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Ship scheduling at Seatrade Reefer Chartering

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Foreword

With this thesis, I am about to finish my study to obtain the title Master of Science in Mathematics, at Leiden University. In this thesis, I study the scheduling problem at Seatrade Reefer Chartering, Antwerp. I would like to thank some people who helped me a lot with this thesis.

First of all, dr. Floske Spieksma, my thesis supervisor. She helped me a lot with her enthusiasm and her mathematical knowledge. Though clearly subject to a very busy schedule, I was always welcome to discuss the proceedings in my thesis.

Second, Hans Nauta, Schedule Manager at Seatrade Reefer Chartering. He helped me to get to know the scheduling practice at SRC a lot better, and was helpful in getting my theoretical ideas back to the ground, in touch with the scheduling practice. This combination was also present in the person of Paul Brouwer, who also helped me a lot.

On the personal level, I would like to thank my beloved, Doortje, who had to let me go to Antwerp for 4 months. As always she has been a very important support to whatever I did, and in this special case: writing my thesis. I would also thank our heavenly Father for helping me while finishing this research, and during my full time as student, more than I possibly did notice.

Chapter 1

Introduction

While the seas have never been more empty than these days, their surface is more crowded than ever. Seaborne transport is the main international transportation mode. Driven by commercial means, many ships are operated by big or small corporations, seeking to sail as much cargo as possible, earning as much as possible, within the boundaries of limited time and cargo space. Thus, companies seek efficiency.

Seatrade Reefer Chartering in Antwerp is such a company. It is one of the most important players in the reefer market, the market for refrigerated shipments. In the period June-September 2010, I worked as an intern at Seatrade Reefer Chartering. From this internship I started the research described below.

1.1 Research

In this thesis, I combine two types of research. First, I describe the way maritime scheduling is done at Seatrade Reefer Chartering (SRC) world, as experienced during an internship at SRC. The main aim during this internship is to investigate whether it is useful to implement a Decision Support System (DSS) at the scheduling department. Another instance of such research is described in [1]. A DSS is a system, as the name says, to support the decision-making of its user, by making all relevant information easily accessible.

Secondly, the research consists of a more theoretical exploration of the field of maritime scheduling. The aim of this part of the research is to investigate

how maritime scheduling problems can be modelled, and what mathematical theory is needed to solve this problem.

The research done in this paper could be summarized in four main questions:

1. How is scheduling at Seatrade Reefer Chartering done? What decisions can be effectively supported by a Decision Support System?
2. How should the maritime scheduling problem at SRC be modelled?
3. How can this problem be solved?
4. How can a program solving this problem be implemented within Seatrade Reefer Chartering?

The research I do is comparable to the research in [2], a research also conducted at Seatrade Reefer Chartering, in 1996. However, where in [2] the focus is on the full description of the problem, I will focus more on practical mathematical modelling and implementation.

1.2 Layout

Due to the interaction of the two questions, the questions are not handled separately. In chapters 2 - 4, I first explore the world of maritime transportation, narrowing towards Seatrade Reefer Chartering and the scheduling business. In chapter 5, I discuss some methods to analyze the quality of a schedule in an unknown future, to forecast the market, and how to employ such methods in the scheduling business. In chapter 6, I describe a general framework for modelling ship scheduling problems, and which algorithms are available to solve them. In chapter 7, I describe the DSS I designed to support ship assignment.

Chapter 2

Maritime transportation and OR

Where Scheduling is a subject on its own within Combinatorial Optimization, Maritime Scheduling is a subject on its own within Scheduling. In this chapter, I will describe some of the peculiarities of maritime scheduling, when compared to 'normal' scheduling. I also will describe some related problems. Besides that, I will describe some problems in maritime transportation on the strategic, tactical and operational level, and its relation to Operations Research. Most of this chapter is based on the introduction on maritime transportation by Christiansen, Fagerholt, Nygreen and Ronen in [3], Chapter 4: Maritime Transportation.

2.1 Maritime transportation

Maritime transportation is the term used for both seaborne transport and other waterborne transport, such as transport on inland waterways, for example transport by barges. In this thesis, however, I will focus on seaborne longhaul transport only. Longhaul transport is transport where the total distance is the most important factor in time, and where only a few ports have to be called. A typical example of a longhaul voyage is a voyage from Equador to the Mediterranean, without any ports of call halfway.

Seaborne transport has a monopoly on the displacement of large volumes of goods between continents. Its only competitors consist of airplanes and pipelines. However, these two types of transportation each have their own limitations: pipelines can only deliver fluids in bulk, and airplanes have only very limited capacity, especially on weighing goods. Moreover, planes

have a very high cost per volume ratio. Therefore, planes are only a feasible option when the transported goods must travel quickly over great distances, or have a very high value per volume.

Estimates of the amount of worldwide seaborne transportation in 2007 as percentage of total international transport vary between 65% and 85% .

While the international trading fleet faced overcapacity in 1980, in the period between 1980 and 2003, the total fleet capacity increased by 25%. The fleet also gained in efficiency. Doing so, it was possible that in about the same period, from 1980 to 2005, the total amount of seaborne transportation increased by 67%. Tanker shipping increased modestly, but most of the increase was realized in general cargo (cargo like cars, furniture, barbeques) and dry bulk cargo (non-fluid cargo, which is directly stored in the ship, without boxes). Also the use of containers skyrocketed, with an increase of over 700% in container-carrying capacity in the period 1980-2003.

2.2 Maritime operations in Operations Research

Despite of the vast importance of maritime operations for worldwide trade, it is not a frequently researched topic in Operations Research, when compared to other modes of transport, like railways or trucking. The first review of scientific work on the area was published only in 1983, by David Ronen [4], covering about 40 publications, tracing back to the 1950'ties. One highlight from this period was the paper by Appelgren [5]. Until this time, most research on transportation was done on trucking and flight. Several reasons for this discrepancy are identified.

- *Limited visibility.* Where trucks pass by on the road every day, ports are quite distant industrial areas. Most intra-national transportation is done by trucks or trains. Only the Netherlands may be a possible exception, due to its abundant presence of water. In most countries, however, trucks and trains are the most important mode of transportation, and get the most attention. Researchers seem to follow this public attention.
- *Commercial sponsorship.* Operations Research is for a great deal sponsored by large companies. Where there are lots of large trucking companies, companies that own or operate such an amount of ships that automated planning is inevitable, is only limited. On the contrary: due to the low barrier of entry (basically, one has to buy a ship, and

one can sail), lots of ships are the property of a family business. This fragmentation of the market has been no fertile ground for commercial sponsorship of large research projects.

- *Less structured problems.* Compared to other modes of transportation, maritime shipping has lots of different types of contracts, cargoes and limitations. This makes the field hard to enter by standardized OR procedures, making the customization of such procedures an expensive part of the implementation of a possible scheduling system.
- *Lack of procedures.* Where a transportation mode like airborne transport is highly captured in standardized procedures, this is not the case for maritime transportation. There are no computer systems or systems of notation which are used everywhere. The lack of procedures, and the subsequent incompatibility of data, makes it difficult to build an information-dependent system, which is a basic need for a working OR tool.
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- *Long tradition.* Maritime shipping is the oldest type of transport for large volumes of goods, dating back to ancient times. This long tradition makes maritime shipping a conservative business, and somewhat averse to decision-supporting information systems. Many people in maritime operation companies have a nautical background, and do not feel comfortable when feeding and relying on a computer system.

While the first four of these drawbacks are practical problems, the last one is the most difficult one to overcome. Information systems are quite sensitive for wrong or incomplete information. When the culture among captains and at charterer offices is averse of passing precise and detailed information, it is impossible to build a reliable system. A way to overcome this drawback is to implement measuring and reporting systems in all ships. This, however, would require a huge investment. It is uncertain, if not unlikely, that this investment will repay itself on short term.

Despite all of these drawbacks, research in scheduling and planning in maritime operations has increased over the last decades. Where in the period 1950-1983 about 40 articles were published, in the decade between 1983 and 1993, this amount was the same, but now in one decade. In the years from 1993 to 2004, the amount was almost doubled. The diverse character of the business seems to be done right in the different studies: in comparison with studies in other modes of transportation, more studies are based on real cases and problems. This illustrates the difficulties when designing a multi-purpose DSS: not any two problems seem to be the same.

The only way to achieve similarity between problems is to neglect details. However, to choose what details are irrelevant is very hard. Sometimes, details are not to be neglected, while at first glance neglectable, for neglecting details could make the solution infeasible or not applicable at all.

2.3 Decision issues

Like decisions in many fields of management decisions in maritime transportation can be categorized in three categories: strategic, tactical and operational, respectively applying to the long-term, mid-term and short-term future. I will describe some issues at each level, relevant to the design of a Decision Support System.

2.3.1 Strategic

The first strategic decision to be made is which market and trade the company should choose. We have seen that in the maritime transport business, the choice of trades is quite large, and all trades have their own peculiarities. This decision has to be made in tandem with the decision on which routes the company decides to be active.

Another strategic decision to make, for a larger shipping company almost continuously, is to decide what the appropriate fleet composition is.

While strategic decisions are very important and also very interesting from the point of view of a general manager, it is less appropriate from the point of view of designing a DSS. Strategic decisions are based on lots of arguments, and numeric data and modeling only cover a part of them. Moreover, such calculations are made only a few times, and a structural implementation of a model to base such calculations on would not pay.

2.3.2 Tactical

On the tactical level, decisions concern the deployment of the fleet, according to the strategic planning. How does the strategic decision about the number of vessels influence the current fleet? Should there be especially large vessels or small vessels, or both? Should new vessels be built, or old vessels scrapped? Should some vessels be put in lay-up, i.e., taken out of the market?

Tactical decisions are also taken with respect to the assignment of ships. Given the choice for a specific trade and trade route, in what way should the fleet be deployed to sail on these routes most profitably? What vessels should be assigned to what routes? Which ports should a liner service call? When handling these questions, a DSS could be very useful. On one hand, a lot of options should be compared and calculated in the same manner. On the other hand, the amount of information needed and the effort needed to make a proper DSS for such situations, could be outweighed by the improvements made possible by such a DSS, and the effort calculations by hand require.

2.3.3 Operational

On the operational level, decisions concerning the individual ships are made. These decisions include the individual routing of a ship, the speed and so on. On this level, a DSS is not of much use. It takes lots of information to have the DSS make decisions which are easily made by an experienced scheduler or operator.

2.4 Related problems

Besides the ILP-approach I chose to implement, other terrains are open to explore. In this section, I will describe some related issues: Tanker Scheduling, Aircrew Scheduling and the Vehicle Routing Problem.

2.4.1 Tanker scheduling

Tanker scheduling is one of the most studied shipping problems. The relation to our problem is clear: there are ships that have to carry commodities within a time schedule from port to port. The perspective this problem is studied from, however, is different from our approach. This setup is used

to find the minimum number of tankers needed, or the minimal costs to fulfill a fixed number of contracts. Thus, the objective function is a linear function of the assignment of contracts to ships. In our problem, this is not the case.

The tanker scheduling problem is often studied as a network-flow model.

2.4.2 Vehicle Routing Problem

The Vehicle Routing Problem (VRP) is a much studied problem. In this problem, several customers have to be served, by several vehicles. Each customer has a location, and the problem is solved if we have found a routing of the available vehicles such that the vehicles have visited each location at minimum cost.

Since in principal each vehicle can visit each customer, this is slightly different from our problem. This problem is solved often with heuristics based on the comparison of parts of the routes, for example the k -OPT heuristic.

2.4.3 Air crew scheduling

In the air crew scheduling problem, we want to create a schedule for airline personnel. Constraints may involve juridical restrictions, the objective function might be minimal waiting time for the personnel while not at the home-airport. The difference with our problem is that in our case, only one contract may be transported on each ship, while in the air crew scheduling problem, a larger crew can be on one airplane.

2.5 Conclusion

In this chapter, we did see some reasons why abstract results from Operations Research are not ubiquitous in maritime scheduling. We also saw that the most promising level of decision where a DSS could be implemented is the level of tactical decisions. For a maritime DSS, it is essential that the DSS is deeply rooted in daily routine. Therefore, my research is a case-study of the daily scheduling business at Seatrade Reefer Chartering.

Chapter 3

Seatrade Reefer Chartering

In this chapter, I introduce Seatrade Reefer Chartering. First, I will describe some history of the company, and the most important business of the company. Then, I will describe the organizational structure of the company, and see where the scheduling department fits in.

3.1 History

In 1951, five Dutch captains and ship-owners agreed to work together, and pool their ships. They established Scheepvaartkantoor Groningen, in Groningen. In 1961, a ship called MV Arctic joined Scheepvaartkantoor Groningen. With this ship, Scheepvaartkantoor Groningen entered the reefer market. In 1973, the fleet exists of 15 vessels, and Scheepvaartkantoor Groningen is renamed to Seatrade Groningen.

Due to legal issues, for the period of 1993 to 1998 Seatrade is renamed to Scaldis Reefer Chartering. In 1998, the move from Groningen to Antwerp is finalized. By this time, Seatrade operates about 100 refrigerated vessels. Nowadays Seatrade operates about 130 vessels. This makes Seatrade one of the most important market makers in the reefer market.

3.2 The Seatrade Pool

The Seatrade Pool refers to the ships operated by Seatrade Reefer Chartering. In this pool, some ships are in ownership of Seatrade Group Curacao, other ships are in ownership of other parties. Pooling the ships can save

overhead costs and enable the owners to deploy a combined market-strategy. Nowadays, consisting of 130 vessels, the Seatrade Pool is the largest group of reefer ships in the world. The variety of ships within the Pool is great, regarding size, speed, capacity and equipment.

Seatrade Group Curacao is the official manager of the pool. The Antwerp branch office, Seatrade Reefer Chartering, is responsible for the commercial management of the ships in the Pool. The Groningen branch office is responsible for the material management of the ships that are owned by Seatrade Group. The owner of a ship pays for all costs that are necessary to keep the ship operational: crewing, supplies and maintenance. Fuel, port costs and cargo handling are paid directly from the freight revenues.

The net-profit from voyages, minus a small percentage of commission, is divided amongst all different ship-owners. This division is made on the basis of so-called Pool Points. Each ship is awarded an amount of pool points, depending on the characteristics of the ship, such as speed, fuel efficiency, capacity and others. The owner gets the part of net result that corresponds to the sum of the pool points of his ships.

Remark that the Pool Points are awarded to a ship, regardless of what actual profit is made by a ship: ships that are idle at the moment, also receive payment in accordance to their Pool Points. In a period of over capacity, ships can be withdrawn from the Pool. They are not for hire (off-hire) at that moment. Such a ship is said to be in lay-up. The choice to put a specific ship in lay-up is made upon the operational costs it takes to operate the vessel, for instance a high bunker consumption, or the amount of needed personnel.

The daily business at the SRC office in Antwerp is the commercial management. The daily business is to search for employment of the ships, and to schedule the contracts as efficient as possible on the available ships. This schedule, made by the Schedule Manager, is distributed to the ships by the operators. Operators are the link between the Schedule Manager and the captains, passing through status updates from captains to the Schedule Manager, and orders vice versa.

3.3 The reefer market

Seatrade operates in a niche market of worldwide shipping: the reefer market. Reefer vessels are vessels with refrigeration capabilities. The most transported goods by Seatrade vessels are different types of fruit, fish, meat

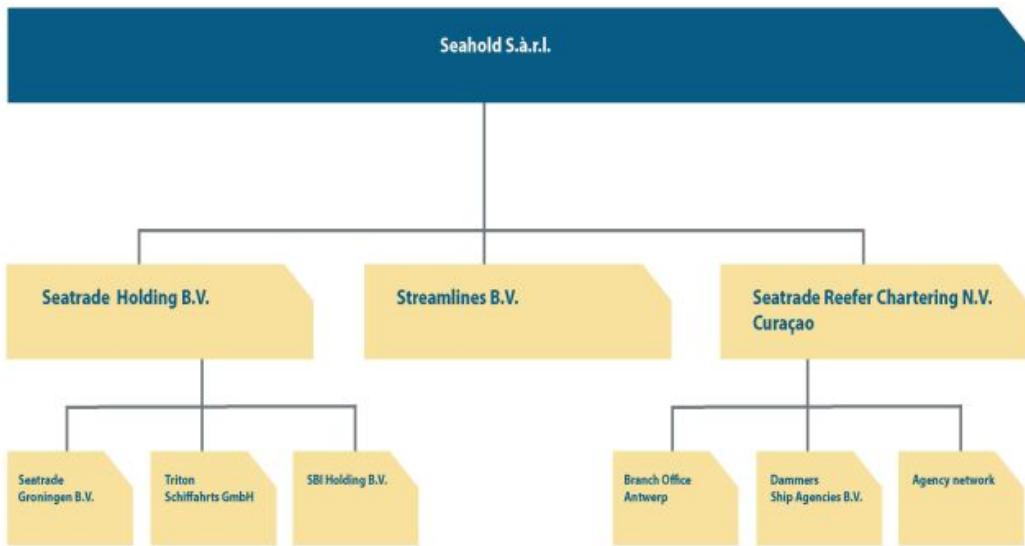


Figure 3.1: Organigram of Seahold

and chicken. As every market, the reefer market consists of supply and demand. The good offered here is basically refrigerated deck space.

3.3.1 Demand

The demand side of the market of cooled deck space is divided in two main parts: space for fruit and space for frozen cargo (short: fruit and frozen). There are some other goods, such as potatoes and cars, but these volumes are smaller than the cargoes mentioned below.

Fruit

Within the fruit segment, the most important product is bananas. In 2008, about 15 million tons of bananas were transported, 99% of them by ship. Since bananas are harvested in areas near the equator, this is a year-round trade. These bananas are mostly transported from Ecuador, Colombia, Costa Rica and some neighboring countries.

A second type of fruit transported by Seatrade is citrus, consisting of fruits as grapefruits, lemons, limes and oranges. Citrus is also harvested year-round. However, the area of harvesting varies per season. From May until September, citrus is harvested in South Africa and Argentina, from Novem-

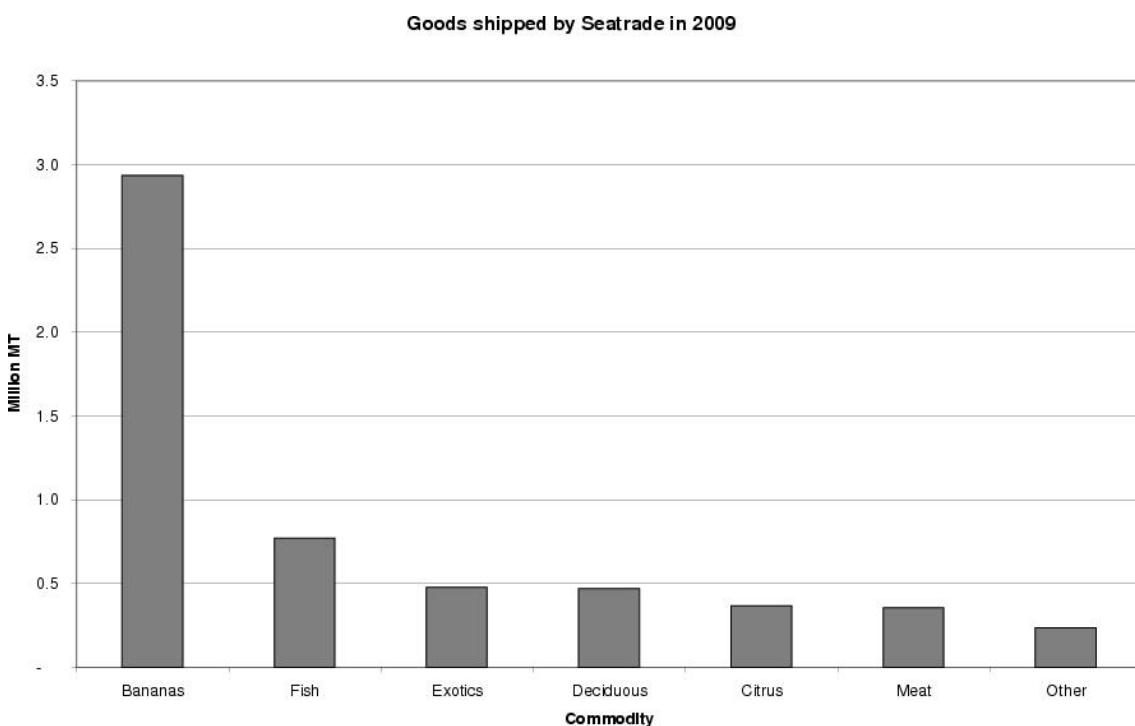


Figure 3.2: Overview of the transported goods

ber until April in Morocco, Turkey and Egypt. From these regions, the citrus is transported to Western Europe, the countries bordering the Mediterranean and Japan. About 5 million tons of citrus was transported by ship in 2008, 46% of the total amount of citrus.

The third type of fruit is deciduous fruit. This is the fruit of leaf-dropping trees or plants: apples, pears and grapes. This trade is seasonal, depending on the harvesting seasons in South America (Chili, Argentina), New Zealand and South Africa. The mostly used trade routes are South America to North America, South-Africa to Europe or North America, and New Zealand to Europe.

Frozen

One frozen commodity is fish. The most used trade routes are from Europe to West Africa, from South America to West Africa and the Far East, and from Alaska to Europe. In 2008, a total amount of 14.7 million tons of frozen fish was transported by ship.

The second important frozen cargo is frozen meat and poultry, especially chicken. These goods are transported from the United States and South

America to mostly Russia (poultry) and Europe (meat). Both trades are all-year trades. In 2008, over 18 million tons of poultry and meat were transported seaborne, accounting for 57% of the total meat and poultry cargo.

3.3.2 Supply

On the supply side, about a market share of about 45% is transported by specialized reefer vessels. The other half is transported by container ships in reefer containers. Seatrade Reefer Chartering is the largest specialized reefer shipping company, regarding both number of ships and total capacity. In the specialized reefer market, SRC has a market share of about 20%. Main competition comes from Lavinia, Green, NYKcool, Star and FCC.

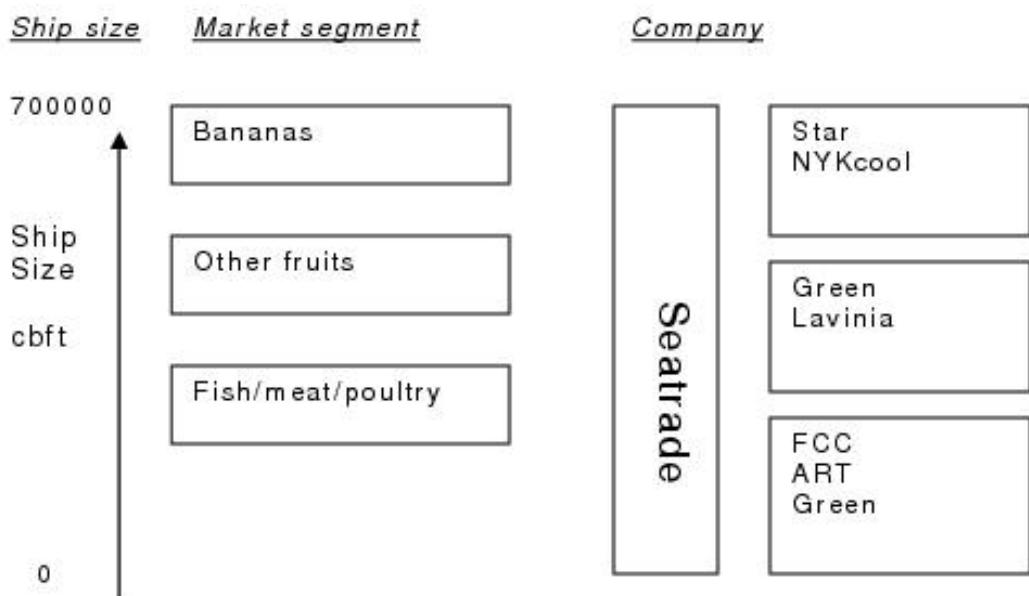


Figure 3.3: Reefer market in ship sizes

Most competing companies have specialized in a specific vessel size range. Seatrade operates ships in all size classes. Recently, however, the smaller ships have been transferred to the new found company Hamburger Reefer Pool, which now operates the ships in the smaller segment. These ships have a capacity up to 350,000 cubic feet. Besides Seatrade, ships from Alfa

Reefer Transport (more commonly known as ART) and Green reefers joined the Hamburger Reefer Pool.

3.4 Types of contracts

All cargo is transported on the basis of a contract. However, there are several types of contract.

The **linerservice** is the simplest one. A ship assigned to the liner service sails from port to port as scheduled. This schedule is known in the market. Cargo space can be booked for (a part of) the journey.

The **Parcel contract** is a type of contract that is related to the liner service contract. Like a liner service contract, freight of different charterers is transported on one ship, which sails according to a pre-announced schedule. However, where the liner service sails on a regular basis, the parcel service is offered depending on the demand in the market. This demand is estimated by the Seatrade trade managers. Some weeks before the deployment of a parcel service, this is announced in the market.

The **timecharter** (TC) contract is also a simple type of contract. In a time charter contract, a vessel is operated by the charterer for the contract time. In the contract the specific vessel or a type of vessel is agreed, as well as the delivery port and the port where the ship is open again, at the end of the contract, also known as the re-delivery port.

The **Contract of Afreightment** or **COA** is a contract where the owner and a charterer agree to deliver several ships to the charterer. In these contracts, the price is set, as well as the type of the ships to be delivered, a delivery port and a re-delivery port. These contracts are often agreed for a longer period, and some time in front.

The **Spot voyage charter** is a contract for one trip only. These contracts are often agreed on short-term. A delivery and re-delivery port are agreed, the type of cargo and the financial parts. If a ship is idle, and waiting for a voyage charter (or any other contract) it is said to "lay spot".

The negotiations are often conducted by a local office, representing Seatrade, or by the Seatrade trade managers themselves, depending on the type of contract. The contracts are signed between the charterer and by a representative of the SRC Antwerp office. Contracts over a longer contract period are also signed by the Seatrade Group office at Curacao.

In my research, I will focus on Contracts of Afreightment and spot-voyages.

These types of voyages are most suitable for mathematical scheduling on a regular basis. How to schedule liner services, and where to set up such services, are strategic decisions, as seen in chapter 2. Parcel services, on the other hand, only sail from time to time. When the parcel-ship is fully booked, it could be considered as a voyage charter, however.

3.5 Finance in maritime transportation

When valuate the result of a maritime operation, it is not just the net revenue we look at. We also look at the used capacity and the days for which the vessel is on hire. This calculation unit is called Time Charter Equivalents (TCE), or 'cents', as it expressed the amount of dollar-cents earned, for each cubic feet on the ship, per month for which the ship is on hire. In formula:

$$\text{Cents} = \frac{\text{NetRev} \cdot 3000}{\text{Capacity} \cdot \text{Days}} \quad (3.1)$$

Here, NetRev is the net revenue of the round trip, Capacity is the total capacity of the ship in cubic feet, and days (obviously) the length of the hire period in days. The factor 3000 comes from $30 \cdot 100$, where 100 is needed to express the earnings in dollar-cents rather than in dollars, and 30 to scale the revenue over a period to months, instead of days.

Measuring in TCE's or 'cents' is a tradition in the reefer market. Results of not only one vessel can be measured in cents, but also of groups of ships, or of an entire company's fleet. Results of a company are also often expressed in cents. To see that cents are really the main measuring unit, we only need to remark that also the market price is expressed in cents. An example of this is seen in figure 3.4. The peak in spring and early summer is caused by the high demand of reefer capacity during that months. In low seasons, rates drop, and also regular dry cargo is transported to keep the ships sailing.

Some remarks at the use of cents to express the result of a ship. First, the result drops if the same cargo is transported on a bigger ship. This is justified by the less efficient use of the available cargo space.

Second, because we use the net revenue to calculate the cents, the amount of cents is highly dependent on the ship's characteristics. The fuel consumption has the biggest influence, but also the onboard gear such as cranes, port costs etcetera.

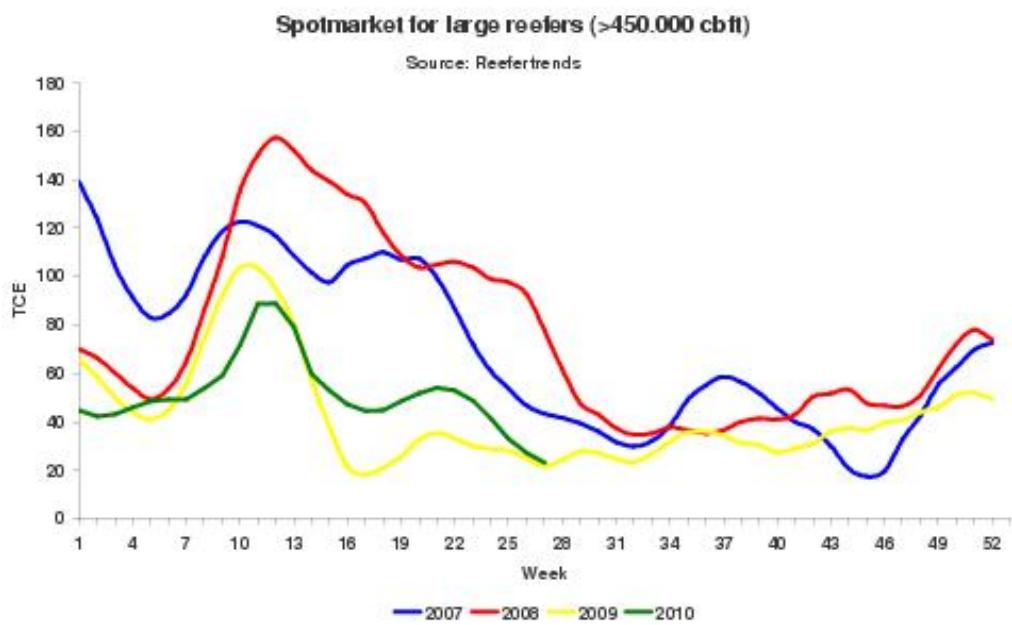


Figure 3.4: Reefer spot market rates in recent years

Chapter 4

Seatrade Scheduling

In this chapter, we will zoom in on the scheduling practice at SRC, and try to see what problems arise from the scheduling practice.

4.1 Seatrade Scheduling: Daily practice

The key person in the Seatrade scheduling practice is the Schedule Master. He keeps watch on the ships position, and develops plans to send ships around the world the next weeks, up to 8 weeks ahead. He also presides the daily Schedule Meeting.

4.1.1 The Schedule Master

The Schedule Master has two important tasks:

1. To keep track of the fleet positions
2. To plan how to direct the ships, and how to fulfill fixed contracts

The Schedule Manager keeps track of the total fleet on a daily basis. This is based on information from the Operators, who base their information on information from captains and log-reports. With this information the Schedule Manager updates estimated times to arrival (ETA's), and keeps track of the vessels to see whether they are still on schedule, or if a delay causes a problem in the near future. If this is the case, a solution is proposed, and discussed with the trade managers and relevant operators.

Because of the oversight of the Schedule Master on the positions of the entire fleet, he has a lot of contact with the people who are essential to keep the ships sailing.

First, there are the trade managers. The schedule is made primarily for their information. They seek for new contracts. They need to know where ships are open, and where ships will be in a couple of days. They then can look for contracts in that area. On the other hand, since they are in the middle of the market, they know where opportunities lie, and thus, what good ports are to end up in. Of course, this is also dictated by the annual schedule of high- and low seasons throughout the different regions.

Second, there is Fleet Support. This division is responsible for, among other things, the material condition of the ships. They know in what period a ship has to come in for inspection, and they check with the Schedule Manager when the ships are near to a suitable port.

Third, the Schedule Manager is in direct contact with the bunkering manager. Bunker is the nautical term for fuel. The bunkering manager makes sure that enough fuel is ordered. Since the prices fluctuate per port, he also plans when the bunker is loaded, and how many. However, the differences in bunker prices have no leading role in the planning of the ships. Commercial means are leading, bunkering is secondary. Big differences in bunkerprizes, however, may sometimes be discounted in offered shipping rates.

The operators are the fourth important group for the schedule manager. Operators maintain the contact between the Seatrade office and the ships and captains. Operators receive ship directions from the schedule manager, and receive updates on the ship's status from the captains. They thus feed the pile of information needed by the Schedule Manager.

4.1.2 The Schedule Meeting

All people relevant to the schedule practice meet in the daily Schedule Meeting. In this meeting, the schedule for the next days is fixed, and optional contracts are discussed, in combination with the possibilities concerning the scheduling of ships to these contracts. Decisions made in the Schedule Meeting are afterwards confirmed by the Schedule Manager and are updated in the lists with open dates and ship positions.

4.2 Scheduling problems

From the perspective of my research, the scheduling practice deserves extra attention. To effectively investigate whether an automated scheduling tool could be implemented, and to solve what problems, I first look for problems within the scheduling department that could be solved with the use of mathematical procedures.

Most scheduling done by the Schedule Manager is short-term scheduling. Most new spot contracts are fixed a few weeks in advance, not months. Since the ports in a contract often are at a distance of several days from each other, the main scheduling issue faced is not a planning issue, but an appointment issue: what is the ship that best fits the contract? This question is also asked the other way around: what ship should be agreed in the contract?

The main problem is: what is "the ship that fits best"? This is a complex combination of characteristics speed range, capacity, container capacity, the location of the ship, fuel consumption, and last but not least: the preferences of the charterer. It is not easy, if not very hard, to model this decision. However, the question whether a ship is feasible for a contract, is quite easily answered by the Schedule Master. He does this on the basis of experience and a good knowledge of the available ships. If it is not directly clear what type of ships is the best to fit the contract, this can also always be discussed with the relevant Trade Manager.

Consider contracts that are available each year on a regular basis, but not part of formal contracts with a long-term duration. Is it possible to include such future market opportunities in the long-term blueprints? What assumptions must be done to handle this knowledge? What advantages or disadvantages would handling these expectations involve for the Schedule Manager?

Recapitulating, we find the one of the main questions we also found in the introduction:

How should the maritime scheduling problem at SRC be modelled?

This question is here split into two questions:

1. What are the criteria to judge what the best ship to fulfill a contract is?

2. How can (implicit) expectations effectively be considered while scheduling ships?

In the following chapters, I will try to answer these problems in a mathematical way. These answers are used in chapter 7, where I present the design of a working DSS. These questions concerning the long-term planning are addressed in chapter 5.

Chapter 5

Modeling the scheduling problem

In mathematics, the scheduling problem is studied a lot. However, many times in these studies, the tasks to be scheduled are known a long time in advance. Compared to our problem, the major problem of this approach is that the existence of possible contracts is uncertain a long time in advance. However, some contract are implicitly known in advance, by knowledge of the market available within the company. For example, it is known that there will be cargoes of citrus out of South Africa by the end of July. When a contract is fixed in the more distant future (i.e. a couple of months), an ideal schedule should judge the worth of this contract based on the available knowledge of the future. In this chapter, I will develop a model to deal with the available knowledge.

In effect, in this chapter we search for the design of a proper way to valuate a schedule. This valuation method needs to deal with future expectations properly.

5.1 Literature

The available literature on ship scheduling suggests a general framework for the aspects of the valuation method. According to Appelgren in [5], the costs and profits of a schedule should consist of up to six elements, being:

1. Revenue from optional cargoes.
2. Premium for idle time at the end of the planning horizon.
3. Premium for idle time within the cargo sequence.

4. Deduction for use of ship capacity beyond the planning horizon.
5. Position cost.
6. Voyage and fuel costs.

The first item deals with optional cargoes, contrasting with already closed contracts. The premium for idle time, or better said, a method to attach value to idle time, is thoroughly discussed in section 5.3. Position costs are discussed together with the premium for idle time.

The deduction for use of ship capacity beyond the planning horizon means to correct for the time that a ship is not available in the next period, while the contract income is earned in the current schedule. Clearly, a part of the income is earned in the period beyond the planning horizon. This part of the income is deducted from the value of the current schedule.

The costs for bunkers and other voyage cost are rather straightforward, and therefore not discussed here.

5.2 Available knowledge

We first investigate what knowledge is available at SRC. Later on, we will see how this information could be used when designing a scheduling framework. The market knowledge consists of two major parts:

1. Knowledge of supply and demand of transport capacity.
2. Knowledge of price development throughout high and low seasons.

Remark that in economical theory the second would be dependent on the first.

Knowledge of the supply side of the market (offered space on ships) is only partial. Since SRC is one of the market leaders, SRC has knowledge of their own positions. This amounts a important part of the supply side. Besides this, also some knowledge of strategies and positions of other companies is available, by sightings of ships, and by news bulletins within the field.

The knowledge of the demand side of the market, the demanded amount of trading capacity, is more difficult to describe. This consists of knowledge of the amount of contracts on the several trading lines and the asked amount of capacity per contract, depending on seasonal changes.

Market price development is documented in historical data. The time of peak season and low season is known, but every year, or even month, an

adjustment due to world-wide economic circumstances may be necessary. Thus, the available knowledge is mostly directional: given the time of year, it is known if the prices are going up or down. To a certain level it is known what the height or depth of a rise or decline in price will be. These expectations may be wrong for up to 25%, however.

To employ this knowledge in a mathematical environment, we need to describe it properly. I will do some proposals on how to manage this.

First of all, it seems to be more appropriate to look at trading lanes between ports rather than at ports themselves. By doing so, it is more easy to identify busy periods on specific routes. After all, routes are the basic element of the trading schedules.

The amount of cargo and the rates for these cargoes from ports in the same region are highly correlated. When considered as a starting or ending point of a trade lane, it seems to be more appropriate to look at these regions rather than at individual ports. This has two main advantages: first of all, when looking at the entire regions, simply more data is available. Second, it is more simple to implement, since much less transport lines have to be modelled.

Looking to classify the ports, it seems to be most appropriate to identify the following regions, according to the classification already in use at the scheduling department:

1. Western Europe
2. Mediterranean
3. Far East
4. Mid East / Indian Ocean
5. West Africa
6. South-America East coast / Plate Area
7. South-America West coast
8. United States East-coast / Caribbean
9. United States West-coast

Now, ideally all $9 \cdot 8 \cdot 2 = 144$ possible trade lanes between the regions should be modeled, with the seasonal fluctuations in offered numbers of cargo, cargo sizes and prices. I will describe some ideas to model arrival of cargoes to trade lane.

5.3 Idle time valuation models

In the list of items that determine the value of a voyage in section 5.1, the second and third item were about idle time valuation. In this section, I will describe some models to valuate idle time. The models I introduce are threefold: straightforward time valuation, random contract generation and manual contract estimation.

All these models aim at one thing: to reflect the expected value of the extra money a ship can make on a day, during the time being scheduled as idle time.

5.3.1 Straightforward waiting time valuation

I first describe one of the early approaches to this problem. The valuation of waiting time in a schedule was already addressed by Appelgren, in one of the pioneer articles in this field. He proposed to valuate the waiting time by an convex function, calling this valuation *time value*. He described it as follows:

.... a daily premium for idle time after completion of the last cargo in the scheduled sequence for a ship. This premium makes it preferable to concentrate the idle time to some ships. The time value should vary between ships with size and cargo capability and reflect the expected daily revenue from unknown cargo opportunities. The time value should also vary with time, since the probability of new cargoes generally increases with time.

This time value reflects the expected value a ship could make, because of the number of idle days left. This value can be earned in two ways.

First of all, in a planned idle period a ship could sail a new contract, which is not known at the moment of scheduling. The probability that this occurs, and thus the expected return on the idle period, increases with the length of the period.

Secondly, when scheduling, first of all one determines whether a ship could make it in time. Most of the time this is calculated using the full speed option. This is justified, because when a ship is hired all of its time, it should go full speed, making the most of its hired time. Moreover, most of the time when a ship is on hire it should meet a due date on its discharging. However, when a (ballast) trip is followed by an idle period, why make haste? A ship could then switch to the most economical speed, burning the least fuel on the trip. The savings thus made can amount to several thousands of dollars each day.

The time value Appelgren describes here applies to idle time at the end of the period. Something similar applies to idle time within the period. This is, however slightly different. During this period, the time value needs to be dependent on the open port of the ship, and the next loading port. At the end of the period, this is not the case. Within the planning horizon, we know a lot about the idle period. Both the open port at the beginning of the period and the next loading port are known. Therefore, we can estimate the value of the idle time quite accurate. However, at the end of the period, we know much less. We only know the open port, but nothing about the total length, and moreover: it is a longer time away. Therefore, it is better to split the valuation of this time in a premium for idle time, and a valuation of the open port.

In both cases, also a valuation of the distribution of the ships over the world map would be needed. This is explained by the following example.

Suppose there are two ships to schedule, and there are two regions, each producing one contracts each month (on average). It is better to divide the ships over the 2 regions, than to have them wait both at the same spot. In expectation, when both ships are located at the same region, only one of them gets a contract. If divided among both regions, however, in expectation they both get a contract. In this example, dividing the ships gives an expected income of up to twice as much.

This valuation could be achieved by multiplying the sum of all time values on a day for all ships waiting in the same region by a discount factor. In formula:

$$TV_{day} = d(r, n) \sum_{j=1}^n St_j I_{\{Sp_j=r\}} \quad (5.1)$$

where n is the number of ships, St_j the time value of ship j on that specific day. This value can be calculated by taking the average of the total time value of ship j , and divide by the length of the idle period. $d(r, n)$ is the discount factor for n ships in region r . Sp_j is the position of ship j .

Note that this Time Value may be different for periods within the schedule and at the end of the schedule, as well as that waiting periods close to the present day may be worth less than waiting days in the more distant future, due to the fact that the probability that a contract is found is smaller when the idle period starts sooner.

The above would suffice as a model when we would work with an infinite planning horizon. However, since we do not, we have to value the ending positions of the ships. We would not want all ships to end up in a region where there are no cargoes to pick up. If this were the case, we would need to ballast all ships back to loading positions. Thus, it is reasonable to add the expected needed ballast costs. This is the product of the expected length of the ballast trip and the expected daily revenue.

This position value is rewarded for the last open port in the schedule, also when it is followed by idle time. This is because the value awarded to idle time is also dependent on the port. This results in high positioning costs for ships in discharging regions, and low positioning costs in loading regions. The costs could be estimated on the basis of historical data.

Example 5.3.1 Example setup

Some concepts in this chapter are rather abstract. To clarify these concepts, we will follow an example situation throughout the chapter. The basis of the example is the same each time.

Consider three ports α , β and γ , and three ships, A , B and C . All ships have the same characteristics, if not mentioned otherwise. A picture of the ports can be seen in figure 5.1. The numbers next to the arrows denote the rates on the tradelanes and the number of days, respectively. When a ship sails with cargo, cargo handling takes 4 days, 2 in each port.

For instance, it seems that on average there is no freight at all from α to β and vice versa. It requires 6 days of sailing, making -40 cents. Since there is no freight, it also takes no port handling time. However, γ is a classical discharging area, getting freight against good rates from both α and β . Note, however, that some incidental contracts may be offered at traditional ballast routes. These will be often offered at quite low rates, however.

Example 5.3.2 Time Value

Consider only one of the three ships, ship A . Suppose A is open in α . Suppose also it has been scheduled to pick up a cargo in β . How to calculate

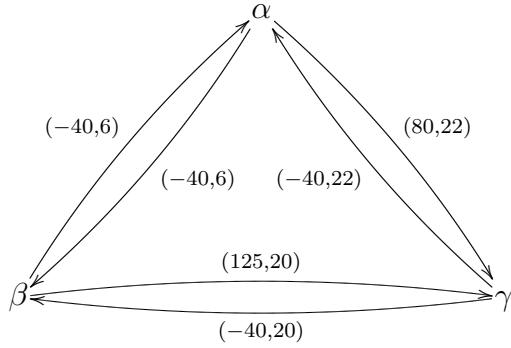


Figure 5.1: The three-port example

its time value, depending on the number of days left to the pick-up date? Suppose the schedule is feasible in the first place, we know that at least there are 6 days to get from α to β . In these 6 days, it would make -40 cents on a monthly basis. However, suppose more time is assigned. Then, in the first two days, A could use this spare time to sail eco speed instead of full speed. This raises the result from -40 , to -30 , for instance. Thus, in the first two days, the ship can make 10 cents each day. Increasing the assigned time even more, there is no alternative but to ballast to β and wait, not making money. However, when the waiting period is 45 days or more, A is feasible for doing trips such as $\alpha \rightarrow \gamma \rightarrow \beta$, or after 46 days the trip $\alpha \rightarrow \beta \rightarrow \gamma \rightarrow \beta$. How to calculate the expected return then? The first time a new contract becomes available is exponentially distributed. Thus, the probability that there will be a contract fitting in the route of ship A on route $\alpha \rightarrow \gamma \rightarrow \beta$ is given by

$$P(C) = 1 - e^{-\lambda(Sw_A - 46)} \quad (5.2)$$

with Sw_A the waiting days of ship A and λ the rate at which contracts arrive to the system. Note that this is true, because $Sw_A - 46$ is the number of days spare to find a contract, and the system with Poisson arrivals is memoryless. Suppose now that ship A has a capacity of 450.000 cubic feet, the current market value is 55 cents, and that in all loading ports contracts arrive once a week in average, so that

$$\lambda = \frac{1}{7}.$$

For this rather straightforward value, it is too complicated to consider all possible route combinations and feasible schedules during idle time. The market rate has a nice property to overcome all this. As said before, the market rate is based on a round trip. Often, also a pre-ballast and de-ballast

fee are paid. Thus, if we manage to find a suitable cargo for the ship, we could consider it from that time as that the ship is on time charter against market rate for the whole period. The Time Value formula, for the moment without estimation of the fuel savings, thus becomes

$$TV = (1 - e^{-\max(0, Sw_A - 46)/7}) \cdot Sw_A \cdot \frac{450.000 \cdot 55}{30 \cdot 100} \quad (5.3)$$

In the first two days, the vessel can save \$10.000 each day by sailing on economical speed, instead of sailing full speed. This extra money for the first two days should be added. The Time Value, dependent of the number of waiting days, is shown in figure 5.2. Note that this function is not

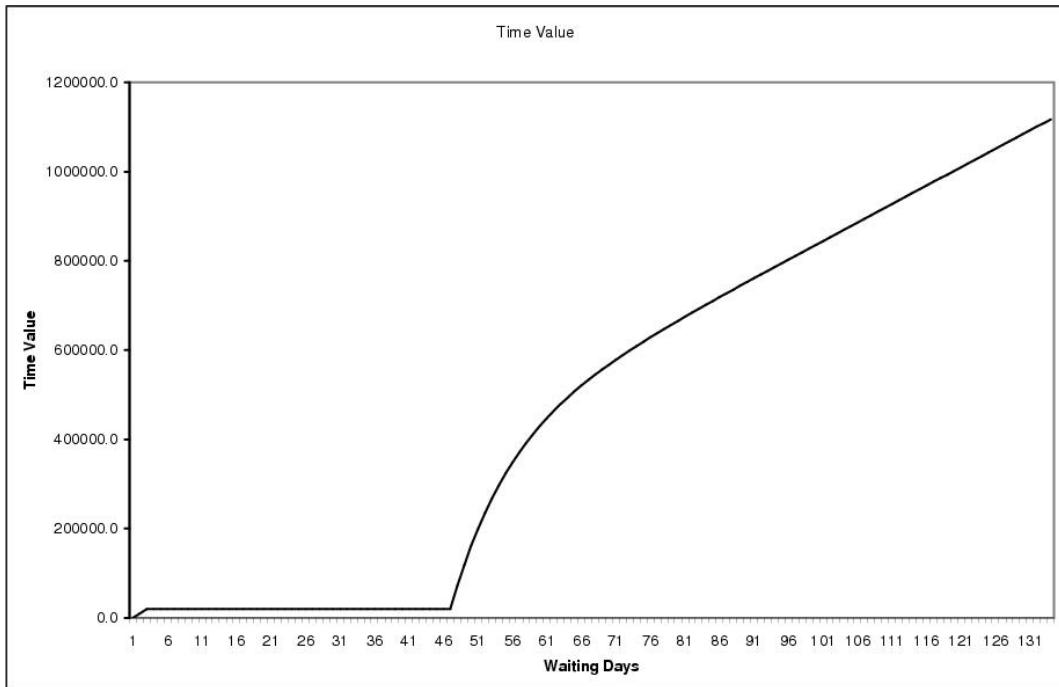


Figure 5.2: Time Value in example 5.3.2

convex. It is a more realistic approach, however, than Appelgren proposed. Because of the large threshold, idle time will also be concentrated on only a few vessels. This clearly gives a higher expected revenue than lots of small idle periods on different ships.

Summarizing, the procedure by which we found the Time Value, is as follows.

Procedure 5.3.1 Time Value Calculation

Follow the next steps:

1. Find shortest route measured in days with positive result, starting in α , ending in β .
2. Determine the first loading port P_{load} , being the first port that is at the start of a positive edge.
3. Set λ as the rate at which contracts arrive to port P_{load} .
4. Calculate Time Value according to formula 5.3.

Idle time at the end of the period is valued somewhat different. First of all, we would like that the ship is scheduled to be in a good position at the end of the period. Thus, the first point of the procedure is to ballast the ship to a position which is the starting point of a positive edge. The selection of such a point we discuss later on. After ballasting, it should get the normal time value, but only proportional to the amount of time that is within the current time horizon.

To make this more concrete, let us look at the mathematical form. Denote the time within the scheduling period on which the ship is open in a loading area by t_0 . Denote the end of the planning horizon by H . Then the probability density that at time t a contract will start, is

$$f(t) = \lambda e^{-\lambda(t-t_0)} \quad (5.4)$$

When a contract starts the ship will sail under contract an estimated return trip to its current open port, making the market rate. Thus, during 1 day the ship gets

$$Sr = 55 \cdot \frac{1 \cdot 450000}{30 \cdot 100}. \quad (5.5)$$

The expected value the ship gets within its idle time at the end of the planning horizon thus becomes

$$TV = \mathbf{E}(Sr \cdot (H - t)) = \int_{t_0}^H 55 \cdot \frac{450000}{30 \cdot 100} (H - t) \lambda e^{-\lambda(t-t_0)} dt \quad (5.6)$$

This is easily numerically evaluated, because we schedule only on a day-to-day basis.

5.3.2 Random contract generation

In this case, the basic idea is that with a model of the market, we are able to generate random cargoes. The drawback is, that it is hard to estimate

an entire market. Also, a lot of information is necessary, of which some information might have to be estimated.

A major advantage is that with this model several scenarios can be run, so that a final decision can be made, based on several options. For example, a worst case scenario and a best case scenario can be easily run by just changing the parameters.

This model is discussed extensively in section 5.4.

5.3.3 Manual contract estimation

When modeling real contracts, the most simple model, but also the most elaborate one, is to manually enter possible contracts. Basically, this is nothing but making the implicit knowledge available by estimating explicit contracts, based on the company's experience. An advantage may be that it is certain that the contracts are plausible, and it is easy to understand what is going on. However, a drawback could be that it could be quite elaborate, and it does not provide a way to transfer the knowledge on which the newly entered contracts are based. Besides that, this system is not capable of generating unexpected cargoes, obviously.

A variant of this approach is to set the contracts that have been in negotiation last year as possible contracts. This method, however, is not capable of handling new market opportunities.

5.4 Market modeling

To generate random contracts, we need a market model. In this section I will investigate what form this model could have.

The most important feature of this market model is that it has to be time-dependent, where the influence of the season may be different for the different trade lanes. An outlay for a basic model of the reefer market is found in figure 5.3. For our case, this market only needs generating contracts in the several trade lanes, which could be accepted for scheduling.

We might ask whether it is useful to model a full market, also presenting possibilities that are only rarely seen in the SRC voyages. This could occur when the model is based on all historical data. It does not seem logical to do this. Such voyages, however they sometimes occur, are not representative for a normal schedule.

This is explained by two things. First of all, the mean number of such

voyages each year is near to zero. Besides, such a rare voyage could influence the normal schedule too much, when the randomly produced value is quite high. The expected value of the idle time may then be increasing or decreasing a lot, due to one voyage. A schedule mainly used to look into probable future opportunities does not need to cover rare opportunities.

5.4.1 Random event generation

To generate events on random times, the most used distribution is the Poisson distribution, partly because of its memoryless property. The memoryless property is good for our model. One could argue that the market is not memoryless: the chance of a cargo arriving to the market increases when there has been no cargo for a while; for example, harvesting bananas continues anyway, and all those bananas have to be transported. However, when considering a larger area, it seems to be unknown when exactly a cargo will show up, only the expected number can be estimated. Thus, the memoryless distribution seems useful.

However, the intensity of arriving is changing throughout the year. Therefore, our candidate-distribution for the model is the Non-Homogeneous Poisson Process (NHPP). The NHPP is characterized as follows. With $\lambda(t)$ the time-dependent rate of the process, let

$$m(t) = \int_0^t \lambda x dx \quad (5.7)$$

$$m(t+s) = \int_0^t \lambda x dx \quad (5.8)$$

Then the probability of n events occurring in the time window between time t and time $t + s$ is

$$P(N(t+s) - N(t) = n) = \frac{e^{-(m(t+s)-m(t))} \cdot (m(t+s)-m(t))^n}{n!} \quad (5.9)$$

Essentially, this is a normal Poisson Process, with expectation $m(t+s) - m(t)$ in the time window $(t, t + s)$. Some additional properties of the process include the following. First, the expectation over a time interval equals the cumulative intensity:

$$E(N(t)) = \int_0^t \lambda(x) dx = m(t) \quad (5.10)$$

The second property is about the relation between a Homogeneous Poisson Process (HPP) and a NHPP. If E_1, E_2, \dots are time intervals in a HPP with

$\lambda = 1$, then $m^{-1}(E_1), m^{-1}(E_2) \dots$ are interval times in a NHPP with cumulative intensity function $m(t)$. This, in theory, enables us to easily generate NHPP event times.

Now we only have to estimate an intensity function to generate the cargoes. This can be done by fitting a curve to the historical data concerning the seasonal changes. To model the year-to-year change, an extra factor representing the economic development could be added.

A layout of this basic model is presented in figure 5.3.

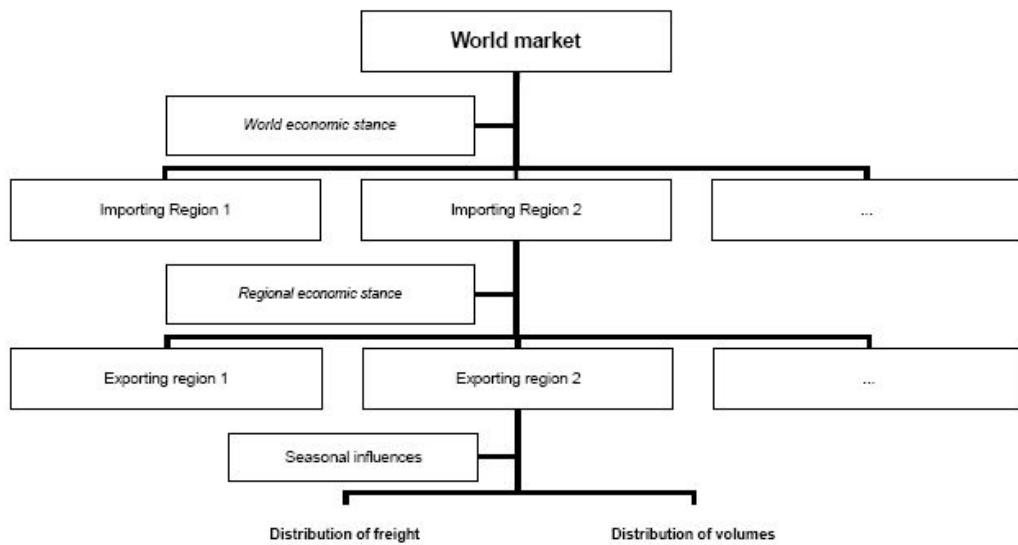


Figure 5.3: Reefer market model

5.4.2 Cargo characteristics

When generating cargoes, we also have to generate the properties of the individual cargoes. Some of the most important are:

- Load and discharge port
- Load and discharge time window
- Need for capacity
- Estimated net revenue
- Cargo type

The values of all of these properties can be dependent on the season. Every time an event is generated by the above described process, we must determine the characteristics of the new contract randomly. This choice can be made on the basis of historical data, so that the distribution of the characteristics of the contract is equal to those of the former contracts. This, of course, could be adjusted to new expectations.

5.4.3 Practical limitations

A close survey of the available data shows that theory and practice do not always go hand in hand. It would be ideal to model all 144 trade lanes. However, the available data does not support this idea. On several trade lanes the traffic has an intensity which is too low to model in a useful way. Trades on these trade lanes occur only sporadic, leaving too less data to implement a realistic stochastic model. The data is suitable to fit a useful model to only 6 trade lanes. Only on the 6 busiest trade lanes, there is enough week-to-week traffic to fit to a Poisson Process. On the other lanes, only sporadic voyages occur. This may be the consequence from the fact that there is a lack of demand, but too from the fact that in the data, only closed contracts are available. On the busiest tradelanes, this is enough to get a good picture of the trade. On the less frequented lanes, however, there is simply to little data.

How to handle with this restriction is explained in the next section.

5.5 Mixture approach

All three approaches presented in section 5.3 have their advantages. The best option to profit from all their advantages is, obviously, to combine the models. A graphical layout of this system, together with some advantages and drawbacks of each step, is found in figure 5.4.

First, we apply all knowledge that is explicitly available, in that sense that we make explicit what contracts we expect to sail.

Then, we apply less specific knowledge: we let our model for the different trade lanes generate random contracts. If the expected number of contracts arriving to a trade lane is n , and there are $i < n$ manually entered, let $\lambda = n - i$, with λ the parameter for that month of the NHPP.

In the last step, to value the opportunities for non-regular cargoes, employ a time-value function. The value for waiting should be lower then the value for contracts, in expectation. This reflects the fact that non-regular cargoes

are mostly less profitable than the regular cargo within the regular trade lanes, because they, for instance, do not use the reefer capacity.

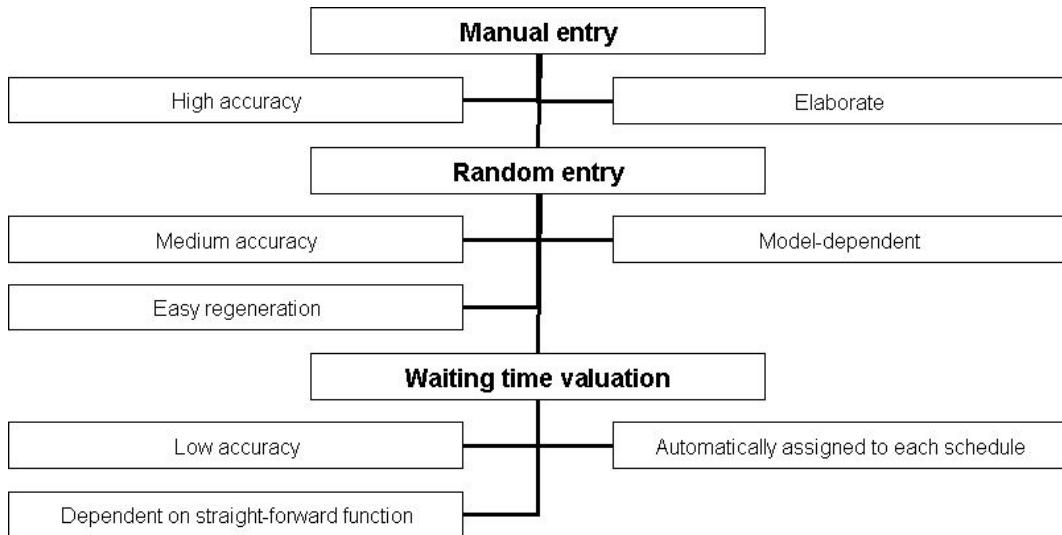


Figure 5.4: Future valuation in the mixture approach

Procedure 5.5.1 Mixed Approach

In short, we have the following procedure. This procedure could be repeated several times, to gain a more secure schedule.

1. Enter already fixed contracts in the system.
2. Enter expected contracts in the system (manual entry).
3. Let random contracts be generated by the system, representing future opportunities on frequently sailed tradelanes. Label these contracts as optional
4. Schedule all contracts. Doing this, apply the Time Value to value scheduled idle periods.
5. Delete phoney contracts (i.e.: contracts that are not fixed, but estimated or randomly generated) to obtain the proposed schedule.

Example 5.5.1 Mixed Approach

Let us continue our example as set up in example 5.3.1. Assume that ship

A is in α , B in β , C in γ . Suppose we have the following contracts fixed:

$$\begin{aligned}\beta \rightarrow \gamma & \quad 128 \text{ ct} \quad \text{loading day 0} \\ \beta \rightarrow \gamma & \quad 128 \text{ ct} \quad \text{loading day 40} \\ \beta \rightarrow \gamma & \quad 128 \text{ ct} \quad \text{loading day 80}\end{aligned}$$

We now have one contract under consideration:

$$\gamma \rightarrow \alpha \quad 40 \text{ ct} \quad \text{loading day 25}$$

How to schedule this?

If these are the only contracts to sail, we would have the following schedule:

Ship	Route	Starting date	Length	Terms
A	$\alpha \rightarrow \beta$	0	6	Ballast
A	β	6	40	Waiting
A	$\beta \rightarrow \gamma$	40	66	Contract
B	$\beta \rightarrow \gamma$	0	24	Contract
B	$\gamma \rightarrow \alpha$	25	51	Contract
B	$\alpha \rightarrow \beta$	51	57	Ballast
B	β	57	80	Waiting
B	β	80	104	Contract
C	γ			Waiting

However, now we employ our mixed approach. First of all we do a manual estimation.

We know that the cargo available on days 0, 40 and 80 is only half of the available cargo. These are the ones we fixed in a COA. However, on days 20, 60 and 100 the other half is sailed, but not within a COA contract, but on a market basis. Suppose, further, that we have a big chance to get these contracts, because of our good relationship with our client.

Now we arrive at the phase of random contract generation. Imagine that while we only have fixed contracts on lane $\beta \rightarrow \gamma$, the other lane is more frequently sailed with cargo, on average every 10 days. We generate some cargo until day 80. With an exponential distribution, we find the following

sailing dates on the route $\alpha \rightarrow \gamma$:

$\alpha \rightarrow \gamma$	80 ct	loading day 2
$\alpha \rightarrow \gamma$	80 ct	loading day 2
$\alpha \rightarrow \gamma$	80 ct	loading day 15
$\alpha \rightarrow \gamma$	80 ct	loading day 18
$\alpha \rightarrow \gamma$	80 ct	loading day 27
$\alpha \rightarrow \gamma$	80 ct	loading day 60
$\alpha \rightarrow \gamma$	80 ct	loading day 67
$\alpha \rightarrow \gamma$	80 ct	loading day 69
$\alpha \rightarrow \gamma$	80 ct	loading day 80

These contracts are all optional.

Now, we start scheduling. In figure 5.5 there are some possible routes. Note that ship B is the only ship that can pick up the first contract in time. Also note, that it is not possible for a ship to pick up the two other fixed contract cargoes subsequently.

For all routes we calculate the revenue. When sailing cargo, we earn the applicable rate on that trade. On route $\alpha \rightarrow \gamma$, when sailing with cargo, we thus earn 80 cents. When ballasting, the costs are -40 cents. From these amounts, we can calculate the rewards for fixing a contract.

From the ballasting and idle periods, we can also calculate the Time Value per route. We do this using the procedures in example 5.3.2. For example, consider ship A idling 23 days at the end of its schedule at port α , a loading port, with market rate at 55 cents. The its time value is calculated by

$$TV = \sum_{i=1}^{23} P(t = i) (23 - i) \frac{55 \cdot 450.000}{30 \cdot 100} \quad (5.11)$$

With $P(t = i)$ given by

$$P(t = i) = e^{-\lambda(t+1)} - e^{-\lambda t}$$

We said before port α would have $\lambda = \frac{1}{10}$. Then the Time Value becomes

$$TV = \$119.170, -.$$

This example illustrates the method of valuating idle time within a schedule. The ships are now ready to be scheduled by the scheduler or an algorithm, optimizing the value of the schedule.

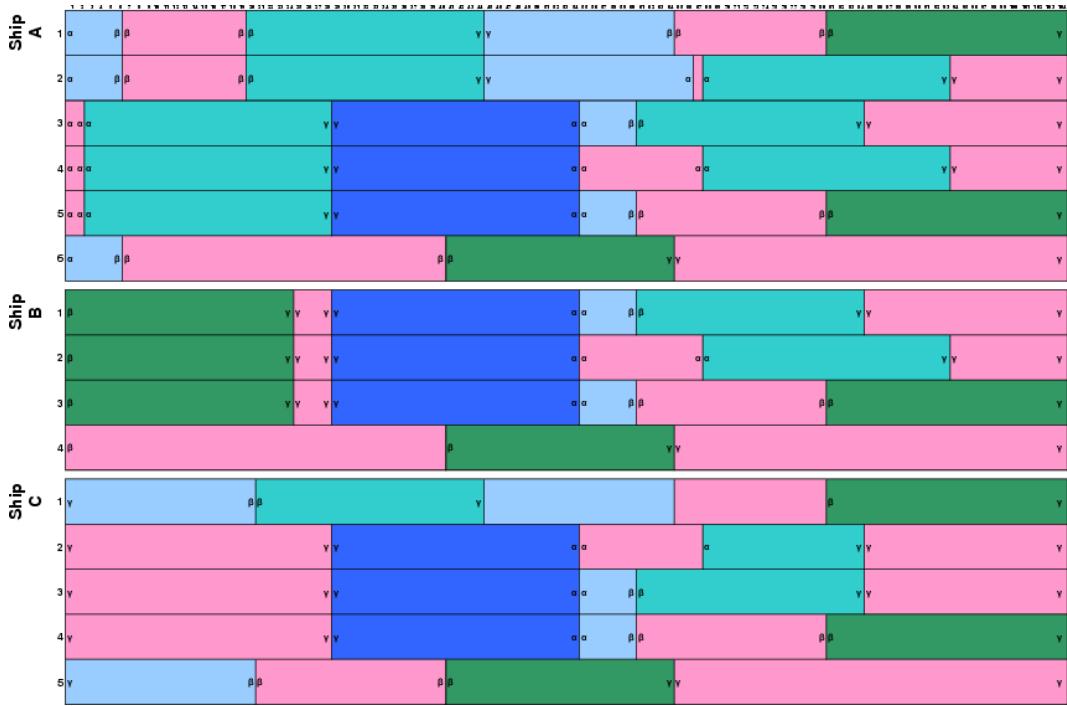


Figure 5.5: Some possible routes

5.6 Short and long term

Normally in planning problems, a horizon is set at the boundary of the time we have knowledge about. However, when planning ships on contracts, the more distant a possible contract is in time, the less sure we are about it. It can still be fixed by a competitor, it can still change a few days in ship delivery window, etcetera. This uncertainty has to be dealt with.

On the other hand, we are especially interested in planning proposals on the short term, since these are the decisions that we cannot change back. Once a ship has been handed over to an operator, to organise its next trip, the decision can hardly be undone. Indeed, the decision is already made when there is no real alternative choice. Therefore, the real deadline for a decision is the latest time at which there is an alternative. The closer this deadline is, the more important it is that the right ship is scheduled. When picking the right schedule, which is discussed in the next section, this has to be taken into account.

5.7 Suggest the right schedule

Random generation of contracts could cause very different schedules. In the end, we will only look at scheduling fixed contracts. However, we must propose one solution. How to pick the right one?

First of all, it is questionable whether the schedules will differ very much. First of all, random contracts are only generated in the regular tradelanes. Therefore, exceptional scenarios sending ships off their regular routes are quite unlikely. Besides this, like every simulation, it is wise to run the simulation multiple times.

From this set of solutions, we still have to pick the best solution. It is the most logical to pick the most occurring solution, in a way. It may be the case that when compared, all solutions are different, because of the assignment of a cargo to a different ship. Therefore, we have to look a little closer, to see how much the schedules differ from each other. To find out what solution this is, we have to quantify the difference between schedules.

I propose to do this on the basis of a measure on the set of schedules S . The most basical measure is to take the distance between two elements S_1 and S_2 the number of elements that has to be changed in order to move from S_1 to S_2 . This idea is also used in the k -opt neighborhood in Local Search. The k -opt neighbourhood is the set of solutions that is obtained when k components of the initial solution can be changed. For example, the 1-opt neighbourhood of a solution is the set of solutions where only 1 component is different. In our case: if only 1 contract is scheduled on a different ship. Let us look into this concept a little more.

Typically, such a neighbourhood is used to search for a local optimum. In our case, however, the solutions are the result of different simulations. However, we may still use the concept to compare schedules. I first give an example of using k -opt neighbourhoods. Let us consider 2 candidate solutions, S_1 and S_2 . The distance $\|(S_1, S_2)\|$ is given by the following formula:

$$\|(S_1, S_2)\| = k \text{ if } k = \min_n : S_2 \in N_{n-opt}(S_1) \quad (5.12)$$

Thus, the distance is the minimal number of components that need to be changed in order to move from S_1 to S_2 . This formula says that the distance between the solutions is k if S_2 is an element of the k -opt neighbourhood of S_1 , and not of the $k - 1$ -opt neighbourhood. This number could also be calculated when comparing the two assignment matrices A_1 and A_2 . The componentwise difference $A_\delta = A_2 - A_1$ gives a -1 where a component is

removed from A_1 , and a 1 where a contract is added. Thus,

$$k = \sum_{i,j} \frac{|a_{ij}|}{2} \quad (5.13)$$

with $a_{ij} \in A_\delta$, $i \in C$ and $j \in S$.

Note that a lot of different measures could be used to quantify the difference between two schedules. The above measure, however seems a good one to start with, because of its frequent use in local search.

Now, we have all components in place to calculate the most frequently used set. With the mentioned measure we can easily calculate the distance between all schedules. We would want to pick the schedule that is the best representative of the set. This is, in some way, the mean of the set. However, we cannot calculate a normal average, but we can calculate the center of the set. We just find the schedule S_p satisfying:

$$S_p = \min_{S_i \in S} \sum_j \| (S_i, S_j) \| \quad (5.14)$$

This schedule S_p has the lowest average distance to all other generated schedules. To attach more importance to longer distances, the individual distances could be raised to a power greater than 1, to diminish their influence, this power should be smaller than 1.

The last thing to do now, is to give more importance to decisions to be made for the short term. We saw that a decision is made at the time that there is no alternative ship available to pick up a fixed cargo. The closer in time such a deadline is, the more important the decision is. For each schedule $S_n \in S$ the deadline is dependent on the total schedule S_n . Let us call this time until the deadline $D_{S_n}(a_{ij})$. To attach more weight to the decisions that are close by, the measure can be altered to

$$k = \sum_{i,j} \frac{|a_{ij}|}{2 \cdot (D_{S_n}(a_{ij}) + 1)}. \quad (5.15)$$

This deadline can be calculated by finding the latest open date of a ship j' that is not currently scheduled to cargo i . If the day of scheduling is given by S_{date} , then the date of the deadline is given by

$$D_{S_n}(a_{ij}) = \max(0, \min(Sa_j, Sa'_j) - S_{\text{date}}) \quad (5.16)$$

with Sa_j the last open date of ship j before being assigned to cargo i . Note that this number can be 0, when no alternative is left. Therefore, 1 is added in calculating the measure, to avoid dividing by 0. Notice that this makes no difference, however: since there is no alternative, all optimal schedules will have scheduled these contracts to the same ships.

5.8 Application in scheduling

To put all this to use, we need to recall what we set off to do. Our questions were twofold:

1. What are the criteria to judge what is the best ship to fulfill a contract?
2. How can (implicit) expectations effectively be considered while scheduling ships?

To accomplish the first goal, we needed to describe what the "best schedule" would look like. This is the schedule that sees the current contracts in the best perspective with respect to the future. To describe this future, we devised the *mixed approach* method and the position costs for the very distant future.

On this basis, we can make a schedule. Now, when looking at the actual schedule, we can forget about all made up voyages, compensation costs and so on. The only result we want to see, is the assignment of cargoes to ships. However, how to value this result? In daily SRC business, all voyage results are described in cents, as explained in chapter 3. To evaluate the performance of the schedule, also these cents should be calculated over the entire horizon. All generated contracts have a gross revenue, the time value represents the expected profit in idle periods. Therefore, adding all incomes and subtracting all costs gives the net revenue. With the total used capacity (all ships used in the schedule) over the planning horizon, the cents-value can be easily calculated. With such a tool in place, the Schedule Manager could also easily evaluate the effect of a new contract entering the schedule. If this contract lowers the (expected) result, it might be wise to decline the contract proposal.

5.9 Conclusion

In this chapter, we saw some methods to attach a value to a schedule. An estimation of future opportunities is the most elaborate part of such a method. The proposed mixture approach seems to be a promising combination of the nice properties of each of the underlying methods, being manual contract entry, model wise contract generation and idle time valuation. These methods can be used to estimate an expected schedule revenue, even without full knowledge of available contracts. The application of this

approach is twofold. The schedule manager can use this method to find the best schedule fitting all the currently closed contracts. On the other hand, he can also use this to evaluate whether entry of a new contract raises the expected fleet result, or makes it more inefficient, lowering the result.

Chapter 6

Scheduling Theory

Before starting the implementation of the methods described in the previous chapter, I will first do a survey of the theory on planning and routing of ships.

We will look at the available mathematical procedures for the scheduling problem, that fit the methods we described before.

6.1 Basic elements

First we will define the basic elements which will be needed in all possible solutions: ships, contracts, and ports. Here, I describe the most useful features of the basic elements. More extensive lists can be found in [2].

6.1.1 Contracts

When compared to a regular scheduling problem, the contracts to be fulfilled can be considered as jobs. Let there by C jobs (or cargoes), indexed by i . These cargoes i are characterized by the following characteristics.

- $Ccap_i$ Amount of cargo in appropriate usage type (i.e.: needed square meters of floor, needed space in cubic feet, etcetera). This tuple can also be used to denote the number of containers, if applicable.
- (Cr_i^l, Cd_i^l) : pick-up window.
- (Cr_i^d, Cd_i^d) : delivery window.

- Cp_i : processing time. Includes loading, unloading and travelling time. Of course, this is dependent on the loading port and delivery port, and the speed of the assigned ship.
- $Cport_i^l$: loading or delivery port and $Cport_j^d$: discharging or redelivery port.
- $Ccons_i$ describes the constraints concerning the handling of the cargo. This might be required licenses, required onboard gear, etcetera.

6.1.2 Ships

The ships can be compared to servers in a standard scheduling environment. Denote the number of ships by S , index them by j . The ships are characterized by the following properties.

- Capacity $Scap_j$ of the ship. This characteristic describes the amount of capacity available when measured in the different types. This tuple is comparable to the needed cargo capacity, $Ccap_i$. If a cargo fits to a ship, necessarily

$$Ccap_i \cdot x_{ij} \leq Scap_j.$$

Here, x_{ij} denotes the assignment of cargo i to ship j .

- Range of possible speeds. We will consider two speed types: full speed and economic speed. These are denoted by $Sfull_j$ and $Seco_j$ respectively.
- Ship constraints: $SCons_j$. This describes constraints that can be met by a ship. For instance, the certificates a ship has (such as US clearance), the draught of the ship, and some other constraints. This is a tuple of the same length as $Ccons_j$. For a ship to be feasible for a specific cargo, all constraints should be met, or

$$Scons_i \cdot x_{ij} \leq Ccons_j.$$

- Location Sl_j and time Sr_j at which ship j is available to start the next trip.

6.1.3 Ports

The last class of objects considered in the scheduling problem is the class of ports. In effect, the restrictions of ports influence the restrictions on the cargo. This happens via the loading and discharging port. If a restriction applies for one of these ports, it also applies to the cargo. Moreover, the ports also play an import role when determining the handling time, because of their mutual distances. This time could be estimated as a characteristic of the cargo, but it would be more sophisticated to consider the class of ports.

Let there be P ports, indexed by p . Each port p is characterized by

- $Ploc_p$ is used to denote the location of the port, and thus determines the distance to other ports.
- $Pcons_p$. Port restrictions, such as draught, demanded clearances, etcetera. The structure of this variable $Pcons_p$ is the same as that of $Scons_j$ and $Ccons_i$. The restrictions for a port are expressed in $Ccons_i$, expressing the elementwise maximum of the constraints, making sure that a ship transporting cargo i can enter both the loading and the discharging port.

6.1.4 Objective function

Like for most privately owned companies, in the end the objective is to maximize profit. The gain g_i for every cargo i is quite uncomplicated: for every cargo shipped, an amount of money is paid.

The costs involve somewhat more. The costs are not solely determined by the distance a cargo has to be transported over, but also by the combination between the ship and the port. Therefore, the costs are a function of both cargo and the ship the cargo is assigned to. The costs are denoted by c_{ij} , with cargo i assigned to ship j .

Our main objective is to maximize the sum of overall profits $\pi_{ij} = g_i - c_{ij}$. The sum of profits is expressed as

$$\Pi = \sum_j \sum_i \pi_{ij} x_{ij}, \quad (6.1)$$

with x_{ij} the assignment of cargo i to ship j . Note that this objective function only covers the (theoretical) case of planning over the total fleet, in a world with perfect knowledge of future contracts.

6.2 Straightforward formulation

The most straightforward approach to this problem is to determine all contracts and ships, with all their characteristics as described above. Then, look for an assignment matrix, that respects all constraints. These constraints, however, may be numerous. Here I present a short layout of the various types of constraints, and their mathematical forms.

First of all, all cargoes must be transported. Thus, for each cargo i necessarily

$$\sum_j x_{ij} = 1. \quad (6.2)$$

Second, all cargoes must be shipped on time. Let the loading and discharging windows as described above. Then if s_{ij} is the starting time of the trip of cargo i on ship j , necessarily

$$Cr_i^l \cdot x_{ij} \leq s_{ij} \leq Cd_i^l \cdot x_{ij}. \quad (6.3)$$

Likewise, the discharge date d_{ij} must be within the discharging window. Thus, necessarily

$$Cr_i^d \cdot x_{ij} \leq d_{ij} \leq Cd_i^d \cdot x_{ij}.$$

When $x_{ij} = 0$, let $s_{ij} = d_{ij} = 0$

Third, all ships may only carry one cargo at a time. Let all cargoes i be enumerated according to their starting date. Then $d_{ij} \leq s_{i+n,j}$ for $n = 1, 2, \dots$ if $x_{ij} = 1$.

Finally, all combinations of ships and cargoes must respect all constraints, thus necessarily

$$Ccons_i \leq Scons_j \cdot x_{ij}$$

6.2.1 Implementation

In the worst case scenario, each contract must be constrained from being planned before or after each other cargo on a certain ship. Thus, we have $O(C^2 \cdot S)$ constraints: for each combination of 2 contracts, $\frac{C(C-1)}{2}$ combinations, and 1 ship, giving S options.

These constraints denote whether 2 contracts can be planned on the same ship. With these constraints we will run into the boundaries of the ordinary Microsoft Excel Solver, which is included in all recent copies of Microsoft Excel. This solver-utility can only handle 100 constraints. However, with the full problem of 100 ships and some hundreds of contracts, we have some hundreds of thousands of constraints. This problem can be solved in two

ways. First, we can consider the relaxation of the problem. This leaves an ordinary LP, and for this kind of problems, we have no limit on the number of constraints. Second, we can try to leave out some constraints which we expect to be satisfied anyway.

By the above approach, a problem arises. It is questionable if the objective function Π is linear. This Π is calculated from π_{ij} 's, calculated for pairs i, j . However, as we have seen in chapter 5, the value of a route is not only determined by the contracts assigned to the ship, but also by, for instance, the amount of idle time.

This problem can be accounted for, by adding a dummy task for all idle periods, with exactly the right starting and ending port, and the correct value. This approach leads to huge amounts of dummy tasks, however. In turn, this leads to huge extra amounts of constraints.

This dummy tasks do not seem to be a good solution. A less subtle approach might be the altering of the pricing function into a linear function. However, this highly limits our options.

Another approach is to generate full (feasible) routes. This approach is discussed in section 6.3.

6.3 Column Generation

A more sophisticated approach is the method of column generation. The name refers to the procedure of adding columns to the optimization tableau of the main problem. This solution to the ship scheduling problem was proposed by Leif H. Appelgren in 1969 [5]. The method is also roughly described in [3], section 4.2.1. More details on the implementation of Column Generation are to be found in [6].

The column generation method consists of two parts.

1. Master-problem: select a subset of routes that are assigned to ships, in a way that is optimal regarding profits, and such that all cargoes constraints are met.
2. Sub-problem: decide what routes should enter the master problem.

First, we have the master-problem: to find the optimal assignment of routes to ships. The set of routes to select from starts quite small, with only the routes to make one feasible schedule. Routes are added to this set by solving the sub-problem. Remark that the name Column Generation

originates from the routes that are added to the master-problem. In the LP-formulation this amounts to adding columns.

The sub-problem is to find the route that has a better result on a certain ship, and still is not in the set with routes. This route is added to the set of routes used for the master-problem, and the master-problem is solved again.

6.3.1 The master-problem

Instead of assigning cargoes to directly ships, we will assign cargoes to routes, and routes to ships. A route can be seen as a collection of contracts. These routes must, of course, respect natural constraints as time windows, of the contracts. When routes are assigned to ships, these routes and ships must match: the time windows must be feasible regarding the ship's speed, the ship's size, etcetera.

Let the set of all possible routes for all ships denoted by R , and let the set of possible routes for ship j be denoted by R_j . Let the assignment of cargo i to ship j in route $r \in R_j$ be denoted by a_{ij}^r , with

$$a_{ij}^r = \begin{cases} 1 & \text{if cargo } i \text{ is assigned in route } r \text{ to ship } j \\ 0 & \text{otherwise} \end{cases} \quad (6.4)$$

The route r is characterized by a vector of cargo assignments to ship j and the total profit of using this route. The vector is given by $(a_{1j}^r, a_{2j}^r, \dots, a_{nj}^r)$. The set of all cargoes is denoted by C . Let the profit made by ship j when sailing route $r \in R_j$ be denoted by π_j^r :

$$\pi_j^r = \sum_{i \in C} a_{ij}^r \pi_{ij}. \quad (6.5)$$

Now, let x_j^r denote whether ship j follows route r :

$$x_j^r = \begin{cases} 1 & \text{if } j \text{ follows route } r \\ 0 & \text{otherwise} \end{cases} \quad (6.6)$$

Since each ship can be assigned to at most one schedule, we have

$$\sum_{r \in R_j} x_j^r \leq 1, \forall j \in S.$$

Since each cargo must be transported exactly once, we have the restriction

$$\sum_{j \in S} \sum_{r \in R} a_{ij}^r x_j^r = 1, \forall i \in C.$$

The final form is

$$\max \sum_{j \in S} \sum_{r \in R_j} \pi_j^r x_j^r \quad (6.7)$$

$$S.T. \sum_{j \in S} \sum_{r \in R_j} a_{ij}^r x_j^r = 1, \quad \forall i \in C \quad (6.8)$$

$$\sum_{r \in R_j} x_j^r \leq 1, \quad \forall j \in S \quad (6.9)$$

$$x_j^r \in \{0, 1\} \quad (6.10)$$

This would result in a total schedule consisting of routes assigned to each ship, resulting in an optimal combination of routes.

Remark that, if we alter the problem to a situation with optional contracts besides the already fixed contracts, constraint 6.8 should be split in a closed and an optional part.

6.3.2 The sub-problem

In the sub-problem, we look for routes that have not yet entered the master problem, but that have the potential to increase the value of the schedule. In the end, we want to add all routes that are necessary to be sure that the result is optimal, while adding a minimum of columns. Therefore, we need some criterion to judge routes on. To find this criterion, we will look at the theory of Linear Programming.

Consider the starting tableau of a feasible starting solution. From LP-theory, we know that the reduced-cost variable when adding a column is given by

$$p = P_B^T B^{-1} N - P_N \quad (6.11)$$

Here B is the matrix describing the tableau, P_b is the vector describing the gains by all routes constrained to the routes in a basic solution of the master-problem. P_N is the coefficient of the variable associated with column N in the objective function. N is the column that is about to enter the problem. p is the resulting reduced-cost variable.

In LP problems, we keep on optimizing until all cost variables are positive. Thus, the greatest improvements can be made when selecting the routes for which p is the most negative. We also know, from LP theory, that when there is no route with negative reduced cost, we have arrived at an optimal solution.

6.3.3 Interpretation of the selection criterion

Besides the fact that the current selection criterion provides an optimal solution, we would like to have an interpretation of the rule. With this interpretation, we could obtain some intuition on why this rule provides an optimal solution.

We first introduce some further definitions. Let Q denote the total set of routes, that have not yet entered the master problem. Let F denote the set of routes already available in the masterproblem. Let $f_j \in F$ denote the route assigned to ship j in the current optimal schedule (i.e., the most recent outcome of the masterproblem). Let profits be denoted as defined before, by writing π_j^r for the profit ship j is making when sailing route r . Let $r^* \in Q$ denote the route in Q that is next to enter the master problem. Denote the column corresponding to route r and ship j by r_j . The tuple of the optimal route to add and the corresponding ship is given by

$$(r^*, j^*) = \arg \min_{r \in Q, j \in S} P_B^T B^{-1} r_j - P_{r_j} = \arg \min_{r \in Q, j \in S} \pi_j^{f_j} - \pi_j^r \quad (6.12)$$

The profit of this route r^* , when sailed by ship j^* , the ship on which the optimal profit is realized, is denoted by $\pi_{j^*}^{r^*}$.

Remark that this route, although it is selected for the profit it is making on ship j , might be assigned to other ships. The profit for these ships may be different from the profit when sailed by ship j .

The correspondence between P_{r_j} and π_j^r is quite obvious; both variable denote the reward for ship j sailing route r . To see that the statement in equation (6.12) is true, let us calculate the expression

$$p = P_B^T B^{-1} r_j - P_{r_j}. \quad (6.13)$$

more explicitly.

We start by looking at the feasible starting solution. Here, we have routes that have each been assigned to precisely one ship, and the sets of contracts served in the different routes are all disjoint. The number of basic variables is $C + S$. We have S basic variable associated with route-ship pairs. Hence, a basic solution contains C variables corresponding to the ships. Thus, we have a starting tableau with the following structure

$$\left(\begin{array}{c|c} Z & I \\ \hline I & 0 \end{array} \right) \quad (6.14)$$

Here, Z is a matrix denoting for all routes what contracts they involve. Remark that the number of ships is the same as the number of routes. The dimensions of Z are $C \times S$. Since all routes are assigned to one ship, the matrix in the down-left corner can be arranged such that it is an identity matrix, with dimensions $S \times S$. In the same way, the square matrix in the upper right corner, describing the slack variables that are needed for the equality constraints, can be arranged such that it is an identity matrix. Since there are C slack variables (one for each contract), this is a $C \times C$ matrix. The block in the down-right corner is a zero-matrix, with dimensions $S \times C$.

The inverse is now given by

$$\left(\begin{array}{c|c} 0 & I \\ \hline I & -Z \end{array} \right) \quad (6.15)$$

It is easily checked that this is correct:

$$\left(\begin{array}{c|c} 0 & I \\ \hline I & -Z \end{array} \right) \left(\begin{array}{c|c} Z & I \\ \hline I & 0 \end{array} \right) = \left(\begin{array}{c|c} I & 0 \\ \hline 0 & I \end{array} \right) \quad (6.16)$$

Now we can calculate the negative reduced cost,

$$p = P_B^T B^{-1} r_j - P_{r_j}. \quad (6.17)$$

A new route r_j added to the tableau is a column vector, with one binary entries. The first C entries have a 1 in position k if contract $c_k \in r$. The last S entries have precisely one 1, in position j if ship j is assigned to this route. This denotes the ship for which the route is feasible. Thus, multiplying B^{-1} with r_j , we get a $C + S \times 1$ vector.

The empty block in the upper left corner makes that for the first the sum of the products over the first C items is 0. This block is followed by an identity matrix of dimension $S \times S$. This block corresponds to the lower S entries in the route vector. Since there is a 1 in only one entry, the j^{th} entry to be precise, in the resulting vector, there is a 1 only in the j^{th} entry. The C lower entries in the resulting vector correspond to the dummy variables. The pricing vector awards a profit to each of the S considered routes, π_j^r to variable x_j^r . For all dummy variables, the profit is 0. Thus, the pricing vector P_B^T multiplied with $B^{-1} r_j$ gives π_j^r , the value of the route that is at this moment assigned to ship j . We denoted this special route before with f_j .

P_{r_j} gives the reward for the new route, $\pi_j^{r^*}$. Thus, if we want the most negative solution of the criterion, we have:

$$(r^*, j^*) = \arg \min_{r \in Q, j \in S} \pi_j^{f_j} - \pi_j^r \quad (6.18)$$

We also want to guarantee that a new entering route can also be scheduled in a feasible schedule. Therefore, suppose that r^* contains the set contracts C^* . All of the contracts $i \in C^*$ are in the last feasible schedule contained in some other routes. For all routes $r \in F$ that contain one or more of these contracts $i \in C^*$, call the set of the routes that remain when these contracts are removed from the route several routes F_C^* . Instead of these removed contracts, idle time is added to these routes.

The main idea of the algorithm is as follows. We start with a feasible solution. Then, we add routes meeting some criterion to the master problem. This criterion we will work out further on. Then, we re-solve the master problem. Repeating this, until no routes match the criterion anymore, we will arrive at the optimal solution.

6.4 Algorithm

Now, we have introduced enough terminology to set up the algorithm.

Algorithm 6.4.1

Initialize

1. Find feasible solution
2. Set $F :=$ all routes from the feasible schedule.

Do:

1. Solve sub-problem: calculate (r^*, j^*)
2. $F := F \cup \{r^*\} \cup F_C^*$
3. Solve master-problem: find optimal schedule on the basis of the set of routes F

Loop until $\left(\pi_{j^*}^{f_j^*} - \pi_{j^*}^{r^*}\right) \geq 0$

6.4.1 Partial proof of optimality

We can prove that there are no individual routes left out of the masterproblem that would improve the outcome.

Write the problem in LP-form. Suppose that the master problem is solved to optimality on a given set of routes. Then, we only have to check whether there are routes that will not enter the master-problem, while they are needed in the optimal solution.

Suppose the algorithm delivers a solution, which is not optimal. Call this schedule S^- . Call the optimal schedule S^* . Then we know from LP-theory that there is a route $f_j^* \in S^*$, that has not yet entered the master problem, and that has negative reduced cost $p = P_b^T B^{-1} N - P_N$, according to equation (6.11). However, then the algorithm would not have terminated. Contradiction.

However, this is only partial. It needs extra research to check whether it is possible that groups of routes exist where each of the individual routes would not be selected, while combined, they could raise the profit.

The following ideas could lead to an answer, or fix the algorithm:

1. Change the restriction that cargoes may be transported exactly once by the restriction that the should be transported at least once. Then, more options are feasible in the LP. A really feasible solution is obtained by leaving the cargo out of the schedules of all but one ship, in the most optimal way.
2. When stuck in an optimal integer solution, drop the restriction that all route assignments should be binary, thus allowing fractional solutions. If in the new optimal solutions fractional assignments exist, change the criterium as follows. Denote the set of fractional assigned routes to ship j by R_j^{frac} . For ship j , set the ship-route combination to

$$(r, j) : \arg \min_{r \in R_j^{\text{frac}}, j} \pi_j^r \quad (6.19)$$

With this new (sub-optimal) routes assigned to all ships that had fractional solutions, start solving the sub-problem again.

6.4.2 Solving the master-problem

The master problem is closely related to the minimal set covering problem. The formulation of the minimal set covering problem is as follows.

Let \mathbf{U} (for universe) denote a set, and let \mathbf{S} denote a family of subsets of \mathbf{U} . The Cover is a set $\mathbf{C} \subset \mathbf{S}$, such that $\cup \mathbf{C} = U$. In the minimal set covering problem, the problem is what subsets of \mathbf{S} should be chosen, such that the number of sets from \mathbf{S} in the cover is minimal. Or, with some cost function $c(S)$ assigning costs to elements of $S \in \mathbf{S}$, and x_S a decision variable denoting the assignment of S to the cover \mathbf{C} :

$$\min \sum_{S \in \mathbf{S}} c(S)x(S) \quad S.T. \quad (6.20)$$

$$\sum_{S : e \in S} x_S \geq 1 \quad \forall e \in U \quad (6.21)$$

$$x_S \in \{0, 1\} \quad \forall S \in \mathbf{S} \quad (6.22)$$

Our version of the problem is slightly different, but on headlines the same. The formulation of the master problem is as follows.

Let F denote the set of routes, that have already entered the master problem. These routes contain fixed contracts. We want the total optimal combination of routes, such that all contracts are served. Suppose x_j^f can only become 1 when ship j can sail route f , regarding feasibility constraints. Then our formulation thus becomes:

$$\max \sum_{f \in F} \sum_{j \in S} \pi_j^f x_j^f \quad S.T. \quad (6.23)$$

$$\sum_{j \in C} \sum_{f: i \in f} x_j^f = 1 \quad \forall i \in C \quad (6.24)$$

$$x_j^f \in \{0, 1\} \quad \forall f \in F. \quad (6.25)$$

We see one major difference: in equation (6.24) we demand equality, where in (6.21) we demand only that the sum should be at least 1. However, since we know that in every step in the algorithm there is a feasible solution, this should not pose a big problem.

Regarding the similarity of the two problems, the normal procedures of solving set covering problems can be followed. A good summary of the possibilities is given in [7]. The solutions can be divided in three types:

1. Linear programming and relaxation
2. Heuristics

3. Exact algorithms

It is beyond the scope of this thesis to discuss these algorithms thoroughly. Remark that if we want guaranteed optimality, we need to use the exact algorithms.

6.4.3 Unimodularity

It is interesting to see whether the master-problem we formulated is totally unimodular. Total unimodularity guarantees that we will have an integer solution. However, unfortunately this is not the case. When looking at the formal description of the Integer Linear Program (ILP), we have the following form

$$\max cx | Ax = B \quad (6.26)$$

The matrix A is made up out of two blocks: one block describing the feasibility of assigning ships to routes, and one block describing the contracts that are found in routes. A is totally unimodular if for every non-singular square submatrix C of A holds that

$$\det(C) = \pm 1 \quad (6.27)$$

However, imagine the case with 3 contracts, and three routes. Each row represents a contract, each column represents a route. A 1 denotes that the contract is included in the route. Imagine the following assignment of contracts in routes.

$$\begin{vmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{vmatrix} = 1 \cdot 1 - 1 \cdot -1 = 2 \quad (6.28)$$

Remark that if this would not have been the case, the set covering problem would have been solvable in polynomial time, because we would have reduced the ILP to a normal Linear Programming (LP) problem. This result is as expected, since the set covering problem is known to be NP-hard, and an NP-hard problem is not solvable in polynomial time.

6.4.4 Unimodularity in a special case

A second remark is to be made on a special case. Suppose all ships can sail only one contract, due to the fact that all contracts have to be sailed in the

same timespan. Then we can formulate our problem as minimum cost flow problem, or better stated: a maximum profit flow, which is essentially the same. The formulation can be as follows.

Consider an origin (representing the starting dummy contract) with S ships, such that each of them has to reach the sink (the ending dummy contract), via some route through a network. There is a straight route to the sink, for each ship, representing the idle contract. Besides that, there are also at most $C \cdot S$ indirect routes to the sink, representing the contracts. The routes to the contract can be seen as dummy edges with capacity 1 each, and profit 0, each for one ship that is able to carry the contract, that is represented by the next node. From the contract-node to the sink, there is only one edge, with capacity 1, and a profit that depends on the ship that is assigned to that edge. An example of such a network is found in figure 6.1.

This network formulation is in itself of not much use. However, the matrix

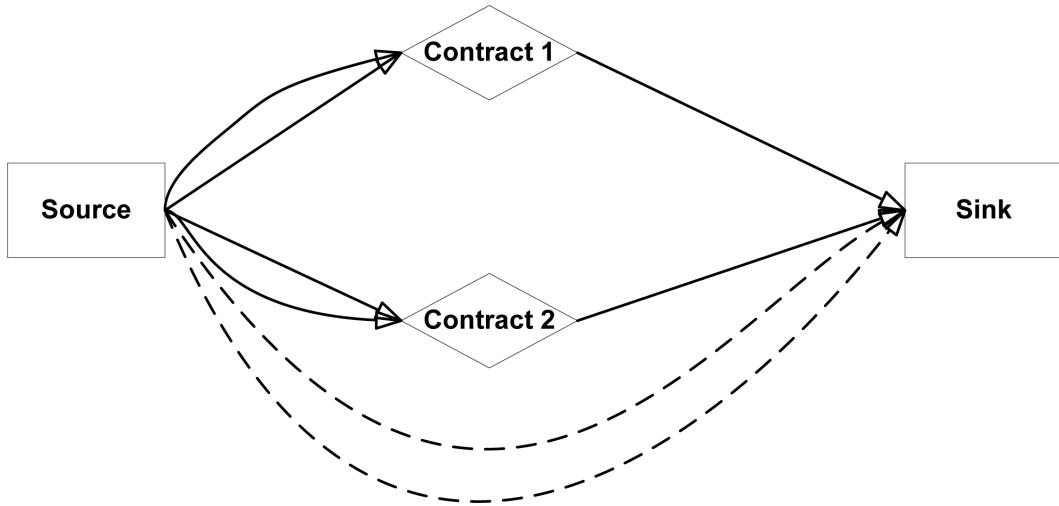


Figure 6.1: An example of the network setup, with 2 contracts and 2 ships.

that arises from this formulation, is the matrix that we have to optimize on. Since this matrix has risen from a network-flow-cost problem, we know that this matrix is unimodular, and that therefore integer solutions are ensured. In the DSS that I designed, this case is often found.

6.5 Conclusion

In this chapter, we have seen various ways of putting mathematics to work to solve the scheduling problem. We have developed an algorithm to solve the scheduling problem. We have also seen a condition, unimodularity, that guarantees that a solution is integer. In the next chapter, we will try to use some insights from this chapter to work.

Chapter 7

DSS within Seatrade Scheduling business

In chapter 6, I described a general formulation of a route-assignment problem, and how to solve this. However, the amount of variables is huge. This means the system should be fed with a pile of information. As seen in chapter 4, this is not an ideal start for a newly implemented DSS. Besides that, the experience available in the company is not involved, which seems to be an immense loss of information in itself. In this chapter, we will investigate how we can address the knowledge of the schedule manager, and fit this into the approach described in chapters 5 and 6.

7.1 Schedule Manager input

Before we start designing the program, we have to think about what we want the program to do, and what the role of the scheduler should be.

As we saw before, the shipping business is an industry with a lot of exceptions to procedures. It thus seems not a good idea to directly connect the program to some Enterprise Resource Planning (ERP) program. The schedule manager will therefore be responsible for gathering the input and putting the output of the program to work. This is recommendable, because the schedule manager remains in charge of the full planning.

These ideas about the role of the schedule manager have been implemented in the current setup. The input from the Schedule Manager is essential in this setup. First of all, he imports the current schedule, by selecting ships

he thinks are appropriate. This can be done before the program even starts. To speed up solving the problem, in the first calculation round, the feasible combinations are determined, when only looking at the open dates, delivery dates and ship sizes. This limits the possible routes for each ship, thus speeding up the program.

After the first calculation steps, the Schedule Manager can select in two ways. Either he can exclude options, setting $x_j^r = 0$ for that option, or he can secure options, setting $x_j^r = 1$ for that option. Doing this, he excludes indirectly x_m^r with $m \neq j$ and x_j^s for $s \neq r$. Also an option is available to undo securing or exclusion. Now, the schedule can be recalculated, and manually adjusted until a feasible and desirable schedule is found.

7.2 Program line-out

The basics of the program are as described in chapter 6. The basic elements of the program are ships and contracts. These are read from the input sheets in the program. Contracts are then combined with ships, to form assignments. Assignments with the same ships then can form routes. The structure is illustrated in figure 7.1.

The begin and end of a route are formed by dummy assignments: empty

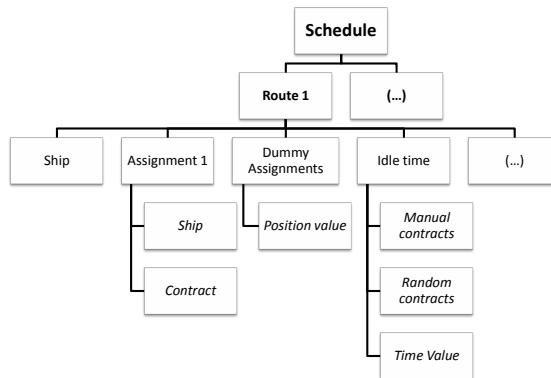


Figure 7.1: Hierarchie of the objects in the program

assignments, to denote the entering of the ship to the schedule and to denote

the end of the planning horizon. The program generates several possible routes. Due to the fact that, for the moment, the fixed contracts are to be sailed in about the same time window, the routes all consist of at most one contract, besides the dummy contracts. For each ship also an idle route is calculated, with only two dummy contracts.

In the next step, the values of all routes are calculated. This is done with the values of the contracts, and the pool-value of the ships. The program thus employs, besides the fixed contracts, the idle-time valuation method described in section 5.3. For the valuation of the idle time at the end of the schedule, for each day an amount equal to the pool-value of the ship is added. Besides, an amount is subtracted for the expected ballast time from the last port.

In the calculation step, the optimal schedule is calculated via a linear integer programming procedure called Solver, which is included in all of the most recent Microsoft Excel versions.

To present the outcomes in an easy understandable way, the outcome is reduced to an advice how to employ the ships, and the corresponding cent-value for the ships.

After this first calculation procedures, a menu is shown, allowing the schedule manager to interact with the program.

7.3 Working with the program

One requirement of the program was that it should be easy accessible for persons with basic computer skills. Therefore, I chose Microsoft Excel to be the implementation platform. The program is easy accessible with basic knowledge of Excel. Also, since all scheduling administration is now done in Excel as well, communication between the program and the now-used administration is quite easy. A copy of the program is available, along with the manual. The manual is also found in the appendix of this thesis.

7.4 Theory and practice

Not all theory developed in chapters 5 and 6 has been incorporated in the program.

First of all, the program does not handle the general scheduling problem, planning more contracts on one ship, after each other. The program selects only one contract per ship. Doing so has also its consequences for the

valuating the idle time in the schedule. Since only one contract is fixed on each ship, manual contract estimation and random contract generation are of no use. The idle time valuation is done only with the Time Value-approach.

Due to the fact that each ship can only have one contract, we know that the problem is unimodular. Thus, we can loosen the restrictions that the decision variables x_j^r may only attain binary values: the restriction that

$$0 \leq x_j^r \leq 1$$

gives the same result. Moreover, the program is much faster due to this relaxation.

In the program no column generation is used, but a quite simple LP-structure, where for each route the profits are calculated in advance. This is possible, since in the current situation, only a relative small number of contracts and ships have to be scheduled.

We have seen that the chapters on modelling and mathematical theory describe much more than is now implemented. More sophisticated methods, however, also require more and more accurate data. If the data is not good, the decisions proposed by any program are useless. The unbeatable principal at work:

Garbage in = Garbage Out

Chapter 8

Conclusion

In the introduction we posed four questions.

1. How is scheduling at Seatrade Reefer Chartering done? What decisions can be effectively supported by a Decision Support System?
2. How should the maritime scheduling problem at SRC be modelled?
3. How can this problem be solved?
4. How can a program that solves this problem be implemented within Seatrade Reefer Chartering?

In chapters 2-4, the first question is answered. The tactical decisions, about the scheduling and deployment of the fleet, can effectively supported by a DSS. This DSS can help the Schedule Manager to easily see the consequences of decisions he takes.

The second question is answered in chapter 5. I designed a method to model the scheduling problem at SRC. The third question is answered in chapter 6. Here, I described the mathematics needed to solve problems like these. I developed an algorithm, which can be used for these problems. Moreover, I derived a special case can be easily solved, since it satisfies the unimodularity property.

This statement makes a beginning with answering the fourth question. The special case, where each ship only has to transport at most one contract, is implemented within a Microsoft Excel environment.

Concluding: in this Thesis, I have addressed a practical problem, as seen every day within Seatrade Reefer Chartering, and tried to solve it with

mathematical procedures. It is not easy to have a program propose a better schedule than the Schedule Manager himself. However, the Schedule Manager no longer has to start from scratch. He now has an easy accessible DSS-tool at his disposal, which he can use to calculate different scenario's with. This DSS is rooted into mathematical theory and based on advanced forecasting methods.

However, the theoretical possibilities go much further than the methods now implemented. With this program as a prototype, SRC can evaluate its working, and make a better decision on whether a full-scale scheduling system should be implemented.

Bibliography

- [1] Kjetil Fagerholt. A computer-based decision support system for vessel fleet scheduling—experience and future research. *Decision Support Systems*, 37(1):35 – 47, 2004. [cited at p. 1]
- [2] Jeroen Vermeer. Scheduling at seatrade reefer chartering. Master’s thesis, TU Delft, 1996. [cited at p. 2, 43]
- [3] C. Barnhart and G. Laporte, editors. *Handbooks in OR and MS*, volume 14. Elsevier, 2007. [cited at p. 3, 47]
- [4] David Ronen. Cargo ships routing and scheduling: Survey of models and problems. *European Journal of Operational Research*, 12(2):119–126, 1983. [cited at p. 4]
- [5] Leif H. Appelgren. A column generation algorithm for a ship scheduling problem. 1969. [cited at p. 4, 21, 47]
- [6] F. Vanderbeck. Implementing mixed integer column generation. *Working Paper*, U-03.28, 2003. [cited at p. 47]
- [7] M. Fischetti A. Caprara and P. Toth. Algorithms for the set covering problem. *Anneals of Operations Research*, 98:353 371, 2000. [cited at p. 54]

Appendices

Appendix A

SRC Scheduling Tool Manual

A.1 Contracts

Before starting, contracts have to be filled in. This can be done at the worksheet Contracts. Contracts have to be filled in from the second row, just down the header, without empty rows until the last contract.

The columns need also to be filled in. It is possible to leave some columns empty, but that may result in strange calculation results. The only real optional column is ViaPort. All other columns are required, although also 0 or an empty cell is accepted by the program.

A.2 Starting

After filling in the contracts go to the worksheet Frontpage and click the button Start to start the program. Starting up may take a few seconds, because the first calculation is made. For details on the calculation, and the relevant dialog boxes, refer to that section.

When starting the program, first of all it reads the selected ships and contracts. When a ship is not found in one of the sheets containing information on the ships (Blad 1, Consumption, Poolpoints), a dialog box is shown warning for this. This box gives both the name of the ship, and the sheet on which it is not found. Please note this name and sheet, and make sure the either the ship is deselected or that the appropriate information is supplied. After this, the combinations of ships and contracts are made, into routes. For each route the sailing time and idle time is calculated. To do this, dis-

tances between open port, loading port, via port and discharging port are calculated. If a distance is not found, the program tries to search on the basis of 5 routing points. The user is asked to select the routing points en route from starting port to ending port. If from a certain point, there are only dead ends, the user is asked to select the proper next route point, and give the distance. This distance can be acquired from NetPass.

A.3 The main menu

When the first calculation is finished, you arrive in the main menu.

A.3.1 Command buttons

On the bottom line, we find 4 command buttons. From left to right:

1. Finish: Calculates new solution, closes the menu, and unloads ships, contracts and schedule settings from memory
2. Calculate: Calculates new solution, but leaves the menu open, and keeps ships, contracts and schedule settings in memory.
3. Hide: closes the menu, but keeps ships, contracts and schedule settings in memory
4. Close: Closes the menu, and deletes ships, contracts and schedule settings in memory

A.3.2 Objective

On the top of the menu, we find the Objective frame. The difference between the two settings is essential. The standard setting is Route Value. With this setting, the best solution is calculated on the basis of estimations of waiting value, revenue from the contract, position value, and etcetera. This is the best setting for planning spot voyages.

The other setting is Waiting Days. With this setting, only the best fit is calculated, on the basis of ballast days and waiting days. This is the best setting when looking for the best delivery of ships to TC voyages.

A.3.3 Schedule

In the Schedule frame we find two options. The frame is displayed in figure A.1. First, we have the Toggle Exclusion button. With the reference box on the left of this button, we can select options on the schedule which we consider not desirable. If, after this selection, you click toggle exclusion, the selected cells which were not yet excluded, are now excluded. But also the other way around: if they were already excluded, now they are again included in the calculations. Exclusion is shown by displaying the cells in light red.

Second, you have the Select Ships option. Clicking the box to the left takes you to the worksheet Blad 1, containing the schedule. Select the ships which you want to include or exclude, and click the Select ships button. The ships are now selected or deselected. Selection is shown by displaying the ships in light green.

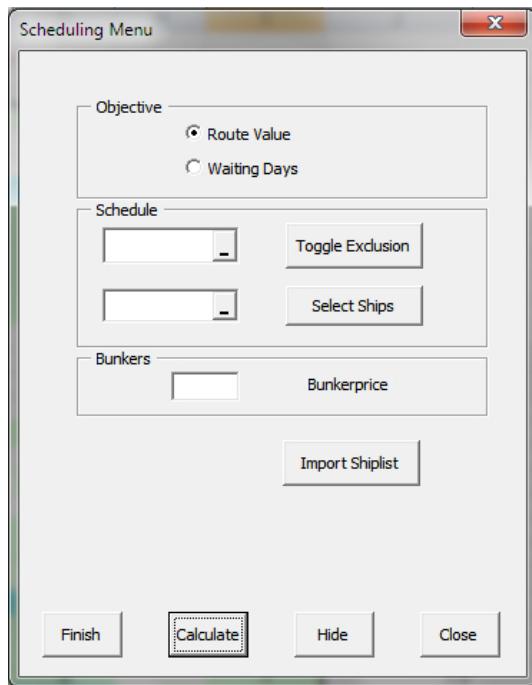


Figure A.1: The scheduling menu

A.3.4 Bunkers

Use the box in this frame to set average bunker prices. Bunker prices do not differentiate per port.

A.3.5 Import schedule

Click this button to import a new position list. To do this, the sheet (normally distributed as Sched 1) must be placed in the same directory as the Scheduling Tool, and be renamed to Schedule.xls. Then click the button. If Blad 1 is already available (which it is, if everything is all right), the program asks if you really want to continue.

After importing a new position list, you need to select new ships. If you forget this, you might need to select some ships yourselves by coloring them light-green, before starting the program again.

A.4 The schedule

The sheet Schedule is the centre of the program. The sheet is displayed in figure A.2. The green cells denote feasible options, considering containers,

		12010 28-10-2010	22010 4-10-2010	32010 12-10-2010	52010 14-10-2010	62010 8-10-2010	Idle 12:00:00 AM	
Spring Dragon	Lagos	27-9-2010		0		0		1
Everest Bay	Cristobal	27-9-2010						1,0
Whitney Bay	Vado	27-9-2010						1,0
Changuinola Bay	Guayaquil	27-9-2010		0	0	0		1,0
Koala Bay	Piraeus	27-9-2010		0	0	0		1,0
Humboldt Rex	Odessa	27-9-2010		0	0	0		1,0
Season Trader	St. Petersburg (Rus)	27-9-2010		0	0	0	0	1
Glacier Bay	Varna	27-9-2010		0	0	0		1,0
Sable Bay	Varna	27-9-2010		0	0	0		1,0
Kashima Bay	Guayaquil	27-9-2010						1,0
Izumo Bay	Piraeus	27-9-2010						1,0
Yasaka Bay	Mersin	27-9-2010						1,0
Kasuga Bay	Santa Marta	27-9-2010						1,0
Prince Of Sounds	Odessa	27-9-2010		0	0	0		1,0
Atlantic Hope	St. Petersburg (Rus)	27-9-2010						1,0
Prince Of Streams	Oran	27-9-2010		1	0	0	0	1,0
Hudson Bay	Varna	27-9-2010						1,0
Prince Of Waves	Odessa	27-9-2010		0	0	0		1,0
Prince Of Tides	St. Petersburg (Rus)	27-9-2010		0	0	0	0	1,0
Pacific	Cristobal	27-9-2010		1	0	0	0	1,0
Lake Phoenix	Philadelphia	27-9-2010		0	0	1	0	1,0
Marine Phoenix	Odessa	27-9-2010		0	0	0		1,0
River Phoenix	Mersin	27-9-2010		0	0	0		1,0
Sea Phoenix	Odessa	27-9-2010		0	0	0	1	1,0
Summer Phoenix	Cristobal	27-9-2010		0	1	0	0	1,0
Santa Maria	Santa Marta	28-9-2010		1	0	0	0	1,0

Figure A.2: The scheduling sheet

capacity range and delivery time. The clear blue cells denote the best three options, regarding maximal profit (resp. minimal waiting time) for this particular contract. Remark that the right green column is denoting the idle assignment, the situation where the ship is (for now) planned idle for the full period.

The number 1 denotes that the ship in this row is assigned to the contract

in this column. For convenience, in the comment label of the ships there is some information on the ships added, as well as in the comment label of the contracts.

If you want to change something in the contracts or ships information, please do this on the Contracts or Blad 1 sheets. Changing on the Schedule sheet has no effect.

A.5 Planning

With this schedule, a planning is produced. This planning is found on the sheet Planning. This sheet provides some details on the decisions made in the Schedule sheet. It denotes expected net value from the voyage, cent value, waiting days, ballast days, starting date of the contract, and expected discharging date. Also it gives an estimation of the value that could be earned in the remaining idle time in the schedule.

A.6 Errors

The program was severely tested on errors. Some errors are known to occur. If any errors occur, please choose end and try to restart the program. If the error is still available, follow instructions on dialog boxes, if provided. If such instructions are not provided, describe exactly what you did, and the message you received when the error occurred, and contact the author.

A.7 Contact

If anything needs to be explained, changed, improved or fixed, please contact:

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List of Symbols and Abbreviations

Abbreviation	Description	Definition
COA	Contract of Afreightment	page 14
DSS	Decision Support System	page 1
ERP	Enterprise Resource Planning	page 59
HPP	Homogeneous Poisson Process	page 31
ILP	Integer Linear Programming	page 55
LP	Linear Programming	page 55
NHPP	Non-homogeneous Poisson Process	page 31
SRC	Seatrade Reefer Chartering	page 1
TC	Time Charter	page 14
TCE	Time Charter Equivalent	page 15
VRP	Vehicle Routing Problem	page 8

Symbol	Description	Definition
a_{ij}^r	Decision variable for assigning cargo i to ship j in route r	page 48
C	Set of available contracts	page 43
c_{ij}	Costs of assigning cargo i to ship j	page 45
$Ccap_i$	Needed cargo capacity	page 43
$Ccons_i$	Constraints connected with transporting cargo i	page 44
Cp_i	Processing time of cargo i	page 44
$Cport_i^l$	Loading port of cargo i	page 44
$Cport_i^d$	Discharging port of cargo i	page 43
(Cr_i^l, Cd_i^l)	Loading or delivery time window	page 43
(Cr_i^d, Cd_i^d)	Discharging or redelivery time window	page 43
P	Set of ports	page 45
$Pcons_p$	Constraints to be met when calling port p	page 45
$Ploc_p$	Location of port p	page 45
Π	Total profit of a schedule	page 45
π_j^r	Profit of ship j when sailing route r	page 48
π_{ij}	Profit of assigning ship j to cargo i	page 45
R	Set of all routes	page 48
S	Set of ships, also denotes the total number of ships	page 44
s_{ij}	starting time of ship j carrying cargo i	page 46
$Scap_j$	Capacity of ship j	page 44
$Scons_j$	Constraints connected with using ship j	page 44
$Sfull_j$	Full speed capabilities of ship j	page 44
$Seco_j$	Economic speed capabilities of ship j	page 44
Sl_j	Location at which ship j is available to start next voyage	page 44
Sr_j	Time at which ship j is available to start next voyage	page 44
x_j^r	Decision variable for assigning route r to ship j	page 48
x_{ij}	Decision variable for assigning cargo i to ship j	page 45

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