feasible and effective. This is really a type of precedent for future research. But the model used is NP-complete model, which is too complexity. Once meet larger samples will have difficulty in solving it. The only recovery objective of this model is to minimize total cost. This is not enough for a complete vessel schedule recovery.

2.4 Existing Problems

According to 2.1, we can find that scholars from all over the world have done plenty of research on how to design a better network to develop liner-shipping's maritime transportation system. But seldom of them has talked about whether the system they want to set up is executable. So recent years, some scholars also begin to study how to deal with uncertainties during navigation. By reviewing mentioned literatures, still find problems existing as below:

- *Research model of design or optimization on liner shipping is too strategic to fit the real situation*

However there has a lot of sea contingency and port time uncertainty in real world that cannot be foreseen when make pro-forma plan. Shuaian Wang, Qiang Meng (2012)[6] proposed to design liner ship's schedule with the consideration of uncertain events happened either at sea or in port. A mixed-integer non-linear stochastic programming model is designed for mentioned service schedule to minimize total cost while maintaining the quality of service. However, although uncertainty is taken into consideration in this model, it still deals with a strategic level.

- *Most of research are concerning on designing a pro-forma schedule. But a lot of uncertainties that happened during navigation cannot be involved for real situation is more complicated, and these may cause heavy extra cost to owners or charters.*

Notteboom (2006) [7] analyze the negative effects disruptions caused to liner shipping and what are the actions taken by those liner-shipping companies to save extra cost. Also, statistics show that about 70% to 80% ships would be delayed in at least one port in liner shipping. Once these delays happen, huge amount of extra cost may occur if cannot be recovered on time. The later paper by Notteboom and Vernimmen [8] demonstrates how the increased bunker price has a significant impact on the liner shipping business. The cost of fuel is main cost driver when transporting containers, nevertheless in order to deliver good service level, shipping companies are willing to burn more fuel to arrive on schedule. Notteboom and Vernimmen [8] argue that if the schedule speed can be lower, fuel can be saved, which in turn vessels can have more buffer time and the operators more flexibilities to recover from disruption factors.

Since second half of 2014 till now, bunker price is under a slight downtrend. To some extent, this may impact the period for a whole rotation. So, if vessel schedule delayed, speeding-up can also be a way for schedule recovery. But current shipping market has excess capacity. It should be carefully evaluated if speed-up is a sensible choice. So the objective of this paper is try to find out the way that when making schedule for certain services, it is hard to estimate what would happen in real situation. So no matter how much buffer reserved, schedule will sure be impacted. Since every situation happened, it would be a one-off case when handling it. A more sufficient way is to suppose logic of what kind of method to be taken at certain level of delay instead of proposing a certain method.

3. Liner-shipping Schedule Recovery

Actually, shipping is a kind of service. The quality of this service depends on schedule reliability. Among shipping industry, especially liner-shipping, short transportation duration would be set by companies in order to satisfy shippers or consignees. To maintain goodwill, vessels need to sail in accordance with published schedule. If not, not only goodwill of shipping companies would be decreased, but also do damage on value of goods. That's why we say that timeliness extends to shipping policies. Once vessel is behind schedule and do not recovery in time, trade will be impacted. With these situations, it is reasonable for shippers or consignees to ask for compensation of cargo demurrage since shipping companies cannot perform the contract well. Therefore any disruption happened during the whole transportation that caused delay would increase additional operation cost and opportunity to ship owner. Meanwhile, shipping is really a high-cost industry, if further delay is carried, that will be a great loss. One more thing is that, if shipping company can provide stable high quality delivery on certain service, competitiveness will be undoubtedly improved.

So, what is schedule disruption for liner shipping? Container ships face uncertainties while going under one rotation, such as bad weather, port congestion, port closure and so on. These can make ships unable to berth or unberth as scheduled/planned, finally leads to schedule delay. Schedule recovery after disruption happened is to take some measurement to help vessels be on time as soon as possible. For instance, speed up, omission, port swap and so on. In following parts of this chapter will going to see in detail about disruptions (uncertainties) and measurements that can be taken.

3.1 Disturbing Factor Analysis

During the whole transportation rotation, uncertainties could be encountered dense fog, typhoon, strong wind and etc. Affairs like these do not often happen but are unpredictable. These bad weathers would impact vessels' schedule. For example, due to low visibility when having dense fog, vessel cannot go with high speed and cannot make estimated arrival time. Even would impact ports' normal operation--productivity may be reduced. Sometimes, bad weather will last for a long time. During March to April in Chinese northern ports, dense fog is possible to last for a week's time, in southern port, dense fog may last for certain hours every day. Most of time, not too much buffer is reserved/remained in schedule. Once delayed too much time, it will cause huge loss.

3.1.1 Port Congestion

The impact caused by port congestion cannot be underestimated. It can influence production and sales of an enterprise, more safety stock is needed. For liner shipping market, congestion will not only impact the ports' ability to handle vessels come in but also upset the whole schedule. Main reason for port congestion is due to demand unbalance in different countries and regions and changeable international trade. For example, around Chinese New Year, there has a shoot up of shippers' orders and gate-in containers in container yard.

However, it is unavoidable to go with labor insufficient since everyone is on holiday. Then we need longer port-stay for ships alongside and longer waiting time for approaching vessels. For charters, they may not be willing to waiting in anchorage. Sometimes operator will choose omit. If certain port cannot be omitted, in order to minimize schedule deviation, vessels need to sail with maximum speed. Higher bunker cost can't be avoided.

3.1.2 Low Port Productivity

In most situations, when make a pro-forma schedule, estimated volume of containers and lowest productivity would be taken into consideration for calculating safe port stay. Different ports have different productivity; this is what we call service level of terminal. Also it can be measured by the flexibility of how terminal handles emergent issues. Like Yantian Terminal, although port closed and cargo operation suspended for half to one day due to dense fog, the situation can be released within one day, while Shanghai terminal may take one or two days' time. That depends on the productivity of certain port.

3.1.3 Tidal Issue

For different types of container ships have different drafts. Considering the scale of economy, ships with larger size have already become normal. One thing need to be mentioned is that, such 3-E type vessel of Maersk, although max draft declared 14.5m, actually it can be 15m. Once ship's draft hit this line, berthing and unberthing time will have more restriction due to channel depth. Vessels with deep draft can only passing channel with high tide. And for safety, it could be requested by pilot to enter/exit the channel with rising or falling tide for port side alongside or starboard side alongside. Usually this will have several hours' deviation. All this time may be get from time at sea, which means more bunker need consuming.

3.1.4 Canal Impact

Although the use of canal provides a lot convenience to shipping, canal also has great impact on vessel's schedule, especially for liner shipping. Take Suez canal for example, since there has limitation on canal width, it is unidirectional. Usually it takes 11 to 16 hours for passing. Which means if vessel delayed and cannot catch Suez's window, it will be behind schedule for around half day.

All five situations mentioned above are those would cause delay to vessels' schedule, and delay that vessel carried cannot be recovered by slight adjustment of speed.

3.2 Method for Schedule Recovery

No matter how perfectly the schedule is designed in advance, delay is unavoidable if encounter with any disruption issue as mentioned above. Considering the heavy cost carried by vessels behind schedule, operators of certain vessel should take any action to get schedule recovered with minimum cost. Actions are as below:

3.2.1 Adjusting vessel speed

When delay carried by liner shipping, here have two situations:
If delay is not so heavy, accelerating a bit is enough to help vessel arrive next port on time.

If delay is too heavy, it is better to apply acceleration together with other method. With long distance navigation, higher-speed sailing will take for comparatively longer period, but also have longer time for vessel to recovery schedule.

By taking this method, no doubtfully will increase bunker cost, as well as operational cost. From another side, keep sailing with high speed will accelerate depreciation on vessel, which means higher maintenance cost. It is normal in real case that when vessel keep sailing with high speed for a long distance, main engine always have some problems and even break down. It's really dangerous.

3.2.2 Swapping order of calls

Since importance for each port is different. The importance of port depends on the priority of customer and how many goods need handling. Sometimes when vessel carries delay or certain ports is congested or closed, operators can swap order of calls to let vessel arrive port with higher weight on time. However, this option is better to taken when those ports are close to each other, otherwise longer distance do no help in bunker cost saving. Also this method is more suitable for those vessels with more discharging containers onboard. Since the transportation cycle is shortened, some ports with more discharge containers than loading containers will surly get the priority. Because this method is more focus on the time of delivery.

3.2.3 Omission

This is really an effective way for schedule recovery, but little used, especially for important port. Once taken, containers waiting to be taken in the omitted port will be further delayed. Also, these containers need to be carried by other vessels. Sometimes will choose a feeder, however that may cause higher cost.

Finally operation cost increased. Additionally, if certain port, although not so important, is frequently omitted, shippers or consignees will not be satisfied by the service level, company's goodwill will be harmed. Also, shipping company need to think about if it is necessary to do adjustment to the whole rotation.

3.2.4 Shortening Port Stay

When delay happened on container ships, shortening vessel's port stay is usually an effective way. Sometimes one or two hours' shortening may decide if there will have further delay when passing Suez Canal. And for those carry slight delay, schedule can be recovered with shorter port stay. But in order to get port stay shorter, sometimes more operational cost would be caused. Since more facilitates need be applied on one vessel, and when terminal operation is quite busy, there will have no extra cranes or trucks for delayed vessel. Then some containers have to be rolled before vessel berthing alongside or just be cut since vessel has attached her sailing deadline. To some extend, terminal performance, which decided port stay is important to schedule reliability of liner shipping.

No matter increase or decrease in bunker price, controlling operation cost always has the top priority in a liner shipping company's daily work. Sometimes may deploy more vessels on certain services to reduce bunker cost and also keep vessels calling port as scheduled. This can help company to keep a stable service level and avoid vessel sailing with high speed as well. However, more deployment means more maintenance cost, labor cost and etc.

All above are methods possible to take for schedule recovery, process of how to make decision on what methods would be taken will be discussed later in next charpter.

The aim of this research is try to maintain liner-shipping company's service level, below called schedule reliability, with lower cost. In following discussion, objective is to minimize the deviation between schedule and actual berthing/unberthing time, as well as control relative cost to make maximized return. So in liner-shipping schedule recovery, what measurement can be taken, what the most effective way is, how to keep the deviation to minimum are key points need to be studied in this paper.

3.3 Analysis on Cost of Schedule Recovery

Among researches of liner-shipping transportation cost, different people have their own opinions on how to classify. In general, preferring to divert the cost into fixed cost and variable cost. Suppose fixed cost means the cost that will not change with volume of containers transported. That will only relate to how the company manage their vessels. Variable cost means the cost relates with how the operators work. Cost will fluctuate with factors like volume, schedule and port due, etc. [32]-[35]

3.3.1 Fixed cost

Fixed cost includes below items:

Depreciation: vessel's depreciation happens once the vessel delivered and start sailing, machine and vessel-self cannot avoid getting wear and tear. So that vessel would be devalued. Usually depreciation rate is calculated as certain percentage of the price of buying value. This part of cost has to be removed from revenue.

Labor cost: A safe navigation cannot leave standardized operation of seamen. A group of well-trained crew is vital for shipping company. Seamen need to get their regular wage, bonus, allowance and insurance and etc. Also seamen need to get their off-time after a long time work onboard. During this period they should get their wage as well. The amount of wage they get during holiday is based on contract. However seaman from different countries get different wage. Those who from developed country usually get paid higher than those from developing or under-developed country.

Maintenance cost: A healthy vessel is vital to liner shipping. After running for a long time, machine will sure get worn. Especially for main engine, if any problem happened with it, vessel may be not able to run under a set speed, even worse, the vessel with worried main engine would be very dangerous. In order to avoid machine problem, routine maintenance should be done. Sometimes it's necessary to go into dry dock for renovation. This part of cost usually depends on vessel's value.

Insurance cost: As mentioned in 3.1, there have a lot of uncertainties in ocean and our vessels have risk to be in danger any time. If sailing under bad weather, for example, encountering a typhoon in high sea or main engine suddenly breaks down while sailing, will cause damage to our vessel, even threatens life of crew. So this part of cost cannot be saved, it is essential for shipping management and operation.

3.3.2 Variable cost

Besides fixed cost, we shall divide variable cost into two parts: cost at sea and cost in port.

For cost at sea, bunker cost and canal cost accounts for a much bigger share.

*Bunker cos*t is the total cost of what spend on bunkers when vessel sails under a normal condition, including high sulfur oils used by main engine for providing power and low sulfur oil used to provide electricity. And currently, some regions like U.S.A and Hong Kong have compulsory requirement of using low sulfur oil when approaching coastal area. For bunker price is fluctuating again and again these years, how effective measurements taken for bunker consumption have directly impact of companies' market competitiveness. Meanwhile bunker price differs from place to place, so it also need considering where to take bunker within the whole rotation. From another aspect, in order to maintain the schedule reliability and keep the same as published schedule, it is obviously that vessel cannot always run with slow steam. When vessel speeds up, consumption of oil will suddenly shoot up, not by times but by powers. So speed change while sailing is not a good choice. A good way to control bunker cost is to keep constant speed or RPM (revolutions per minutes).

For cost in port, this is another big share of total operation cost. Ports are connections of the entire service. Since the construction and operation of port need a lot money and labor, so for every call would be charged in different part, for example, pilot cost, tug fee, port due, vessel tonnage due, berth cost, inspection cost, inspection cost, agent cost, container yard management fee etc.. So port cost is consisting of many different parts.

3.3.3 Cost caused by schedule recovery

However, with the changing status of the world trade and economy, and the depressed market as well, shipping is no longer a profitable industry by comparing with its past. Shippers and consignees demand higher level of shipping company's service. Labor cost is also increasing. All these above cause higher operation cost. Some shipping companies cannot afford such high cost, profit cannot balance their losses, company just breaks down. It is also not a one off case that container ship is arrested, customers cannot get their cargo back due to rent hasn't been paid to owner by charter.

In order to reduce high operation cost, liner-shipping companies start to find some way to do some adjustment. For example, alignment. 2M of Maersk and Mediterranean Shipping Company, CKYHE of COSCO, KLINE, YANG MING, HANJIN and Ever Green. These companies enlarge range of their service and share cost by alliance.

Without doubt, a reasonable pro-forma schedule that published to customers can give more flexibility to operators when any uncertainty happens. Not only can control speed and get schedule recovered as soon as possible but also can save company's competitiveness and goodwill. So, the cost caused by schedule deviation can be categorized from three aspects:

Shippers' cost: Because if vessel delayed, goods' delivery will also be delayed, customers need to pay more opportunity cost. Especially for seasonal goods that are for festival, if cannot be delivered on time, cargo owner will carry great loss. In the long run, schedule deviation will also bring down yields of shipping company.

Port expense: Since container vessels have relatively fixed schedule. Liner shipping companies usually have contracts with terminal side, for certain period of a day, the berth should be reserved for one service to call. But if vessel cannot arrive on time, utilization of berth will be lowered. However those berths are public resources, if vessel cannot catch the window, sometimes will cause further delay. More port expense will be charged with unregularly cargo operation and discrepancy with contracts.

Charter rate: it is not difficult to imagine that once chartered vessel is delayed, means charter need to pay more for the vessel to finish the whole rotation, or the vessel cannot be fully used under certain period. So that, if vessel cannot run under schedule, shipping company needs to take a lot of economics loss.

Above all, to deliver containers on time is what shipping companies promise to customers. But by speeding up to catch schedule, bunker cost is quite high; by omitting or swapping ports, a lot of commercial and operational problem may happen. So if we can get the schedule recovered at the extreme, meanwhile satisfying our customers with lowest extra cost or even save some cost, this is what we want to discuss in following passage, to get a win-win situation on both sides.

4. Modeling of vessel schedule recovery problem

4.1 Process of vessel schedule recovery

Before starting with modeling of schedule recovery, I shall go through the process of vessel schedule recovery:

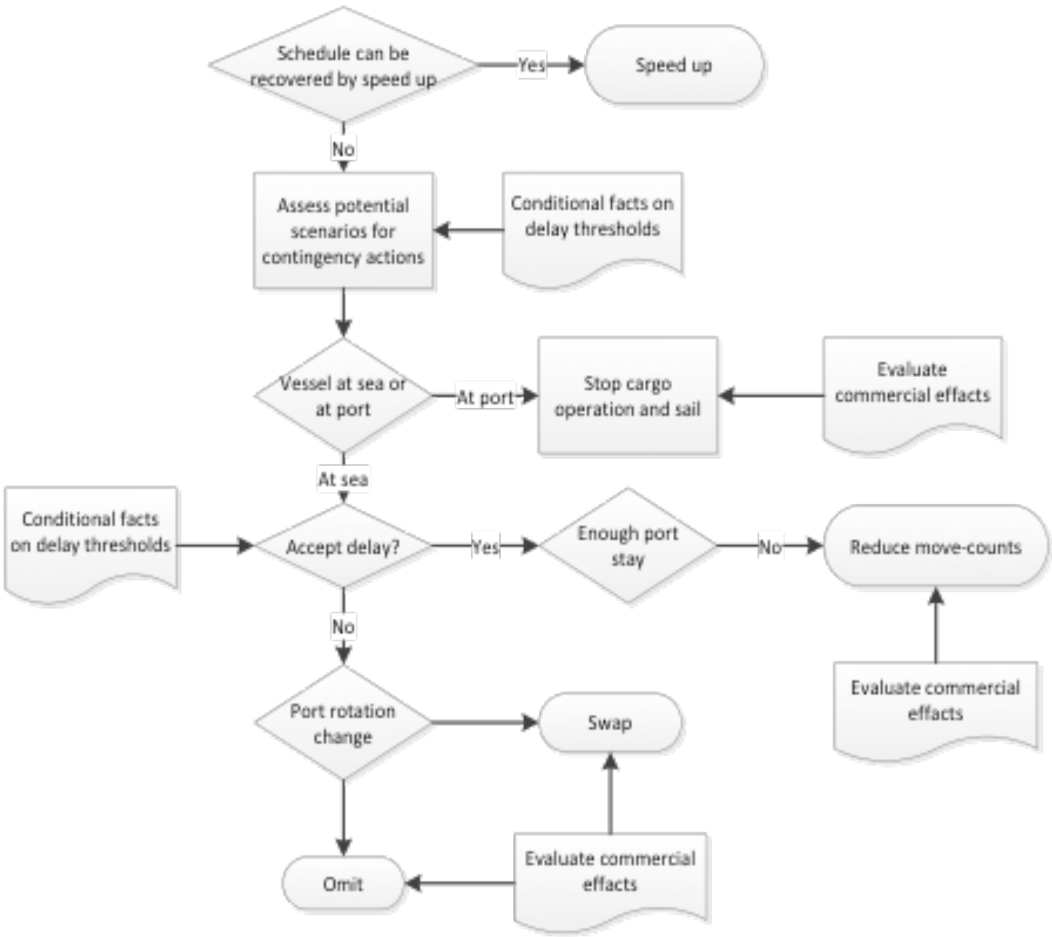

Fig 4.1 Process of vessel schedule recovery

First of all is to monitor vessel status. Vessel operator shall check current status of captioned vessel by comparing with original schedule. And also check port situation or any other information that may impact vessel schedule. Based on the evaluation of current status of vessel, operators need to monitor if any risk of future delay. If so, operator need to decide whether to take specific recovery action for sake of cost saving purpose, that is by using minimum extra cost to get schedule recovered.

If schedule is possible to be recovered by slight adjustment in speed, there is no need to take other actions like reduce move-count, omission and swap which may cause commercial problems. But if it is necessary for above methods to be taken, operators should evaluate what is the most cost efficient way.

Operators need check vessel's location first. Situations should be distinguished when vessel is at sea or at port.

When vessel is alongside the port, if meet the sailing deadline at current port, only one method can be taken is stop cargo operation and sail out to avoid potential further delay in next port. By shortening port stay, certain amount of containers cannot be loaded or discharged.

When vessel is at sea, the evaluated scenario should be different.

When delay is still acceptable but just limited port stay for cargo operation when vessel is alongside, move-counts have to be reduced. The amount of containers can be handled is depend on productivity of ports. Operators need to filter the loading/discharging list and choose those containers with higher priority to be handled first. Thus whenever reduce the commercial affects.

Once delay cannot be accepted, port rotation then has to be changed.

After comparing berth availability in next two or three ports (which are close to each other) and comparing importance of different ports as well, making sure that there has no commercial impact (especially when berthing time earlier than pro-forma time) and no problem with draft issue, operators can swap ports to maintain vessel on schedule in relative important ports.

Recovery can also be considered as port omission. According to the schedule recovery level set, choose to omit the port with least impact for schedule recovery. A lot time and bunker can be saved.

However, final decision of swapping or omission should be depend on extra cost of these two choice caused.

4.2 Basic data needed

According to above process, in this part, will give explanation to basic data needed for schedule recovering problem in detail.

4.2.1 Data of vessel

This part of data including minimum speed , maximum speed, pro-forma speed and bunker consumed at pro-forma speed. Because in this model, we put emphasis on speed when sailing at sea to get schedule recovered. Most of bunker should be high sulphur oil (HSO).

In order to handling those factors that cause delay in vessel's schedule, it is essential to know what kinds of measurements are possible to be taken. Including which port is feasible to omit, which ports are possible to be swapped.

Last but not least, operator of certain vessel or certain service should have idea about what is the deadline for vessel to arrive or depart. This will do great help to get vessel schedule recovered as soon as possible. Otherwise since too much impact may happen with one decision, it is hard to take a timely step to help vessel go back to pro-forma schedule. So to what extent schedule has to be recovered is an important constraints for the following model going to be set. However, this is depend on what service and what direction vessel is going. Will discuss it later in detail .

4.2.2 Data of containers

For containers, delivery date is more important than when does it start being transported. However time of being loaded also influenced time of being delivered, but relatively speaking, time of delivery is more important to customers. But for those containers whose destination is not included in the range that schedule has to be recovered, it is unnecessary to evaluate.

Another information of containers need to be known is what kind service is certain containers in. This is transportation rotation. It is normal that every container will be transshipped for several times before being delivered. In order to promise frequently cargo connection and on time delivery, rotation and service have to be taken into consideration.

Another thing is total move-count at each port. This directly decides port stay of a call. When vessel carries heavy delay, one or two hours difference can decide if the vessel will face further delay or not. Sometimes we have to do some cut and run, which means stop cargo operation and just sailed out. This may cause some problems on commercial side, but will do great help to vessel’s schedule. This paper set cost of commercial side as punishment, which may take 20% of tariff on each container.

Above all, total operation cost of s shipping company is a sum of bunker cost, port due, punishment cost caused by schedule delay and management cost.

4.3 Parameters and variables

Based on components of operational cost mentioned in last paragraph, following is the explanation of parameters would be used in model.

Tab 4.1 Explanation of parameters

Parameters	Explanation
S_1	Transport rotation on service l
P_l	Set of port on service l
B_d	Designed volume of bunker consumed per hour for navigation based on designed speed
p_b	Price of bunker
u	punishment coefficient for omission,
d_j	Distance from port (j-1) to port j
T	Sailing deadline in port j for vessel to departure for schedule recovery
$t_{waiting}$	waiting time after arrival
P_j	Productivity for port j
C_{port}	port due for loading and discharging
M_j	Total move-count in port j

Parameters	Explanation
$M_{k,j}$	The amount of containers transported from port k to j
f	Freight per unit
$L_{k,j}$	Distance between port k and port j
V_d	vessel designed speed
V_{min}	minimum speed of vessel
V_{max}	maximum speed of vessel

Tab 4.2 Explanation of variables

Variables	Explanation
t_j	actual time at sea from port (j-1) to port j
X_{kj}	x_{kj}=1, vessel sail from port k to port j, x_{kj}=0 vice versa
y_j	Based on X_{kj}=1, if port j is omitted, y_j=0;not omitted, y_j=1
d_j^+	deviation of time that exceed preset sea passenger time
d_j^-	deviation of time that less than preset sea passenger time

4.4 Modeling

Vessel schedule recovery model which is going to be set in this paper take reference on recovery model of aviation. The similarity of liner-shipping and aviation has been mentioned in previous part.

Before setting the model, there come with some assumptions:

a) As just mentioned, it is essential for operators to set a deadline for schedule recovery. In following model, we will not take the whole rotation for schedule recovery, but take part of the rotation according to recovery level set to choose starting port and destination port.

b) Suppose capacity of all vessels is well planned, no container would be unable to be loaded due to overload.

c) Do not take holiday into consideration. For most of the case, we shall suppose it happens in non-holiday time.

d) Suppose the voyage revenue does not reduce due to the measurement take for schedule recover, all the cost will be calculated as punishment, which may take u=20% of tariff on each container.

When doing schedule recovery, it is important to solve problem from an overall view. For liner-shipping, there have three constraints:

a) First of all is to keep schedule deviation nearly as small as possible

b) Secondly, when trying to control schedule deviation, shipping company have to control the cost of schedule recovery, including extra bunker cost or port expense etc..

c) Thirdly, control the amount of containers need delivering as few as possible. That is to minimize punishment cost of delayed cargo delivery, which we mentioned above as 20% of tariff.

So, it is easy to find these three objectives have internal conflict with each other.

Bunker cost will undoubtedly be high if we want to keep small deviation on schedule; if we want to keep low bunker cost, delayed delivery of containers cannot be avoided. If we want to keep low bunker cost means rotation need to be changed, some port(s) maybe omitted. If making swap to keep those relatively important discharge port on time, means rotation have to be changed.

In order to solve the conflict, this paper set priority for above mentioned objectives is in descending order, from a to c. Because if change too much on schedule, there may have more potential problems. In order to put things under good control, keeping small schedule deviation should be at the first priority. And comparing bunker cost and punishment cost, bunker cost is much higher than punishment cost.

These three objectives can be expressed as below:

a) Keep schedule deviation nearly as small as possible

$$\begin{cases} \min\{\sum_{i=1}^{k}(d_i^- + d_i^+)\} \\ t_i + d_i^- - d_i^+ = \hat{t}_i \qquad i = 1, 2, \ldots, k \\ \sum_{i=1}^{k} t_i + t_p \le T \end{cases} \quad (4.1)$$

For it is not possible to get schedule recovered between two ports, as mentioned above, a schedule recovery level need to be set. So base line for schedule deviation is the recovery level, which is the sailing deadline T.

b) Keep extra bunker cost nearly as small as possible:

In order to calculate extra bunker cost caused by speed up, in objective b) a method taken as below:

According to the formula of bunker consumption, actual bunker consumption from port (j-1) to port j defined as below:

$$B_j = B_d \times \left(\frac{v_j}{v_d}\right)^3 \quad (4.2)$$

For what this paper calculate is the extra cost caused during schedule recovery, we shall calculate extra bunker consumption by derivation of B_j:

$$B_j^{'} = \frac{3 \times B_d}{(v_d)^3} \times \left(\frac{d_j}{t_j}\right)^2 \quad (4.3)$$

By derivation of actual bunker consumption, we can directly find when $\Delta t_j \to 0$, what is the maximum bunker consumption can be. While d_j^- means deviation of time that less than preset sea passenger time, that is time saved by speed up. So extra bunker cost expressed as below:

$$b \times \frac{3 \times B_d}{(v_d)^3} \times \left(\frac{d_j}{t_j}\right)^2 \times d_j^- \quad (4.4)$$

Objective of minimum extra bunker cost is going to be defined as below:

$$\begin{cases} \min\left[\sum_{j=1}^{k} b \times \left(\frac{3B_d}{(v_d)^3} \times \left(\frac{d_j}{t_j}\right)^2\right) \times d_j^-)\right] \\ t_j + d_j^- + d_j^+ = \hat{t}_j & j = 1, 2, \ldots, k \quad (4.5) \\ \sum_{j=1}^{k} t_j + t_p \le T \end{cases}$$

c) Control punishment cost of port omission and reduced move-counts:

Punishment cost can be divided into two parts: Cost of port omission, means if vessel needs to call port j for discharging, but due to schedule delay have to omit that call, then total move-counts should be calculated with a punishment cost:

$$u \times f \times M_j \quad (4.6)$$

If the case is reducing move-counts, suppose all containers need discharging have to be handled first, those containers cannot be loaded have to be calculated with punishment cost:

$$u \times f \times \overline{M_j^l} \quad (4.7)$$

$\overline{M_j^l}$ means move-counts that cannot be loaded onto vessel in port j due to schedule issue.

To defined the objective in general form :

$$\begin{cases} \min\left\{[\sum_{j=1}^{k} X_{ij} \times (1-y_j) \times u \times f \times M_j^d] + [\sum_{j=1}^{k} X_{ij} \times u \times f \times \overline{M}_j^l]\right\} \\ t_j + d_j^- - d_j^+ = \hat{t}_j \qquad\qquad j = 1,2,\ldots,k \quad (4.8) \\ \sum_{j=1}^{k} t_j + t_p \le T \end{cases}$$

The above three formula, $\min\{\sum_{i=1}^{k}(d_i^- + d_i^+)\}$ expressed the objective of service schedule recovery level is to reduce deviation; $\min\left[\sum_{j=1}^{k} b \times (\frac{3B_d}{(v_d)^3} \times \left(\frac{d_j}{t_j}\right)^2) \times d_j^-)\right]$ and

$\min\left\{[\sum_{j=1}^{k} X_{ij}\times(1-y_j)\times u\times f\times M_j^d]+[\sum_{j=1}^{k} X_{ij}\times u\times f\times \overline{M}_j^l]\right\}$ expressed two part of extra cost that need to be controlled to minimum when doing schedule recovery.

With the priority we mentioned, the mathematic model can be concluded as below:

$$Min = P_1\times[\sum_{j=1}^{k}(d_j^- + d_j^+)] + P_2\times[\sum_{j=1}^{k} b\times\frac{3\times B_d}{(v_d)^3}\times\left(\frac{d_j}{t_j}\right)^2\times d_j^-] + P_3\times[\sum_{j=1}^{k} X_{ij}\times(1-y_j)\times u\times f\times M_j^d + \sum_{j=1}^{k} X_{ij}\times u\times f\times \overline{M}_j^l]$$

(4.9)

With three objectives, we also get four constraints:

a) $t_j + d_j^- - d_j^+ = \hat{t}_j$: This is an identity shows that, actual time at sea from port (j-1) to port j plus negative deviation of sailing time minus positive deviation of sailing time at sea should equal to designed time.

b) $\sum_{j=1}^{k} t_j + t_p \le T$: This is to control total sailing time within the schedule recovery level set; measurements should be taken within this recovery level.

c) $\frac{d_j}{V_{\max}} \le t_j \le \frac{d_j}{V_{\min}}$: Vessel can only sail with speed between designed minimum and maximum speed, otherwise will cause extra maintenance cost.

d) $t \ge 0, d_j^- \ge 0, d_j^+ \ge 0, j = 1,2,\ldots\ldots,k$

5. Case Study and Analysis

It is easy to find out that model in this paper is a linear mathematic model with two kinds of variables: time variable and deviation variable. This is convenient to solve this problem by inputting to Microsoft Excel to get result.

In below two cases, this paper shall take recently examples which happened in May.2015. During this period of time, freight on this service is around 1,200USD per container.

5.1 Case 1----Port Congestion

In case one, I shall take an example from company M. One vessel Emma M** under a service from Europe to far-east Asia had carried heavy delay when come into Chinese port. First port is Qingdao. Port involved in far-east area including Qingdao (TST)- Shanghai (SGH)-Ningbo (NPO)-Hongkong (HKG)-Yantian (YAT)-Tanjung Pelepas (TPP). Vessel's actual arrival time in Qingdao is already 2 days later than pro-forma schedule. But there also has congestion situation in TST, NPO and HKG. Vessel comes with low utilization, planned to export a lot of cargos from China to Europe. Schedule is set to be recovered in TPP to avoid delay in Suez.

Fig 5.1 Rotation for Emma M**

5.1.1 Data collection

Vessel's data as below:

Tab 5.1 the main parameters of the vessel

Parameters	Value
LOA	397.55m
Beam	56.4m
Max Draft	16.02m
Nominal TEU	14304TEU
Max Air Draft	76.5m
Bunker Consumption with maximum speed	260mtns/day
Stability System	LOADSTAR
Designed maximum speed	22.5nots

Pro-forma schedule for captioned vessel calling mentioned port is as below:

Tab 5.2 pro-forma schedule of captioned vessel

PORT	TST	SGH	NPO	HKG	YAT	TPP
	5/4	5/6	5/7	5/10	5/10	5/14

For the move-count each call is company's trade secret, below data is just relative value with each other.

Tab 5.3 the number of containers between ports

Port	Tot. Disch	Tot. Load	Tot. Moves
TST	23	1557	1580
SGH	0	823	823
NPO	100	1400	1500
HKG	296	769	1065
YAT	0	756	756
TPP	1913	1581	3494

Sailing distance from port to port:

Tab 5.4 Sailing distance between ports.

	TST	SGH	NPO	HKG	YAT	TPP
TST		446	466	1166	1153	2535
SGH			144	871	857	2240
NPO				742	746	2129
HKG					60	1462
YAT						1485
TPP						

5.1.2 Solutions

According to 3.2, below table enumerates thirteen possible solutions which could be used for schedule recovery:

Tab 5.5(a) Possible solution set of the liner company

Measurement	NO.	Rotation	Remark
Speed up	1	TST-SGH-NPO-HKG-YAT-TPP	
Omission	1	SGH-NPO-HKG-YAT-TPP	All possible for speed up
	2	TST-NPO-HKG-YAT-TPP	
	3	TST-SGH-HKG-YAT-TPP	
	4	TST-SGH-NPO-YAT-TPP	
	5	TST-SGH-NPO-HKG-TPP	
Swapping	1	TST-NPO-SGH-HKG-YAT-TPP	
	2	TST-SGH-NPO-YAT-HKG-TPP	
Reduce move-counts	1	TST	
	2	SGH	
	3	NPO	
	4	HKG	
	5	YAT	

Based on process show in 4.1, since vessel has already been delayed for 2 days, schedule is not possible to be recovered only by speed-up.

And then, since potential scenario is that vessel would be further delayed in TST, NPO, and HKG due to berth congestion, omission, swapping and reducing move-counts are all possible method to be taken. But if we have a review on move- count in each ports, both omitting TST and NPO are not good choice high moves. So choice for omission is HKG or YAT.

As mentioned in 3.2.2, swapping is for keeping ports which has more discharge on time. However, those ports without congestion have no risk of congestion. So in this case will not take swapping into consideration.

For reducing move-counts, since there still has foreseen congestions in HKG, it is not necessary to reduce move-counts in TST, NPO and SGH.

According to analysis based on process set in 4.1, solutions filtered as below:

Tab 5.5(b) Filtered solution set of the liner company

Measurement	NO.	Rotation	Remark
Omission	1	TST-SGH-NPO-YAT-TPP	All possible for speed up
	2	TST-SGH-NPO-HKG-TPP	
Reduce move-counts	3	HKG	
	4	YAT	

From operation side, schedule deviation should be put in the first priority, while bunker cost and commercial side should also be taken into consideration. So that set P_1=1000, P_2=10, P_3=1, get the result as below:

Tab 5.5(c) Result of filtered solution

Measurement	NO.	Rotation	Result
Omission	1	TST-SGH-NPO-YAT-TPP	1542587
	2	TST-SGH-NPO-HKG-TPP	2262930
Reduce move-counts	1	HKG	3379000
	2	YAT	3379000

Tab 5.6 comparison of solution

Measurement	Solution taken by company M	Solution get from model
Speed up	TST-SGH-NPO-HKG-YAT-TPP	TST-SGH-NPO –YAT-TPP
Omission	NIL	HKG
Swapping	NIL	NIL
Reduce move-counts	HKG	NIL

Since cases mentioned in this paper are those already happened, so we can get comparison of the actual solution taken by operators and solution given by model.

From this case we can see that solution taken by company M is to speed up from TST to TPP, and to cut some moves in HKG. One situation need to be mentioned is that since vessel carried too much containers onboard, draft is too deep when calling HKG, so arrive and departure time is limited to tidal point. This is also a reason for cutting moves in HKG.

However, solution provided by model set in this paper suggest to omit HKG, then schedule will not be so tight, vessel speeds up from TST-SGH-NPO-YAT, and only full speed from NPO to YAT. Since from YAT to TPP is about 1485nm, there can save much higher extra bunker cost to slow down within long distance. This is the consideration form bunker cost side. Meanwhile, because HKG and YAT is close to each other, only 60 miles distance, those containers which should be discharged in HKG can be transshipped back to HKG by feeders. From schedule side, HKG omission can avoid further delay due to port congestion and tide issue. As there has more sufficient terminal resources in YAT and berth is available. It is more schedule wise to choose omit HKG. Also, if we take solution as reducing move-count in HKG, vsl should go under full speed from beginning to the end. Although omission is not a good choice for shipping company when thinking from commercial side, it is still a way to maintaining schedule reliability when vessel is heavily delayed like mentioned case.

5.2 Case 2---Port Closure due to Bad Weather

In case two, I shall also take an example from company M. One vessel Morten M** under a service from Europe to far-east Asia had already carried delay when come into Chinese port. First port is Dalian. Port involved in far-east area including Dalian (DAI)- Busan (BUS)- Qingdao (TST)- Ningbo (NPO)- Shanghai (SGH)- Xiamen (XIM)- Yantian (YAT)- Tanjung Pelepas (TPP). Vessel's actual arrival time in DAI is already 2 days later than pro-forma schedule. But there also has weather impact in NPO. Heavy fog caused port closure. So within the range from DAI to SGH, captioned vessel still sails with slow steam to avoid unnecessary extra bunker cost. Due to congestion in SGH, vessel have to wait for berth for around 20 hours, which caused 4 days delay to schedule when departing Shanghai. Vessel comes with high utilization, but also planned to export a lot of cargos from China to Europe.

Fig 5.2 Rotation for Morten M**

5.2.1 Data collection

Vessel's data:

Tab 5.7 the main parameters of the vessel

Parameters	Value
LOA	399.23m
Beam	59m
Max Draft	14.5 m
Nominal TEU	18340TEU
Max Air Draft	75.34 m/ 73.0m
Bunker Consumption with maximum speed	250 mtns/day
Stability System	Loadstar
Designed maximum speed	23knots

Pro-forma schedule for captioned vessel calling mentioned port is as below:

Tab 5.8 Pro-forma schedule for captioned vessel

PORT	DAI	BUS	TST	NPO	SGH	XIM	YAT	TPP
	5/2	5/4	5/6	5/8	5/9	5/11	5/13	5/17

For the move-count each call is company's trade secret, below data is just relative value with each other.

Tab 5.9 the number of containers between ports

Port	Tot. Disch	Tot. Load	Tot. Moves
DAI	2972	2080	5052
BUS	2338	1198	3536
TST	1053	2723	3776
NPO	302	1494	1796
SGH	1	1938	1939
XIM	512	690	1202
YAT	0	1251	1251
TPP	1659	2501	4160

Sailing distance from port to port:

Tab 5.10 Sailing distance between ports.

Port	DAI	BUS	TST	NPO	SGH	XIM	YAT	TPP
DAI		584	280	597	576	1037	1288	2671
BUS			508	508	487	883	1134	2517
TST				526	446	901	1153	2535
NPO					141	495	746	2129
SGH						606	857	2240
XIM							289	1675
YAT								1485
TPP								

5.2.2 Solutions

Possible solution could be used for schedule recovery:

Tab 5.11 (a) Alternative strategy set of the liner company

Measurement	NO.	Rotation	Remark
Speed up	1	DAI-BUS-TST-NPO-SGH-XIM-YAT-TPP	
	1	BUS-TST-NPO-SGH-XIM-YAT-TPP	
	2	DAI -TST-NPO-SGH-XIM-YAT-TPP	
	3	DAI-BUS-NPO-SGH-XIM-YAT-TPP	
Omission	4	DAI-BUS-TST-SGH-XIM-YAT-TPP	
	5	DAI-BUS-TST-NPO-XIM-YAT-TPP	
	6	DAI-BUS-TST-NPO-SGH-YAT-TPP	
	7	DAI-BUS-TST-NPO-SGH-XIM-TPP	
Swapping	1	DAI-BUS-TST-SGH-NPO-XIM-YAT-TPP	All possible for speed up
	1	DAI	
	2	BUS	
	3	TST	
Reduce move-counts	4	NPO	
	5	SGH	
	6	XIM	
	7	YAT	

The same as case one, first go through the process, and only speed-up is not enough for schedule recovery. So we should go through following parts to see if any other scenario is possible to happen.

As mentioned in 3.2.2, swapping is for keeping ports which has more discharge on time. However, those ports with dicharge containers have no risk of congestion . So in this case will not take swapping into consideration. Also, ports within this rotation are not close to each other, there has no need for swapping.

For reducing move-counts, since there still has foreseen congestions in HKG, it is not necessary to reduce move-counts in TST, NPO and SGH.

Since has berth congestion from DAI to SGH, vessel can only start to recover after departing SGH since there has high move in all congested ports. Comparing the move-counts, should choose to omit XIM.

If we do not do any omission, the only choice is to reduce move-counts in YAT or XIM.

So solution can be filtered as below:

Tab 5.11 (b) Alternative strategy set of the liner company

Measurement	**NO.**	**Rotation**	**Remark**
Omission	1	DAI-BUS-TST-NPO-SGH-YAT-TPP	All possible for speed up
Reduce move-counts	2	XIM	
	3	YAT	

From operation side, schedule deviation should be put in the first priority, while bunker cost and commercial side should also be taken into consideration. So that set P_1=1000, P_2=10, P_3=1, get the result as below:

Tab 5.11(c) Result of filtered solution

Measurement	NO.	Rotation	Result
Omission	1	DAI-BUS-TST-NPO-SGH-YAT-TPP	6433180
Reduce move-counts	2	XIM	10408420
	3	YAT	10408420

Tab 5.12 comparison of solution

Measurement	Solution taken by company M	Solution get from model
Speed up	DAI-BUS-TST-NPO-SGH-YAT-TPP	DAI-BUS-TST-NPO-SGH-YAT-TPP
Omission	XIM	XIM
Swapping	NIL	NIL
Reduce move-counts	**NIL**	**NIL**

Solutions gotten from model is the same as what company M took, XIM is omitted. Schedule recovery level is set to have one day recovered when passing Suez Canal, since when vessel departs SGH, there has already been 4 days later than pro-forma. If still calls XIM, vessel need to sail with full speed within the rotaion SGH-XIM-YAT-TPP. However will still be at least 4 days delay when passing Suez Canal. The reason for at least 4 days is because in real case, captioned vessel in this case is an over specification type vessel for calling XIM port. So vessel can only berth and unberth XIM when tide point is suitable. As usual, a suitable tide point may cause half day's waiting time to vessel. Since vessel has carried such heavy delay in previous, another half day's delay cannot be sustained. Any one hours late when arrive Suez may cause another one day late.

Meanwhile, when evaluate from commercial side, the weight of XIM port in this rotation is not as important as other ports. Those import containers can be transshipped back to XIM by feeders or vessel in other service. With XIM omitted, vessel directly called YAT after SGH. YAT berth is available and also with high productivity. Thus recovery of one day delay when arriving Suez is possible to be realized.

5.3 Conclusions

In order to prove the feasibility of the model, two cases are taken in this chapter. And the result we can get is quite satisfied. One thing in similar is that speed up is always the first choice we choose for schedule recovery. This is because it is hard to estimate what commercial loss of this call caused may impact future. But it is necessary to take measurements like omission or reducing move-counts to mix-wise use with speed up. Because for to what extend schedule can be recovered is limited to maximum speed of vessel, weather and port situation and so on.

6. Conclusion and future work

In chapter 1 and chapter 2, paper introduced current background of liner-shipping and research on design of liner-shipping schedule. Then lead out the point of view of the paper: based on the importance of schedule reliability, how to get schedule recovered during operation. In practice, there has too many unpredictable factors may happen. In order to find out how to keep schedule reliability in real operation, this paper tries to use mathematical way to solve the problem, meanwhile since every port has their own specialty, this paper take both mathematical result and port situation into consideration when doing analysis. Find out a balanced point between smallest schedule deviation and minimum extra cost.

But still has some aspects haven't been fully considered. For example:

In this paper, only considered schedule for one vessel. But actually the has a transportation network for a liner-shipping company. One vessel is delayed or schedule changes, other vessels may be impacted as well. Like omission decision made in case 2. Those containers cannot be loaded in XIM has to be carried by other vessels, then capacity and stowage plan of that vessel should be reconsidered. And under current situation, there has a lot of alliance, solution can be varid.

And also in different ports, calculation method of port due or cargo operation, transshipment cost should be different, just like mainland China and Hongkong. It should be better to take this factor into consideration, then we can make out a more exact balanced pont.

According to above analysis on research background, schedule recovery problem is essential for liner shipping company. How to save cost can do great help to shipping companies in current under recovering market.

However, recovery cannot be focused on one vessel. In future study and work, will do more research on how to get schedule recovered while considering the whole network. In the meantime, there have more and more alliance between shipping companies. Under the vessel sharing situation, how to extend the recovery work on one vessel into the whole network is worth studying in future work.

References:

[1]. Wu Wenyi, Route Option for Container Transportation under Shipping Alliance (2004) [D]. Shanghai Maritime University

[2]Hong bo. The Design of Liners Based on Controlling High Fuel Costs （2001）[D].Dalian Maritime University

[3] Gelareh. A novel modeling approach for the fleet deployment problem within a short-termplanning horizon [J]. Transportation Research Part E: Logistics and Transportation Review, 2010,46(1):P76-89.

[4]Qiang Meng, Tingsong Wang. A chance constrained programming model for short-term liner shipfleet planning problems [J]. OR Spectrum, 2010,37(4):P329-446.

[5]Bair A. Optimizing the container transshipment hub location [J]. Journal of transport geography,2006,14,P195-214.

[6] Shuaian Wang, Qiang Meng ,Liner ship route schedule design with sea contingency time and port time uncertainty (2012) [J], Transportation Research Part B No.46, P615–633

[7] Theo E. Notteboom, The time factor in liner shipping services [J], Maritime Economics and Logistics 8 (1) (2006) P19–39.

[8] Theo E. Notteboom, Bert Vernimmen, The effect of high fuel costs on liner service configuration in container shipping, [J] Journal of Transport Geography 17 (2009) P325–337.

[9]Yu G; Qi X T ,Disruption Management: Framework, Models and Applications,[J]Science of Management ,2004,P23-29

[10] Hu Xiangpei, Zhang Yi, Ding Qiulei et al.. The research progress of disruption management model and its algorithm.(2008) theory and practice of systems engineering P40-46.

[11]Yong Y Y. Multi-objective Airline Schedule Recovery: [D]. National University of Singapore, 2005.

[12]Burke E, Causmaecker P, Maere G et al. A multi-objective approach for robust

airline scheduling.[J] Computers and Operations Research, 2010,37:P822-832.

[13]Maria L. Airline Schedule Planning and Operations: Optimization-based Approaches for Delay Mitigation: [D], Massachusetts Institute of Technology, 2010.

[14] Liu Yanhong, Gao Lin, Li Yaohua,Study on Recovery Model of Flight Delays Based on Economic Loss (2011) . [J] JOURNAL OF CIVIL AVIATION UNIVERSITY OF CHINA No.29,P46-50.

[15]Marielle Christiansen, Kjetil Fagerholt, Bjorn Nygreen, and David Ronen. Handbooks in Operations Research & Management Science: [J] Transportation, volume14, chapter 4: Maritime Transport. Elseview, 2007.

[16]Wu Peijian. Research on Reliability modeling and simulation for Container Liner Shipping Network(2010)[D]. Dalian University of Technology 2010.

[17]Yang Chunxia Wang Nuo. Decision-making Method for Berth Allocation Disruption Management in Container [J] Terminal OPERATIONS RESEARCH AND MANAGEMENT SCIENCE .2011. No.8(4), P90-95

[18]LI Qiang,Tang Shiqi, YANG Chunxia and WANG Nuo. OPTIMIZATION OF OPERATION SCHEME OF CONTAINER TERMINALBASED ON DISRUPTION MANAGEMENT. The Second International Conference of Transportation Engineering (ICTE2009)

[19]Li Qiang, Trade off Optimization of Berth Scheduling in ContainerTerminal(2009) [D], Dalian Maritime University

[20]Zeng Qingcheng, Yang zhongzhen.A Bi-level programming model and its algorithm for operation scheduling in container terminals[J].(2007) Journal of Harbin Engineering University No.28 (3) P277-281

[21]Chen Qiushuang, Du yuquan, Xu Ya(2010).Disruption Management of Container Ports under Uncertain Circumstances(2010).Technology of Logistics No.2, P1-5.

[22]Sun Huijie.Research on disruption management model for berth scheduling with time delay[D].(2010) Dalian University of Technology

[23]Mulder J. Determining the optimal recovery policy in liner shipping networks using a Markov decision model: [D]. Erasmus University Rotterdam, 2009.

[24] Berit D. Brouer, Jakob Dirksen, David Pisinger. The Vessel Schedule Recovery Problem (VSRP) - A MIP model for handling disruptions in liner shipping. [D] DTU Management Engineering.2012

[25] Jing Quan Li, Pitu B. Mirchandani,Denis Bornstein. Real time Vehicle ReroutingProblems with Time windows[J], European Journal of Operational Research. 2009, 193(3) :P711-727.

[26]Jean Yves Potivn, Ying Xu, IIham Benyahia. Vehicle routing and scheduling with dynamic travel times[J]. Computers & Operations Research, 2006, 33(5):P1129-1137.

[27]Feng Huaping. RESEARCH ON DISRUPTION COORDINATION OF SUPPLY CHAIN UNDER MULIT-FACTORS DISRUPTIONS(2008)[D]. Beijing University of Post and Telecommunications

[28]Wang Xuping. Study on Disruption Management for Vehicle Routing Problem (2010) [D].Dalian University of Technology

[29]Al-Yakoob S M, Sherali H D. A Column Generation Approach for Determining Optimal Fleet Mix, Schedules, and Transshipment Facility Locations for a Vessel Transportation Problem[J]. Applied Mathematical Modelling, 2012.

[30] Li J, Sava A, Xie X. Simulation-based discrete optimization of stochastic discrete event systems subject to non closed-form constraints [J]. Automatic Control. IEEE Transactions on, 2009.P128-150

[31]Theo E. Notteboom, The time factor in liner shipping services, [J] Maritime Economics and Logistics 8 (1) (2006) 19–39.

[32]Ren Fei Researeh on Ports selecting model for container lines [D].Dalian Maritime University, 2007.

[33]Zhang Miao . Research on evaluation of liner shipping service system [D] ..Dalian Maritime University,2009.

[34]Ye Chunmei, Liner Ships Routing Optimization Research Considering Ship Speed [D] Dalian Maritime University,2012.

[35] Xu Zhonghua, Research on international liner shipping service design [D].Fu Dan University,2009.