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Investigate the ship routing and cargo allocation in container liner shipping between Europe and Asia

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1 Introduction

Sometimes it is cheaper to import an existing product from another region than to make this product by yourself. A shortage of ingredients or technology in your own region and a specialised industry in an other region will cause the import. Demand for products works in both ways around, which causes trade. Because the distances between the regions, that are trading with each other, can reach an abnormal number of miles, the trades can not be done by foot. There are a few types of transport, that will make this problem not only easier, but will also make the transport of products faster. Examples of the different transport types are transportation by train, by plane or by ship. In the intercontinental trade, transportation by ship will often be chosen to transport products from A to B.

There has been made an estimation by the academic members of the International Association of Maritime Economics that between 65% and 85% of the international trade is borne by ship (Korsvik, Fagerholt and Laporte, 2009). The possibility to transport products in such an easy way is been increased over the years by several causes. The growing population over the years has caused for an increase of the demand for importing products. Globalization have led that regions will trade with other regions over the whole world, what also results in an increasing demand for importing products elsewhere. Trade barriers have been eliminated, so it is become easier to trade. Other causes of the increasing of trade are the increasing standard of living, rapid industrialization and exhaustion of local resources. This all have led to a big transportation network for ship transportation.

1.1 Problem formulation

In this thesis will be looked at the intercontinental trade between Europe, Asia and the Middle-East. This means that there will be looked to the demand of ports within these three continents. The transportation by container ships between different ports will give a very complicated problem of making a network of routes which will be sailed by ships between the ports. Because there is not any good mathematical model to solve this problem, this problem is a good study object for this thesis, where the main reason is to find a good working mathematical model which gives a close to optimal solution to the network problem. In the past, Ka Wang Man has already done some research about this specific topic. This thesis will go further on the thesis of Ka Wang Man, using some of his assumptions together with some new theories.

There are several properties which have to be satisfied to define a good route network. First of all, the selected route network should make profit. When there will be made losses for the company that uses the route network, these losses can lead to bankruptcy. Another property which has to be taken into account is the weekly frequency of demand. This means that every week will be started with new demand. The duration of routes should be expressed in numbers of whole weeks. In that case a route can start with a weekly frequency. Furthermore a route should exist out of a trip from Asia to Europe and a trip on the way back from Europe to Asia, in order to come back to his original port. This does not mean that a ship should sail the same route on the way back. So a route can exist out of two different one-way routes.

In literature, which will be discussed later on, there can be found all kind of models, in which every single model will have their own concept in finding an optimal solution. According to Ka Wang Man (2007) his thesis, routes with weekly frequencies were never discussed in the literature. Another point he discussed, was that the freedom to skip some ports on a route, in order to make cyclical routes possible, were not taken into account in the models. The use of so-called hubs are not be used often in models. It is interesting to find out how much effect hubs will have in optimizing routes. The use of hubs is nowadays a question more port companies have in mind. That's why this thesis will look to the effect hubs will have on the optimization of a route network, next to the main points of Ka Wang Man his thesis. Another point which will be looked at, is the composition of the routes. Should the one-way routes be the same or different from each other.

A big disadvantage in solving the routing problem is that there are too much things which should or can be taken into account to find an optimal solution. If everything will be taken into account, this problem will exist out of an enormous set of variables, which will make the problem only more complicated. That is why it is to complicated to formulate this problem in such a way that only a solver has to be used in finding the one and only optimal solution. Problem is that it is almost impossible to formulate such a big problem, under the given restrictions. That is why most of the time heuristic algorithms are being use to solve this problem. A heuristic algorithm can be defined as follows: "An algorithm that is able to produce an acceptable solution to a problem in many practical scenarios, but for which there is no formal proof of its correctness." (see Wikipedia) Because heuristic algorithms will find pretty good solutions, although there is no proof of correctness, in this thesis heuristic algorithms will be used to solve the problem.

It can causes a lot of disadvantages when routes are not planned efficiently.

The transport of the increasing trade in the world have lead to a network of ships that are sailing over the world, in this case between Europa the Middle-East and Asia. An easy solution is to transport all demand directly from port A to port B. Although this method is easy to execute there are some disadvantages using this method. For example, for every line between 2 ports, a single ship will be used, which leads to the use of a large number of ships to handle the demand. Other disadvantage is that a lot of these ships will not reach their maximum container capacity. The costs using this method will be more than the possible revenue when all demand is satisfied, which will lead to a big loss for port companies. When the losses are getting to big, there are a couple of things port companies can do. First they can raise the import prices of products, so that their losses decreases or become profitable. However this increase in import prices will result in a decrease of demand for their products. An other thing the port companies can do, is deciding to stop transporting their products over big distances, which automatically results in a decrease of demand. Port companies have to watch out that the losses, been made by the transportation and possibly by the losses of demand, are not getting to big, because it can lead to bankruptcy.

When there is found a method which plan routes on a clever way, this will keep the companies strong in their mutual competition. Because of the rising competition, new companies are entering the market and already existing companies will innovate their products and planning methods, it will be important for companies to make these costs for ship transportation as minimal as possible. If other companies make lower costs than they make more profits, but they can also lower their prices to gain more market share. What means that the company will lose customers, which will lower the company his revenue and profit.

Now we have seen the disadvantages of making bad routes, the importance of making profitable routes for companies is clear. There are a lot of possible routes that can be sailed to satisfy the demand for every port. But making a network of these routes will be the hardest problem. There have to be looked at a network which will minimize the total costs, or in other words will maximize the profit. In this thesis the costs will be described the same as in Ka Wang Man his thesis. The costs are split up in capital and operating costs, fuel costs, port charges and transhipment costs.

There are many ways to define how to reach maximal profits. Fuel costs have to be minimized, so the sailing distances of ships have to be minimized or the speed of the ships can be changed to use the fuel in the most optimal way. Further the number of ships can be minimized, this can also be said as minimize the duration of every route. And last, the number of port visits can be minimized, so port charges and transhipment costs will be optimized. The aim is to find an optimal route network by combining these optimization methods.

The goal of this thesis is described as follows: **finding a(n) mathematical/algorithmic method that make a network of sailing routes which will minimize the costs and automatically maximize the profits for the trade line between Europe, the Middle-East and Asia.**

From this goal the following key question is formulated: **What is a good method to handle the problem of making a route network which optimize the costs and profits on the line Europe-Middle-East-Asia?**

There are a few sub questions derived from this key question:

- **What methods are already in literature described about the route network problem?**
- **What effect have hubs on the routes been made?**
- **By which method can the total distance of a route be minimized and integrated in an algorithm?**

- **How can the port visits be minimized and integrated in an algorithm?**
- **How can the number of ships be minimized and integrated in an algorithm?**
- **How should the demand be allocated on ships in order to minimize the costs?**

1.2 Methodology

In order to solve the problem in this thesis, there is made use of a few heuristic algorithms. These heuristic algorithms are methods of Operation Research in order to find a close to optimal solution in this complex problem. The methods that will be used in this thesis are the Travelling Salesman Problem and an adjusted Set Covering Problem. These methods will be explained and discussed further in this thesis. When these methods have found a solution, there will be used an Genetic Algorithm (existing of binary variables) in order to search for a better solution nearby the solution that is found by iteration.

1.3 Structure

The main line of this thesis will be as follows. First of all, there will be discussed some literature about earlier researches with different approaches in the routing problem in the next chapter. After this discussion, the problem will be described and assumption will be made in chapter 3. This will be done in order to define the exact problem formulation used in this thesis. When the assumptions are made, the used methods and algorithms will be explained in chapter 4. This will be followed by a discussion of the results found by these methods and algorithms using an existing example and an own made example in chapter 5. From this discussion a finale conclusion will be made in chapter 6, before ending with recommendation points for further research in chapter 7.

2 Literature

Because handling the ship transportation gives such a complicated problem there has been done a lot of research in finding models for all kind of assets which appears in this problem. Some researchers will have made programming models, like for example Linear Programming or Mixed Integer Programming, and other researchers will use own written algorithms. This paragraph will discuss some of these researches.

There are five types of freight transportation: ship, air, truck, pipeline and rail. Over the world, transportation by ship is the most used type of these five. As stated before, between 65% and 85% of the international trade is transported by ship. Three types of ship transportation are known (Christiansen et al. (2004, 2007)), namely industrial, tramp and liner shipping. Industrial ship transportation means that the ships are from the company which decide how to transport their cargoes. Tramp ship transportation are ships which operates like cabs, by making contracts with cargo owners they will pick up their cargo and bring them to the port of its destination. In liner ship transportation the ships are sailing according to a standard schedule and pick up cargo at the ports they visit. Furthermore there are different types of planning levels, namely strategic, tactical and operational. A strategic plan follows the goals of the whole organization in one main goal. While a tactical plan is being used to make a strategy work. Such a plan concerns what the specific divisions must do in a company. An operational plan is a plan that a manager uses to accomplish all responsibilities. Such a plan is measurable and is used to support the tactical plans.

There are a few reasons why ship transportation is more complicated than other types of transportation. For example in Ronen (2002) it gives a few disadvantages of ship transportation with other transportation types. Ships are often different from each other by size, compartmentation, costs and other characteristics. While trucks are always the same type. In this thesis the assumption is been made that all ships that will be used are the same from each other. In this case there can be said that the ships will be handled in the same way as trucks. Also the vessel will be different for ships than for trucks. In trucks it is possible to stow all different packaged products together in the same truck. While in ship transportation different products have their own container, but in this thesis demand of different products is expressed in containers, what means that no difference between products have been made.

In truck transportation and transportation by plane there is made a lot of use on Operation Research-based decision support systems making their schedules. Companies will handle mostly one ship at a time with their tools (Christiansen, Fagerholt, Hasle, Minsaas and Nygreen, 2009). A disadvantage of this method is that these companies will get only suboptimal solutions. Further the cost structure for ships will make this scheduling problem very complicated.

There can be made differences in types of service routes. In Lim (1996) it describe three types of deep-sea types of service routes. Namely end-to-end, pendulum and round-the-world service routes. Difference between those routes is the number of continents where the vessels are sailing between back and forth. End-to-end routes are between two continents, while a pendulum route sails between three continents, like the Europe-Middle East-Asia line in this thesis, and the round-the-world routes, it says already in the name, are sailing a route around all continents, meaning around the whole world. On a pendulum route the last continent on the route forth is used as turning point.

In Ting and Tzang (2003) they use a procedure which follows 5 steps. The first procedure corresponds the selection of one of the types of service routes. After they selected a route, they have to investigate how many ships they need and which size these ships must have. Next step is to select the ports they have to visit. This depends on the total demand ports have, in which is done research. Till so far this is all preparation for the forth step, which is actually make the ship routing and scheduling. In their last step they will analyse their results. Their ship scheduling model is based on an already existing list of ship routes. What they do is making a schedule for ships when they arrive at a port, how long they will stay there (depends of the time they need to load and unload), when they leave a port and how long it take to arrive at the next port (vessel speed). This method can minimize the vessel costs on an already existing route, but it is not known if this route selection is optimal.

There are a lot restrictions that can be taken into account for optimize a model, but the more restriction are being used, the more complex the model becomes to find a solution. In the paper of Christiansen, Fagerholt, Haugen and Helleberg Lund (2008) the restriction that are taken into account are a limit on stock, a limit on loading/discharging, physical port conditions, number of ships, cost minimizing and a planning horizon. These are all inventory and stowage restrictions. They are also making a priority list of ports which have to be handled first. With this list and a list of the times it take to restore these ports, the ports will be sorted. No their scheduling heuristic will be used to generate a starting set of routes which satisfies all restrictions. Another heuristic will then search if they can improve this set of routes by one of the “neighbour” solutions. Remark on this method is that it is not known if this solution is the best solution or a local best solution.

Making a starting set of ship routes, following by a search in their neighbour solutions to find a set of routes which improves the founded solution, is an approach which is commonly used. This was also the method used in Karsvik, Fagerholt and Laporte (2009). Because constraints are often very tightly they have taken the possibility of exploring infeasible solutions during the search into account. In that way their heuristic ensures a quick decision support to the planner.

However most researchers make a model that only optimize one part of the whole problem, Hsu and Hsieh (2006) have made a two-objective model. These model optimize liner routes, ship size and sailing frequency for container carriers by minimizing the shipping costs and inventory costs. Both of these costs will get there own objective in the model. These model will find a solution according to the Pareto optimal solution. This means that the combination of both costs are being optimized. In the Pareto optimum, none of the costs can be lowered down without making the other costs rise. It will analyze the trade-off between shipping costs and inventory costs. Besides determine the optimal ship size and sailing frequency for any route, this model will show if it is better for a ship to sail on a route through a hub or directly to their destination.

In their case it is more efficient to sail through a hub than to sail directly between the original port and their destination. Which means that there are different lines. There are so-called main lines between those hubs and there are so-called feeder lines which feeds the local/smaller ports around the hub.

Only remark on their case is that there is only one route which visit all ports. They have not investigate if it was more profitable to make a few routes which cover all ports together. This means for example that a port is only covered on one of the routes. This case the routes become smaller and maybe the costs will reduce.

Hsu and Hsieh (2006) are not the only ones which uses a more objective model. In Alvarez (2008) a optimizing method is made for a joint treatment of fleet deployment and route design. The objective minimize the costs defined as the sum of fixed vessel costs (both used and unused vessels), total fuel costs (fuel costs used when the ship sails and when the ships is idle), revenues (revenues for all handled demand minus penalties for unhandled demand) and transhipment costs (loading and unloading). There is a fixed number of vessels for every vessel type over the selected planning horizon. This will give a solution for which routes have to be sailed and how the demand must be allocated to the different routes. In this research, different bunker prices together with high penalties for unhandled demand. Which resulted in the conclusion that how higher the bunker prices, how less services were produced and how less vessels were used. The sailed miles were decreased, while the handled demand was increased.

There are also made some researches in container optimization. Containers are idle for almost 50% of their lifetime. In order to lower this percentage, containers should be used more often. Lagoudis, Litinas and Fragos (2006) have done research to make a model which combines the optimal use of containers together with vessel optimization. Their goal was split up in two things. They wanted the containers, they had to use, for handling the demand be minimized, what means that the percentage of lifetime that containers stay idle will be minimized. At the other hand, they wanted to use the optimal number of vessels, with costs as the minimization function. In this case the size of vessels will be variable and depends on how many ships are being used, because the demand stays fixed. Taken these two goals together, they were looking to minimize the summation of the total vessel costs and total container costs. In that way, the optimal solution does not have to be necessarily the number of vessels with the minimum vessel costs or the number of vessels which use the minimal number of containers. The combination of those two goals will show that for both goals the second best solution can result in the optimal solution. But in this case there is only determined a number of vessels that will be used in stead of also giving also the list of routes these vessels are sailing and which ports they visit. It seems to be that all vessels visit the same ports and in every port there will be a reloading of containers with freight and load them back on the ships. Remark on this is that the possibility to skip a port for some ships on their route is not taken into account. This can maybe reduce the vessel costs, with less port charges etc., and maybe reduce the number of containers been used. Although in this thesis the costs for containers are not taken into account, it is an idea for further research to see what effect it will have, for the route network that is made, when these costs for containers are taken into account.

There is developed an optimization-based decision support system for ship routing and scheduling. This planning tool is called the TurboRouter and is been developed out of a project between researchers from MARINTEK and NTNU and a couple of shipping companies. They made this tool step-by-step, in a way they could handle each restriction in one step. With close interaction and acceptation from the shipping companies they have made heuristics at every step which gave optimal or near-optimal solutions. Finally, they have made a planning tool (TurboRouter) which quickly give a solution. They selected a robust, heuristic approach based on local search and meta-heuristic.

3 Description and assumption

To help understanding the overall problem and the overall idea of solving it, there will be a discussion about the problem in paragraph 3.1. Besides the overall problem some general assumptions will be discussed, followed by assumptions that are important in this thesis, showed in paragraph 3.2.

3.1 Model description

There is a line between ports from Asia through the Middle-East to Europe. The n given ports must all have at least a kind of trade, this can be import or export, with one of the other given ports. In this thesis all trade (demand and supply) will be expressed in TEU's. On Wikipedia a TEU is explained as follows: "A twenty-foot equivalent unit (TEU) is an inexact unit of cargo capacity often used to describe the capacity of container ships and container terminals." Like in the name this container box has a volume of twenty feet long, it is eight feet wide and such a box is easily to transfer. The goal of the model is to optimize the total profit with a route network which can handle all trade from supply to demand, or at least make the profit as good as possible with a route network which can handle this trade.

Because of the complexity of the problem there should be made some assumptions in order to make the problem less complex. If there are no assumptions it could be possible that the problem will become unsolvable. But there must be watched out for assumptions which will make the problem to easy to solve. Also when finding a solution there must be looked if assumption will hold in real life. If the assumptions made, are not possible to execute in real life, the solution that is found becomes useless.

There will now be discussed some general assumptions. First of all, every route will be sailed by one type of ship. Following from this assumption every route in the route network will be seen as a main line. There will not be made use of feeder lines. If they were used, than there probably also would have been more than one type of ship.

The total costs of a route network can be split up in several costs. Capital and operating costs are a fixed number of costs for the use and owning of one ship. Fuel costs are the costs determined out of the number of miles which will be sailed by the route network. Port charges contains every costs a ship will made when visiting a port, excluding all costs made by loading and unloading containers. The costs made by loading and unloading containers are the so-called transhipment costs. The port charges and the transhipment costs together are all costs made in a visit from a ship to a port.

Routes are split up into two one-way routes. A one-way route can be defined as a route which only sails in one direction. In this case all ships will start there route in a port of the Asian contingent. The first one-way route will sail from Asia to

Europe, so they sail in western direction, and the second one-way route will sail the other way around from Europe to Asia, it sails in eastern direction. In this thesis the assumption is made that a route will exist of two symmetric one-way routes. In that way, ships will visit the same ports when they sail in western direction as when ships sail back in the eastern direction.

The sailing distance of every route is expressed in nautical miles, knowing that 1 nautical mile is equal to 1.852 kilometre. Just like in Ka Wang Man his thesis, www.searates.com is used to determine the distances between every possible connection between two ports. To generate the time in which these distances can be sailed, there will be selected a fixed speed of 28 nautical miles per hour in which all ships are sailing.

There is one more point which is important for this model. It could be that there are a group of ports in the same region which do not have trade which each other. It could be that this is only the case between two neighbour ports which is not a problem. When this appears between more than 2 neighbour ports (thus at least 3 neighbour ports), than there will be decided to assign the first port outside this group of ports as a hub, when it concerns the first ports of Asia or the last ports of Europe, or else assign the first ports outside that group of ports at both endings as hubs. There is one condition a hub has to satisfy, which is that the specific port himself can not be a part of a group neighbour ports with no trade. The use of hubs will be discussed later on. It can be possible that a small port will be assigned as a hub. In that case, further research has to be done to look if it is financial achievable or profitable to expand this port.

The process of selecting hubs will cause that this method will be solved step by step. First there will be made a set of routes, existing of the first region of ports, with all containers which have to be shipped to the first hub and further. How this process works will be discussed later on. The set of routes, which is found for the first region, will be the first part of the total route network. The second step is to make a set of routes for all containers which have to be shipped between the first and the second hub and further than the second hub. The routes found between the first and the second hub should than be coupled to the total route network, which now exist out of the first two regions. This process will be repeat until the last hub is reached. Only thing that is left to do, is to make a set of routes between the last hub and the last ports left. There will be looked to all containers which have to be shipped on the way back from the last ports to the hub and all earlier handled regions. For the last time the set of routes found in this last region will be coupled to the existing route network, which now exists of routes sailing through all regions. The assumption is made that the one-way routes in the route network should be the same, so the route on the way back between the last and the first hub, will be the same as the route between the first and the last hub. In this way, the whole loop of a route is made. The ships will start and end in the same hub or port.

3.2 Assumptions

Next to the general assumptions been made, there still are some assumptions which been made for this specific thesis. These assumption are used to find a starting set of routes (route network).

- A1. As already been said, all ships are of the same type, what means that ships can handle all the same amount of TEU's (10.000), will have the same capital and operating costs and will sail at the same speed.
- A2. Ships are staying a fixed time at every port they visit. In this thesis ships will stay one day at a port. This time includes berthing and exiting time as well the time to load and unload the containers, including transhipment actions.
- A3. Demand is fixed for the whole year. This means that every route will start with a weekly frequency.
- A4. The revenue per transported container are fixed and independent of distance.
- A5. A ship can visit a port at any time a day (morning/afternoon/ evening). There will always be a place for the incoming ships at the port to stay idle. Also the loading and unloading process from the containers can be done at any time a day when a ship is in a port.
- A6. At every hub there is the possibility to reload containers which only can be reached by ships of an other route. There will be assumed that this reloading process will be done when all ships are at the hub. In the real problem this probably will not be the case, but in this thesis there will not be specified at what day and hour a ship is at a specific port. Only the duration of the total route will be showed in number of weeks.
- A7. Ships are all at the hub for reloading at the same time.
- A8. There is no limit in use of ships and the number of routes used.

4 Techniques/Methods

In this chapter the used methods will be discussed in more detail of how they work, illustrated by some short examples. First there will be a discussion on the effects of using hubs and the usefulness of it in paragraph 4.1. After that there will be discussed two methods of Operation Research that are be used, namely the Travelling Salesman Problem and the set covering problem, in respectively paragraph 4.2 and 4.4. The algorithms for these two methods that are used in this thesis will be discussed in the paragraphs 4.3 and 4.5. In paragraph 4.6 there will be a description about the allocation methods. At the end of this chapter there will be described a method to look for improvements in the set of routes, found using the methods from 4.2 till 4.5, to get a solution with even more profit.

4.1 The use of hubs

Before there will be discussed if it is reasonable to make use of hubs in a method, there will be a short description of what a hub exactly means (by giving a example) and showing the effects of using a hub in the method.

A hub is a port in a region where all or most of the ships will visit on their route. When a port is selected to be a hub, this port will cover the whole amount of the demand for the other ports in the same area. In this thesis a hub will cover all neighbour ports which have no trade with each other, but were there is trade between this specific port in that area and the hub. To cover all demand in that area, a demand of a specific port should be allocated to a ship which will visit the specific port on his route. This means that at a hub all containers will be allocated to the ship which can handle the containers on their route, looking to which port these containers have to go. Because all or most of the ships will visit a port, it will be very active at a port which is selected as hub. In that way ports which will be selected as hub is supposed to be one of the biggest or main ports in his area. In this thesis, there will not be looked at the bigness of a port or the importantness of a port in his area. This is made as an assumption. In further research there can be looked if it is achievable to select a port as a hub or if it is profitable to expand a port, so it can cover the activeness of ships berthing, loading and exiting the port.

Big advantage of using a hub is that at every hub ships can be reloaded. The possibility of reloading will even have a bigger advantage in making a route network. Because there will be one or a couple of central points on every route where there is a possibility to reload the ships, containers can be allocated to ships which does not reach the container his destination. This will made the allocation problem a lot easier, because before visiting the hub the demand can be load on every ship which passes that port. When these ships visits the hub, than the containers can be unloaded and loaded to the ship which will visit the port of the containers destination on their route. This will be shown in the next example.

There are containers on a ship for Hong Kong, this ship will not visit Hong Kong on his route. It will be possible to unload these containers at a hub, in this case Singapore, and reload the containers on a ship, which visits Hong Kong. Because of the hubs there will come more possibilities to reload ships with the containers they can handle on their route. If there are two hubs, than there are two possible ports where ships can be reloaded with the containers for the ports they will visit after visiting the hub. For example, if there are two hubs, Singapore and Port Said, and containers for Rotterdam are loaded on a ship in Hong Kong which does not visit Rotterdam on his route. In that case, this ship will first visit Singapore where there is the possibility to reload these containers on a ship with Rotterdam as future destination. If that ship can not handle the containers at that moment, because he must use his total container capacity with containers for ports within Singapore and Port Said, they can give it a new shot to reload the containers at Port Said.

First action in using a port is to make as many direct routes between the hub(s) and one port with ships which are fully loaded. This concept is known as direct routing or direct connecting. If this is not possible any more, than there will be searched to a combination of a route between the hub(s) and two or more ports. The goal is to make ships visit the least as possible ports, while being maximal loaded, before visiting the next hub or coming back in the same hub. This will help in minimizing the costs, because there will be the least port visits as possible. In last case, it could be that there is demand left at every port which can be handled by one ship. This means that this ship will visit the hub(s) and all selected ports. To let a ship sail pass more than one ports besides the hub(s) on a route is a so-called Milk Run. This is defined as follows: **a routine trip involving stops at many places**. (according www.thefreedictionary.com)

Another advantage is that using hubs will have a positive effect on the total costs. Because containers can be allocated to every ship which visits the port, without eventually bringing the containers to his destination, it will have a positive effect on the number of routes, and thus the number of ships, in a route network which will decrease.

Now the advantages of using a hub in the route network been discussed, there has to be taken a look to the disadvantage a hub will have on the route network. Main disadvantage is that if a hub will be added to all routes in a route network some of the ships will visit the hub for nothing. If ships have no containers with the hub as it destination, there will be no unloading of containers. When there are also no containers from the hub to a port on the ship his route there also will be no loading of containers. Last possible action a ship can made at a port is transhipment. If a ship is already fully loaded with containers for the next port on his route, there is no need for a transhipment at the hub. In this case there will be made useless port charges, which will lower the actual profit.

In this thesis, there will be supposed that the advantages of using a hub will have bigger effect in increasing the profit than the effect the disadvantage will have in decreasing the profit. This means for the method of route planning that there will be made use of one or more hubs at every route. Because in this case some routes in the route network will have a useless visit to some hubs or ports, there will be looked if it is possible to eliminate a hub or a port visits on a route. A hub or a port can only be eliminated if no action is made when the ship visits the hub or port.

Like stated in the assumptions, a hub does not have to be one of the biggest ports in that region. If one of the smallest ports will be assigned to become a hub for a specific region, they can always do research about rebuilding the port to a bigger port, to check if it will become more profitable than when they does not rebuilt that port into a hub. For example, for Singapore this will not be a problem, like they are a 'natural' hub, which is already the busiest container port connecting with about 600 ports all over the world. But if Port Said will be assigned as hub, they will have to do some research to look if that is possible. Where Singapore has a container traffic of 27.932.000 TEU's in 2007 (see Wikipedia), the container traffic of Port Said is only eight percent of that number.

4.2 Travelling Salesman Problem (TSP)

One important component of the total costs which have to be minimized is the fuel costs. In order to make the fuel costs as least as possible, routes should be sailed in the shortest possible route. This means that the distance that every ship has to sail on a route should be minimized. This is a well know problem, called the Traveling Salesman Problem (TSP). The problem can be described as follows (Wolsey, 1998, page 7): **a salesman must visit each of *n* cities exactly ones and then return to his starting point. The goal then is to find the order in which he should make his tour so as to finish as quickly as possible.** This problem is generally regarded as one of the most notorious problems in Operations Research. The TSP is NP-hard and in general the (asymmetric) TSP formulation is as follows:

$$\min \sum_i \sum_j c_{i,j} x_{i,j}$$

$$s.t.$$

$$\sum_i x_{i,j} = 1 \;\; \forall\, j \in P$$

$$\sum_j x_{i,j} = 1 \;\; \forall\, i \in P$$

$$\sum_{i,j \in S} x_{i,j} \le |S| - 1 \;\forall\, S \not\subset P, |S| > 1$$

$$x_{i,j} \in \{0,1\},\ (i,j) \in A,$$

where i and j are elements from a set of selected ports (P), S is the union of sub tours and $|S| \le [n/2]$ and finally (i,j) is an element from a set of arcs (A).
c_{ij} = the costs for sailing between port i and port j, or the distance between port i till port j.
x_{ij} = 1 if het path from port i till port j is on this is not the case.

The optimizing of the TSP can be expressed in two terms. Minimize the total costs or minimize the total distance of a route. The total costs is equal to the fuel costs. For now it does not matter in which term we express the minimization, because when the distance are decreased the total costs on a route is decreased by the same proportion. In this case the problem is based on a set of distances between all ports which has to be visit on a route, were every port has to be visit only ones. So the ships are the salesmen, the ports are the costumers and the goal is to minimize the sailing distance of the ship for every route. In that way the duration of the routes will be minimized. Because the distance from port i to port j is the same as the distance the other way around, so from port j to port i, the TSP which is used here is called symmetric. The number of possible routes can be calculated by n! (were n is the number of ports).

TSP will handle the minimization of the route distance perfectly. For this thesis the TSP is implemented in a MATLAB function, but can also be handled by the mathematical program of AIMMS.

4.3 Travelling Salesman Problem algorithm

Although the selected ports in the examples are already been ordered at their geographical located place, there still is need to solve the TSP problem on the routes made. For example we have five ports, namely Port Said, Gioia Tauro, Antwerp, Rotterdam and Hamburg. Port Said is selected as the hub which handle all demand in this area. There is one ship which has to sail from Port Said to all of the other ports and then go back to Port Said. So the starting port and ending port is fixed. The distances between the ports are given in table 4.3.1 (Note the distance from Port Said to Antwerp from the example of Ka Wang Man is changed from 3279 to 3260 nautical miles. Thus this example will not hold in reality.).

table 4.3.1: Distances between the five ports in nautical miles.

from\to	Port Said	Gioia Tauro	Antwerp	Rotterdam	Hamburg
Port Said	0	951	3260	3274	3527
Gioia Tauro	951	0	2371	2378	2635
Antwerp	3260	2371	0	149	405
Rotterdam	3274	2378	149	0	305
Hamburg	3527	2635	405	305	0

If we make a route on geographical location, the route which should be sailed will be Port Said -> Gioia Tauro -> Antwerp -> Rotterdam -> Hamburg -> Port Said. This will also equals the route which will be found by the Nearest Neighbour algorithm which will be explained later on. The total distance this ship sails will be 7,303 nautical miles. However if we search for the shortest route out of all possible routes, the route which must be sailed would be Port Said -> Gioia Tauro -> Rotterdam -> Hamburg -> Antwerp -> Port Said. This route will have a total distance of 7,299 nautical miles. Which shows the need of TSP, because making a route ordered at geographical locations will not always result in the shortest route.

To handle with the TSP on the routes which is found, an algorithm must be used to solve the problem in which order the ship must sail visiting the ports on a route. First algorithm which is used for solving TSP is based on giving all possible combinations (the entire solution space) and determine for all combinations the total distance. The optimal route between the ports on a route can be found, because all possible routes were taken into account. The steps which will be used in this algorithm are described as follow:

Step 1 Make all possible route combinations (n!, with n is number of ports) which can be made by the n ports and set i = 1. Go to **Step 2**.

Step 2 For every possible route combination, determine the distance between port i and port i+1 and save these distances for every route. Set i = i+1 and if i is not equal to the last port, go back to the beginning of this step. If i is the last port, than go to **Step 3**.

Step 3 Take, for every route, the sum of all distances on a route. Now the total distances for every possible route combinations are known. Go to **Step 4**.

Step 4 Find the route combination with the smallest route and you have found the shortest possible route between the selected ports.

An example is made to explain how this algorithm works. There are three ports on a route, namely A, B and C. In the first step the possible combinations are made. There are six possible combinations {(A,B,C), (A,C,B), (B,A,C), (B,C,A), (C,A,B), (C,B,A)}. For all of these combinations the distance between the first two ports and the distance between the last two ports are taken together to determine the total distance. This will be done respectively in the second and third step. The last step will select the combination of how to sail on this route with the shortest distance.

Only remark of using this algorithm in MATLAB is that MATLAB has a limit in the number of ports on a route. This means that in some of the cases the entire solution space will become to big to handle from a certain number of possible solutions. The maximum number of ports on a route, for which this algorithm works in MATLAB, are eight ports. This will results in 8^8 routes, which will be eliminated by all useless routes. The 8! possible routes are left. Because this algorithm will not work for routes with more than eight ports, an existing approximative method, the Nearest Neighbour algorithm, will be used for solving the TSP. This method is based (see Wikipedia) on starting at a single port and then sail to the port which lays on the shortest distance from the original port, till the last port on a route is reached. For example, there are three ports A, B and C. If port is selected as starting port, than the distance between A and B and the distance between A and C will be determined. If the distance between A and C is shorter than between A and B, than the ship will first sail to port C. When the ship is at port C there is only one port left, so the ship sails to port B which is selected as the finale port.

Both these algorithms, depends on which one is used, will be executed before demand is assigned to a route in order that the container capacity of a ship will not be violated on that specific route, by changing the order of visiting the ports on the route. Because of the use of hubs

4.4 Set covering problem

Besides TSP there will be used an adjusted model of the set covering problem in this thesis. While the Travelling Salesman Problem generates the shortest routes in every possible port combination, the set covering problem will select out of all these possible routes the routes that are needed to optimize the route network. In this case a set of used routes which have the least number of port visits and the shortest distance if you count them all together.

The set covering problem can be described as follows (Wolsey, 1998, page 6): **given are a number of regions. Then it must be decided where to install a set of emergency service centers. The cost of installing a center are known. As well as which regions it can service. For example, a fire station can service those areas for which a fire engine is guaranteed to arrive within a legally prescribed number of minutes. The goal is to find a cost-minimizing set of service centers so that every region is covered.** In this case a hub is the fire station and the ports that will be covered by the hub are the places where fire is started. The set covering problem is also NP-hard like the TSP. A general formulation of the set covering problem is given as follows:

$$\min \sum_j c_j x_j$$

$$s.t.$$

$$\sum_j a_{i,j} x_j \geq 1 \quad \forall i \in F$$

$$x_j \in \{0,1\} \quad \forall j \in S,$$

where i is an element of places where fire starts (F) and j an element of fire stations (S).
c_j is the installation-costs for setting up a fire station.
a_{ij} is 1 if a fire on location i is covered by fire station j and 0 if this is not the case.
x_j is 1 if fire station j will be used and 0 if this fire station will not be used.

In this case, the set covering problem have to adjust in several ways. Big changes are:

- The description of i and j are changed. In this case i is an element of the set of ports (P) and j is a element of an set of possible routes (R).

- There is already one hub selected so x_j is not the use of a possible hub location but the ships which sails the possible route j.
- In stead of fire locations a_{ij} is now the route and which ports are covered on this route, given by 1 if this port is covered on the route and 0 if not.
- The costs are also different. The optimization in this case is now find a set of routes with minimal costs. So the costs are expressed as fuel costs, capital and operating costs and with all costs that are made in visiting a port (port charges and transportation costs) together.
- The first restriction will change from $\sum_j a_{ij} x_j \geq 1$ to $\sum_j a_{ij} x_j \geq d_i$, where d_i is the maximum of demand from the hub to port i and the supply from port i to the hub. This is expressed in a rate of shipload, so the maximum of demand and supply per port i divided by the shipload per ship.

After editing these changes, the following adjusted set covering problem can be formulated:

$$\min \sum_j c_j x_j$$

$$s.t.$$

$$\sum_j a_{i,j} x_j \geq d_i \quad \forall i \in P$$

$$x_j \geq 0 \quad \forall j \in R$$

This formulation will only work when there is no demand between the selected ports and when a hub has to be assigned to these ports. The total demand per port is defined by the maximum of the total incoming demand and the total outgoing demand in this specific port from the hub and all other ports outside the port selection. In the problem formulation, this is given by d_i. There should be made a note that in the rest of this chapter demand will have a different meaning than should be expected. Namely, when there will be spoken about demand this means: **the maximum number of incoming and outgoing containers (the demand) at a port**.

The problem formulation is first implemented in AIMMS, but in that case the A-matrix will get a different description. It will now longer be a matrix of zeros and ones, but the sum over the ports i should be equal to one. This will change the variable from a constant to a variable, with an own restriction, sum over i should be one. This will leave a very complicated model and that is why there is chosen to keep this A-matrix as a constant. This is done by dividing on each possible route with the numbers of ports which are covered on this route. For example, if there are two ports covered on a route, than the number at every covered port is ½. This will change the explanation of this constant into: **a_{ij} is one divided by the number of ports covered on route j if a port i is on route j and 0 if this is not the case**.

This change in the description of the A-matrix will give a solution but there can be say for sure that this solution is not optimal. For example, there are three ports which have to be covered, with demand rate respectively 0.8, 0.1 and 0.1.

Together these rates are equal to one, which means that this load can be covered by one ship. The answer we will get from the model implemented in AIMMS will be that it can only be covered by at least two ships dependent of the costs per route. This because if there are three ports covered on one route, than a ship can load only at most load of 0.333 demand from the demand rate at every port. The first port will than be stuck with still a demand rate of 0.467 which have to be covered by a ship which sails a route that only covers this port, while the other ports will only cover 10% from the whole ship capacity in stead of 33,3%. This means that there is 46,7% ship capacity unused, while a new ship must cover this percentage of unhandled demand. That is why the amount of demand that will be loaded on a ship at a specific port, must stay variable.

To take this dilemma into account, this adjusted set covering problem is implemented in a MATLAB function. First it will check how many routes can be used which sails only from a hub to one port and then go back. In that case the whole shipload will be used and the costs are minimized. This can be explained as follows, if there are two ports with a demand rate of 1, than it is the cheapest to sail two routes which both cover only one of the two ports directly than sailing twice the route which covers both ports at the same route. If there is still some demand left that can not cover a whole shipload the possibilities of combining port demands on one route will become the cheapest. In this case there will be looked first to combinations of two ports that can cover a whole shipload and if there are more probabilities, the cheapest route will be selected. This situation will go on till the total demand rate left is smaller than one. There will be used one route which will cover the demand that is left. This last ship will not use the fully shipload on his route, but all other ships will be using their full shipload. The algorithm implemented in MATLAB is the one which will be used in this thesis to make a good as possible route network. This algorithm will be explained in more detail in the next section.

Besides the dilemma with the A-matrix this problem can become also too big to implement in AIMMS, because there are 2^{n-1} (with n is the number of ports) possible port combinations. With a big amount of ports this will be very complicated to implement. You probably need already some programs like MATLAB or EXCEL. That is another reason why the algorithm is implemented in MATLAB.

The adjusted set covering model which will be implemented in MATLAB will only be used to generate routes between ports which has to be feed by a hub. This means that there are still ports left between the different regions without mutual trade. For example if there is no trade between the ports in Asia and no trade between ports in Europe, these contingents have to be feed by hubs. Between Asia and Europe there are a few ports in the Middle-East which have mutual trade with each other and trade with both other contingents. There has to be made two sets of one-way routes between Asia and Europe and the other way around. This will not be done according to the adjusted set covering model earlier described, but will be made by an algorithm. Again the two sets of one-way routes will be the same in both ways. The thought of this algorithm is that there will be first looked if all demand between Asia and Europe together with the mutual demand in the Middle-East and the demand between the Middle-East and the other contingents can be handled by the number of already used ships. This algorithm will start looking if all demand which is in the hub in Asia can be shipped to the ports in the Middle-East and the hub in Europe. This means that there will be direct routes between the hub in Asia and the hub in Europe together with some routes which will also visit one port between these hubs. Stepwise there will be looked at each port in the Middle-East if all demand at these ports can be handled by the routes made till that point. When there is mutual demand between two of the ports in the Middle-East, than there must be checked if one of the routes visiting the first port has empty container space left on their ship. If this is the case, that route will also visit the second port. If not all demand can be handled between these two ports, than there will be checked if there are more routes visiting the first port, which can cover the demand. Otherwise a new route must be made which will starts from the first port and sails to the second port and finally to the hub in Europe.

4.5 Set covering problem algorithm

In order to use the adjusted set covering problem, an algorithm must be implemented in MATLAB. The algorithm can be split up into two parts. The first part will handle the regions without mutual trade, according to this adjusted set covering problem. In the second part of the algorithm, regions with mutual trade will be handled, according to an approximative method. Because there are different regions, with and without mutual trade, in the examples that will be shown in chapter 5, this algorithm will handle the assigning problem in steps of small regions, from hub to hub. There will be made a set of routes in each of these regions. By extending the first set of routes with the second set of routes and so on, the actual set of routes, according the algorithm, will be found. The next 12 steps will be followed:

Step 1 Check for every port how many neighbour ports in a row he does not serve. Go to **Step 2**.

Step 2 Start at port i = 1 and go to **Step 3.**

Step 3 If port i is part of a group neighbour ports who does not serve each other, go to **Step 4**. If not, take the group of up following ports till next port which does not serve his next neighbours and go to **Step 8**.

Step 4 Execute the TSP algorithm for the shortest routes for every possible routes from a hub to a combination of ports and back to a hub. If one of the ports is or the first port started or the last port ending, than there is one hub, namely the first port outside this group of ports. If this is not the case, than there are two hubs, namely the first port in front of these group of ports and the first port after these group of ports. Go to **Step 5**.

Step 5 Make the supply and demand rate for every port. Meaning the total demand and total supply in this port dividing by the shipload that is fixed for every ship. Take the maximum rate of these two rates. Round all the maximum rates per port off downwards. These are the numbers of the direct routes from a hub till that specific port and back to a hub. Stop them in the route network. Go to **Step 6**.

Step 6 Set j at j = 1. Go to **Step 7**.

Step 7 All demand/supply that is left now is the rate minus the rate rounded off downwards. That means a number between zero and one. Take the sum of these rates. If you round this number off upwards, than you have got the number of routes have to be found. Find all combinations of j ports. Take the summation of the rates for each port belonging to these combinations. Check if these summated rates can be lower the total rate in a way that the total rate left rounded off upwards is one lower than it was. If there are possible routes left, than find the one with the lowest costs/distance and add this route to the route network. If there is still demand/supply left in some ports, do this step again. If there is no more possible route left and there is still some demand/supply left than set j = j+1 and do this step over. If no demand is left go to **Step 10** .

Short example for the steps 5 till 7:
The ship container capacity is 10 containers. If there are four ports, namely A, B, C and D, with no trade between these ports, having a maximum of incoming and outgoing demand of respectively 5, 10, 1 and 4. In the fifth step there will be determined a demand rate for every port. These are 0.5, 1, 0.1, 0.4. This means that there is a total demand rate of 2, which means that there are two ships needed to handle these demand. To minimize costs the idea is that there are two things which should be minimized, namely the distance and the number of port visits. In order to minimize the port visits we see that every port should only be visit once if you round up the demand rates at every port. If we look to the demand rate rounded off below there is only one port which can fill one whole ship. There is one ship with a route from the hub to port B and back to a hub. Only way to satisfy the restriction of only one port visit and to satisfy the number of ships stays two, the demand left should be handled by one ship. The second ship will sail a route between the hub(s) and port A, port C and port D. Which will be done in the seventh step. Then there is one thing left to do, namely minimizing the distance. For the first ship, this will not be a problem, because it consists only one port. The second ship consists three ports, and between these ports and the hub(s) the TSP algorithm will be solved to minimize the distance. This example has shown how the costs minimization works in such specific example.

Step 8 For every port take the maximum of supply and demand from every port to one of the other ports. Set k at k = 1. Go to **Step 9**.

Step 9 If k has passed the last port, go to **Step 10**. Till k has passed the last port, check for port k if containers can be unload. Check from the maximum in **Step 8**, if there are routes which visits the port where the demand is for, than check if all demand can be handled on these routes. If all demand can be handled, set k = k+1 and go back to the beginning of this step. If not check if there are routes which have some shipload left. If they can handle the demand left, than they will bring it with them to the next port, where they can check again if the demand can be added on a ship which visits the port the demand is for. If all demand is now handled, set k = k+1 and go back to the beginning of this step. If still not all demand is handled, than make a new route which will handle this demand to their ports. Now set k = k+1 and go back to the beginning of this step, to handle the next port.

Also the steps 8 and 9 will be illustrated by an example:
If there are two routes entering Singapore (which is the hub in Asia) and two routes entering Gioia Tauro (which is the hub in Asia). Between these ports are two ports (Jebel Ali and Port Said) with mutual trade. The demand between Asia and Europe will be 14 containers while the incoming and outgoing demand to Jebel Ali and to Port said is both 2 containers. Between Jebel Ali and Port Said there is a demand of 1 container. The ship container capacity will be again 10 containers. In Singapore there will be checked if the demand to Jebel Ali, Port Said and Gioia Tauro can be handled by the two existing routes. To cover the respectively 2, 2 and 16 containers with these two routes starting in Singapore, the first route will sail from Singapore to Jebel Ali and then to Gioia Tauro. The second route will sail from Singapore to Port Said and then to Gioia Tauro. The demand will be allocated as follows, both ships will sail 7 containers from Singapore to Gioia Tauro on their route. Respectively the first and the second route will sail 2 containers from Singapore to respectively Jebel Ali and Port Said. At Jebel Ali the 2 containers will be unloaded which reached their destination and 2 containers will be loaded to sail to Gioia Tauro. There is also 1 container which must sail to Port Said. There is capacity left on the ship, because the container capacity is 10 while the ship is filled by 9 containers, which means that this ship will cover this container and makes a visit to Port Said. At Port Said again all containers will be checked which will be loaded and unloaded. Because it is the last port before the hub Gioia Tauro, there will not be looked to demand between other ports in the Middle-East any more. Now there are two one-way routes, namely Singapore -> Jebel Ali -> Port Said -> Gioia Tauro and Singapore -> Port Said -> Gioia Tauro. When the demand must sailed back from Europe (Gioia Tauro) to Asia (Singapore) these same routs will be sailed the other way around. The demand will be allocated as follows. The ship sailing the first route will take 7 containers for Singapore and 2 containers for Jebel Ali. When this ship visits Port Said, it will be loaded by the container from Port Said to Jebel Ali. At Jebel Ali there will be loaded and unloaded 2 containers from Gioia Tauro and to Singapore and there will be unloaded 1 container from Port Said. The second route will take 7 containers from Gioia Taura to Singapore and 2 containers to Port Said. At Port Said there will be loaded and unloaded 2 containers from Gioia Tauro and to Singapore. This shows that the one-way route can be sailed in both ways to cover all demand.

Step 10 Put the new set of routes at the end of the existing network of routes. If the group of ports includes the last port of the set of ports, than go to **Step 11**. If not, set i on the number of the last hub or the last port of the group and go back to **Step 3**.

Step 11 If the first port or hub in this route network is not the same as the last port or hub, than copy the route between these ports the other way around. Else go to **Step 12**.

Step 12 Determine all costs (fuel costs, capital and operating costs, port charges and transhipment costs)**.** Lower the revenue with these costs to determine the profit.

4.6 Allocation method

Last question is how to allocate the containers over the ships in a way that all demand will be satisfied. The optimal solution can only be reached by a complicated Linear Programming problem, which can be handled by the software AIMMS. But because it is to complicated to formulate such a problem description and because of the lack of time, there is been decided to make use of approximative methods which will solve this problem in a close to optimal way. This paragraph will discuss two methods, in which this problem is been split up in this thesis.

4.6.1 First method

This method will be used in the algorithm to solve set covering problem for generating the routes and will go as follows. Stepwise there will be looked at all supply and demand between two hubs. Ships will sail between these hubs and if a ship visits one of these ports, the supply left at this port will be loaded on these ships no matter if the destination of the supply is on the route or not. Because ports will always be visited by enough ships, all supply will be handled. When all ships are at the second hub (the last port in the group of ports) there will be looked to the destination of all supply in such a way that all supply will be reloaded to a ship which will visit this destination.

While using hubs all supply can be loaded on the ships passing the ports, before visiting the hub. When these ships are at the hub, they will be reloaded with supply with a destination which is on their route. There is only one remark: **all ships has to be at the same time at the port when they are being reloaded**. In this thesis the assumption is been made that ships are at the same time at a hub to reload all ships at once. It can be something to check in further research. There is already a method discussed in an earlier research paper (Lagoudis, Litinas en Fragos, 2006) for container fleet sizes on a route network.

The reloading process at a hub will be shown in the next example. There are five ports covered by two routes, namely {1,2,3,4,5}. The port in the middle of these

group of ports is selected as the hub. The container capacity of the ships are ten containers. The first two port will supply the last three ports from containers. The demand is given as follows:
- Eight containers must be shipped from port 1 to port 5 and two containers from port 1 to port 3.
- Seven containers must be shipped from port 2 to port 4 and three containers from port 1 to port 3.

There are two routes, namely 1 -> 3 -> 4 and 2 -> 3 -> 5. Both routes will start fully loaded from respectively from port 1 and port 2. When they enter the hub (port 3) there will be respectively two and three containers unloaded from the ships which stays at the hub. The ship on the first route has now eight containers to port 5 left, while this port is not on his route. Also at the second route there is some demand that will not be satisfied. The containers left at both ships will be reloaded to the other ship. In that case all demand can be satisfied.

There is one remark to this first method. This method will be used in the set covering algorithm, but there will not be looked at which containers are loaded on which ship. There will only be looked if all containers can be loaded on the number of ships which will visit this port. The percentage of used shipload will not be showed anywhere. This will be analysed by using the second method, which will be used after a set of route is generated.

4.6.2 Second method

After all routes are generated we need a method which can also show the results of used ship capacity per route. This will be done by starting at the first hub looking to all containers that have reached their final destination and all containers which has to be loaded on ships from this port to ports further on the route. This works as follows:

Step 1 Set i = 1. Meaning we are handling the first port on the whole route.

Step 2 Check if a ship has any containers on board left. If not, go to **Step 4**. Otherwise, go further to **Step 3**.

Step 3 Unload all containers with the destination to this port. If this is done, go to **Step 4**.

Step 4 Set j = (original port number + 1).

Step 5 Take the number of containers which have to be sailed from the original port to port j and select all routes which will visit port j.

Step 6 Sort the routes on the number of ports they will visit between the original port and port j. In this case the first route will be the route with the least ports between his origin and destination. Go past all these routes and fill every routes with containers till the ship capacity is reached or all containers loaded on ships.

If the ships capacity on a route is totally filled, than go to the next route. If all containers are loaded on these routes and if j equals the last port on the whole route, than go to **Step 2** with i = i+1. If j is not the last port of the whole route, than set j = j+1 and go to **Step 5**. If there is still demand left go to **Step 7**.

Step 7 Select all routes which will not visit port j on their route and which will visit a port between the original port and port j. Sort these routes on free capacity left and start filling these ships beginning at the ship with the most free capacity. Again go to the next route if a ship is totally filled and stop when all capacity is loaded on ships. If there is no free capacity on ships left while there still are some containers left, these containers will not be handled. If j equals the last port of the whole route, set i = i+1. If i equals the last port of the whole route, than **STOP**. If j equals the last port, but i does not equals the last port, than go to **Step 2**. If j not equals the last port, than go back to **Step 5** and take j = j+1.

Using this method, there will be found a set of ship capacity for every route, while they leave a port. Also the profits will be given per route. This will be given by the total revenue minus the amount of port charges on this route minus the fuel costs minus the capital and operating costs minus the transhipment costs. Because these costs will be determined per route, there is only one problem with the revenue for containers which are transhipped. If a container is shipped by two or more ships, how will the revenue will be split up. The problem of splitting up the revenue over the ships which handle the same container is something for further research which is more an economical issue. In this thesis the revenue will not be split up over the ships, but a ship gets the full revenue for every container loaded on board of that ship.

4.7 Improvements

The starting set of routes found by using the algorithms described in the paragraphs 4.2 till 4.5 is still not optimal, because the methods used are only searching for a close to optimal solution. In this paragraph a method will be discussed which will search a solution in the neighbour of the starting point, which will go as follows:

Step 1 Set i = 1, which means the first route in the set of routes.

Step 2 Set j = 1, which means the first port on route i.

Step 3 If port j is on route i, than skip port j from the original route. Otherwise add port j on the original route. Determine the profit using the second allocation method in paragraph 4.6.2. Save the total profit. If j equals the last port go to **Step 4**. Otherwise set j = j+1 and start **Step 3** again.

Step 4 There are now j different profits. Select the j^{th} profit, which is the highest total profit as long as this is higher than the original profit. If the total profit is higher, than change the original route by skipping or adding the j^{th} port from or on the route. If i equals the last route of the set and the total profit before the first route is the same as the total profit at the last route, than **STOP**. If there is still some change in the total profit, than set i = 1 and go back to **Step 2**. If i does not equals the last route, set i = i+1 and go back to **Step 2**.

This method can be described as a Genetic Algorithm which is formulated as follows: **a randomised search method based on a binary encoding which creates new solutions by mutation and combination**. In this case the algorithm will only make use of mutation. Routes will be changed by skipping or adding a port from or on a route. This means that a route is a vector of zeros and ones where a zero means that port i (for i = {1,…,n}, with n is the total number of ports) is not on the route and one if port i is on the route. The algorithm described above will check if changing zeros into ones or ones into zeros will lead to higher profits. It will only check one change at a time, which results in close neighbour solutions.

There is one remark to the method used in this thesis. It will only accepts improvements in total profit and will not accept a decrease in total profit. The given solution does not necessarily have to be the optimal solution, but can be a local optimal. This will be the result of using mutation in the algorithm. While mutation will only look to close neighbour solutions, which mostly results in a local optimum, there can also be made use of combination. For example, there will be made two set of routes, existing of 100 routes, which will be combined. From these 200 routes, the best routes will be selected into a new set of routes, which results in the best possible outcome. This method could help the algorithm to avoid getting stuck in a local optimum. When combination have found a new set of routes, there can be looked by mutation for a set of routes, in the neighbour of the new set of routes, with a better solution. However the algorithm used in this thesis will only use mutation, it is an idea for further research to use an algorithm which combines the mutation and combination methods.

5 Examples

The goal of this chapter is to show how the methods work and what their results will be. In the first paragraph, the methods from this thesis will be compared with the method used in a former thesis by Ka Wang Man. His example will be used to compare the results. After discussing the differences in results, the methods from this thesis will also used on an own made example in paragraph 5.2. Because it is a new example, the results can not be compared with any other method. That is why the algorithm from paragraph 4.7 is made, which will try to improve the route network that was found by the methods in this thesis.

5.1 Example Ka Wang Man

A few years ago (2007) Ka Wang Man has written a thesis about the same problem. He has found an algorithm to make routes from east to west (Asia-Europe) and the way back from west to east (Europe-Asia) with only one hub in Singapore. The ports in table 5.1.1 are used in his example.

Table 5.1.1: Ports used in Ka Wang Man his example and their numbering.

Number	Port (Short name, Region)
1	Tokyo (TO, Asia)
2	Shanghai (SH, Asia)
3	Hong Kong (HK, Asia)
4	Singapore (SI, Asia)
5	Jebel Ali (JA, the Middle East)
6	Port Said (PS, the Middle East)
7	Gioia Tauro (GT, Europe)
8	Antwerp (AN, Europe)
9	Rotterdam (RO, Europe)
10	Hamburg (HA, Europe)

Between all of these ports he made a O/D Matrix which shows the trade of containers between two ports over a whole year. This O/D Matrix was hand made and not based on any real data. All numbers in the O/D Matrix are in 1,000 TEU's. The O/DMatrix is given in table 5.1.2.

Table 5.1.2: O/D Matrix, demand in 1,000 TEU's

O/D	TO	SH	HK	SI	JA	PS	GT	AN	RO	HA	Total Supply
TO	0	0	0	87	23	11	185	100	223	138	767
SH	0	0	0	92	18	16	211	151	631	364	1483
HK	0	0	0	80	20	14	194	116	312	185	921
SI	118	131	75	0	24	10	420	149	358	277	1562
JA	42	28	36	21	0	0	59	46	51	39	322
PS	34	45	24	18	0	0	64	38	40	24	287
GT	98	168	18	28	9	12	0	0	0	0	333
AN	102	132	113	72	0	10	0	0	0	0	429
RO	110	501	175	155	8	13	0	0	0	0	962
HA	98	280	164	123	3	12	0	0	0	0	680
Total Demand	602	1285	605	676	105	98	1133	600	1615	1027	7746

In making his O/D Matrix, Ka Wang Man made the assumption that there is no trade between ports in the same region. Only exception is that Singapore has trade with all other ports. He has assigned Singapore as hub, which will be passed by every ship on his route. This choice is already made before he used his method to find a staring set of routes.

In the O/D Matrix in table 5.1.2 can be seen that not only the Asian part of the route can form a hub, but also in Europe is no trade between the European ports. The first port which receives any import out of Europe is Port Said. The same way as Singapore is signed as a hub for Asia, can Port Said be signed as a hub for Europe. Unlike Ka Wang Man made his choice to assign a hub before he used his method, the choice of assigning a hub to the route will be made by the algorithm in our case. Although the choice for assigning Port Said as a hub for Europe will maybe not a logical choice, because the port is not as big as Singapore, in this example the choice is made based on the trade in this specific example.

Before using the algorithm there have been made some assumptions which have to be specified. The maximum container capacity on a ship is set on 10,000 TEU's. Because Ka Wang Man made his OD-Matrix based on a whole year, the container capacity will be set on 520,000 TEU's. The speed in which the ships will sail is set on 28 nautical miles per hour. And finally the time a ship stays at a port is set on one day (24 hours).

The algorithms described in paragraph 4.2 to 4.5 have resulted in the following set of routes that are shown in table 5.1.3.

Table 5.1.3: Set of routes found by the algorithms in this thesis. The routes are numbered from 1 till 9. All ports on the route are ordered alphabetically from A till I. Port A will be visit first, port B will be next and so on.

Route	Ports on route
1	SI -> TO -> SI -> JA ->PS -> GT -> PS -> JA -> SI
2	SI -> SH -> SI -> PS -> GT -> PS -> SI
3	SI -> SH -> SI -> PS -> AN -> PS -> SI
4	SI -> HK -> SI -> PS -> RO -> PS -> SI
5	SI -> HK -> SI -> PS -> RO -> PS -> SI
6	SI -> SH -> SI -> PS -> RO -> PS -> SI
7	SI -> TO -> SI -> PS -> HA -> PS -> SI
8	SI -> PS -> HA -> PS -> SI
9	PS -> GT -> AN -> RO -> PS

First thing to notice is that the algorithm has decided that both Singapore and Port Said will be selected as hub for respectively the ports in Asia and the ports in Europe. In the ninth route, we will see that Singapore will not be reached, this because the total numbers of containers which sails through Port Said must be covered by nine ships, while the number of containers which sails through Singapore can be covered by eight ships. In that way it is logical that Singapore will not be reached by this ninth route, because it would lead to a useless visit where nothing happens.

There are two routes which are the same. This can be explained by the choice of making as many routes for a hub which only have to go to one port and then go back to the hub. Because in this case the Asian hub is coupled to the European hub with only one port between, which only have to be visit once, there is not many variety between the routes from hub to hub. There is already an improvement in the number of routes by one route less than Ka Wang Man. The use of one ship less, will decrease the capital and operating costs.

Furthermore the total port visits on all routes together are 52 port visits (Note that the last port on a route equals the first ports on the route, which must be count as one visit). This are 28 port visits less than the 80 port visits will take place in the starting set of routes from Ka Wang Man his method.

As told before all distances were been calculate by www.searates.com. The distances and the number of weeks a ship must sail has been decreased on most routes than in Ka Wang Man results. The result can be found in table 5.1.4.

Table 5.1.4: For each route the total distance is been determined together with the number of weeks, this route will sail with a speed of 28 nautical miles per hour.

Route	Distance	Number of Weeks
1	20424	6
2	16408	5
3	21064	6
4	19500	6
5	19500	6
6	21054	6
7	22894	6
8	17086	5
9	6745	3

Just like in Ka Wang Man result, the routes are almost of the same length and six routes will take the same number of weeks, namely six. Two routes will sail in a week less, and only one route has a duration of three weeks. If we count the number of weeks the ships are on every route, this also denote the number of ships have to be used in this route network. The number of ships are 49 which are 13 less than in Ka Wang Man's results. Because both the distance as the number of weeks is decreased with the results of Ka Wang Man, both the fuel costs as the capital and operating costs.

The information about the cost are given in table 5.1.5, followed by some general information about this route network in table 5.1.6.

Table 5.1.5: Description about the revenue and costs, together with the amount in US dollars ($).

Revenue and cost description	$
Revenues per TEU transported	$ 500
Capital and operating costs per ship per year	$ 18,000,000
Fuel costs per nautical mile	$ 100
Port charges per port	$ 200,000
Transshipment costs per handling	$ 100,000

Table 5.1.6: Description about the revenue and costs, together with their amount.

Description	amount
Number of TEU transported per year	7,746,000
Number of ships per year	49
Total amount of nautical miles travelled	8,563,100
Number of times per year ports are visit	2704
Number of transhipment handlings per year	1664

As result of these numbers we can look to the actual revenue, costs and profit made by this algorithm, which are given in table 5.1.7.

Table 5.1.7: Total revenue, costs and profit in US dollars ($).

Total revenue	$ 3,873,000,000
Total capital and operating costs	$ 882,000,000
Total fuel costs	$ 856,310,000
Total port charges	$ 540,800,000
Total transshipment costs	$ 166,400,000
Total costs	$ 2,445,510,000
Total profit	$ 1,427,490,000

There can be seen that the total profit, that will results in using the set of routes in the algorithm used in this thesis, are $ 1,427,490,000. This total profit has more than doubled (almost tripled) the total profit found by Ka Wang Man, which were $ 521,101,200.

With the second allocation method in paragraph 4.6.2, a schedule is made of how much ship capacity is in use when a ship sails past or through a port. Because we now know how many containers are handled by each single route in the set of routes, there can be looked if each route by itself will gain profits or losses. This is shown in table 5.1.8.

Table 5.1.8: Profit (in US $) and effectiveness per route.

Route	Profit	Route effective?
1	$ 354,695,200	Yes
2	$ 576,628,400	Yes
3	$ 468,167,200	Yes
4	$ 645,800,000	Yes
5	$ 251,050,000	Yes
6	$ 84,219,200	Yes
7	$ 340,151,200	Yes
8	- $ 13,647,200	No
9	- $ 131,474,000	No

There should be kept in mind that the sum of these single profits will not equals the total profit of table 5.1.7, because a route gets always $ 500 revenue when they handle a container, no matter if a container will be handled by two or more routes.

The two smaller routes 8 and 9 both have a negative effect on the total profits. Especially the last route, which will only ship 4,000 containers, from the 520,000 containers ship capacity, to their destination. Route 8 will almost sail the whole route half empty. This will ask for a further research to make these routes more effective and at least to make them break even. Because of that, there will be searched for a set of routes which will results in even more profit, taking the set of routes in table 5.1.3 as starting point. The algorithm from 4.7 is been used with the set of routes from table 5.1.3 and have resulted in set of routes shown in table 5.1.9.

Table 5.1.9: Set of routes found by the algorithms in this thesis. The routes are numbered from 1 till 9. All ports on the route are ordered alphabetically from A till G. Port A will be visit first, port B will be next and so on.

Route	Ports on route
1	SI -> TO -> SI -> JA -> PS -> JA -> SI
2	SI -> SH -> GT -> SI
3	SI -> SH -> PS -> GT -> SI
4	SI -> HK -> PS -> RO -> SI
5	SI -> HK -> SI -> PS -> RO -> SI
6	SI -> SH -> SI -> PS -> SI
7	SI -> TO -> SI -> PS -> HA -> SI
8	SI -> PS -> SI
9	PS -> GT -> AN

There can already been seen that most routes have lost a few ports on their routes, which directly leads to a decrease of port charges. But to make sure that these route is improved, the total profit will be split up for each of these single routes. These profits, together with the effectiveness of the route, is shown in table 5.1.10

Table 5.1.10: Profit (in US $) and effectiveness per route.

Route	Profit	Route effective?
1	$ 428,785,600	Yes
2	$ 472,466,000	Yes
3	$ 652,108,800	Yes
4	$ 689,385,600	Yes
5	$ 589,254,400	Yes
6	$ 388,968,800	Yes
7	$ 787,461,600	Yes
8	$ 157,133,600	Yes
9	$ 358,525,600	Yes

In the new set of routes, none of the routes will have a negative effect on the total costs. This means that all routes will gain profit. If we look to the percentage of used ship capacity, there can be seen that all routes are almost the whole route filled with more than half of the ships capacity and are now at least once totally filled with containers.

The results of the new set of routes can be showed in table 5.1.11 and 5.1.12.

Table 5.1.11: Description about the revenue and costs, together with their amount.

Description	amount
Number of TEU transported per year	6,920,000
Number of ships per year	41
Total amount of nautical miles travelled	7,549,100
Number of times per year ports are visit	1872
Number of transhipment handlings per year	1040

Table 5.1.12: Total revenue, costs and profit in US dollars ($).

Total revenue	$ 3,460,000,000
Total capital and operating costs	$ 738,000,000
Total fuel costs	$ 754,910,000
Total port charges	$ 374,400,000
Total transshipment costs	$ 104,400,000
Total costs	$ 1,971,710,000
Total profit	$ 1,488,290,000

While the first set of routes will handle all supply and demand, this new set of routes will only handle 6,920,000 containers per year. This means that 826,000 containers are not handled which will lower the total revenue. At the other hand, all cost are lowered too. There are less ports on each route, which will lead to a smaller distance these ships have to sail. This also will effect the number of ships needed, because ships will take less time to make there round trip. Eventually the total profit will only increase by a small amount. In this case the algorithm from paragraph 4.7 is not that effective, what can be explained that this could be not an optimal solution, but a local optimum.

There is a remark on the solution found by the algorithm from paragraph 4.7. If the last two routes from the starting set of routes are skipped, there will be found a solution which results in a higher profit. This could be explained that the algorithm from paragraph 4.7 will only take small steps of changing one port on a route.

5.2 Own example

A method could work well for one example, but this doesn't mean directly that a method will work in all cases. Because this method is based on creating hubs, an example should have regions without any mutual trade. If there is an example with none of such regions, this method will not give a good solution at all.

In the example of Ka Wang Man there were two ports which were assigned as hubs in their region. There is now made an example with the possibility of assigning four ports as hubs. Still the O/D Matrix is not based on reality. Another change that is made in the example differencing from the previous example is that there is made a bigger region with mutual trade between two hubs. In stead of three ports, there is now a region existing of four ports. The O/D Matrix is given in the next table.

Table 5.2.1: O/D Matrix, demand in 1,000 TEU's, together with the numbered ports used in this example.

O/D	TO	SH	HK	SI	PK	CO	NS	JA	JE	PS	IS	GT	VA	LH	SO	AN	RO	HA
Tokyo	0	0	0	87	64	43	26	23	68	11	13	185	124	92	87	100	223	138
Shanghai	0	0	0	92	75	22	28	18	91	16	18	211	195	100	91	151	631	364
Hong Kong	0	0	0	80	58	27	18	20	87	14	26	194	98	84	62	116	312	185
Singapore	151	184	75	0	0	35	25	24	109	10	33	420	207	126	102	149	358	277
Port Klang	118	133	64	0	0	10	22	16	46	5	29	238	137	22	83	99	196	86
Colombo	64	89	34	26	20	0	8	9	12	7	18	224	87	48	67	73	104	73
Nhava Sheva	37	44	23	34	16	9	0	0	0	3	22	167	62	39	36	45	88	102
Jebel Ali	42	28	36	21	19	20	0	0	0	5	17	59	43	23	44	46	51	39
Jeddah	191	128	101	67	54	1	0	0	0	2	9	112	51	64	79	62	90	66
Port Said	34	45	24	18	13	5	8	7	12	0	3	64	37	12	22	38	40	24
Istanbul	55	67	38	40	44	15	13	17	19	4	0	23	18	14	32	22	13	9
Gioia Taura	98	168	18	28	69	22	14	9	36	12	3	0	7	11	19	17	23	9
Valencia	87	238	94	84	87	16	19	11	37	13	4	2	0	6	8	3	10	4
Le Havre	93	174	77	83	139	31	23	7	59	9	8	11	12	0	0	0	0	0
Southampton	123	138	103	119	126	12	12	3	111	11	11	8	3	0	0	0	0	0
Antwerp	102	132	113	72	141	7	18	0	63	10	19	18	11	0	0	0	0	0
Rotterdam	110	501	175	155	116	19	29	8	76	13	14	16	19	0	0	0	0	0
Hamburg	98	280	164	123	133	26	16	3	62	12	9	4	10	0	0	0	0	0

As can been seen in this example, probably Singapore, Colombo, Port Said and Valencia will be assigned as hubs. The total number of TEU´s that can be transported in this example will equals 17,717,000.

The algorithm has found the set of routes given by table 5.2.2.

Table 5.2.2: Set of routes found by the algorithms in this thesis. The routes are numbered from 1 till 18. All ports on the route are ordered alphabetically from A till S. Port A will be visit first, port B will be next and so on.

Route	Ports on route
1	SI – TO – SI – PK – CO – NS – PS – IS – GT – VA – LH – VA – GT – IS – PS – NS – CO – PK – SI
2	SI – TO – SI – CO – JE – PS – IS – GT – VA – SO – VA – GT – IS – PS – JE – CO – SI
3	SI – SH – SI – CO – NS – JA – JE – PS – GT – VA – AN – VA – GT – PS – JE – JA – NS – CO – SI
4	SI – SH – SI – CO – PS – GT – VA – RO – VA – GT – PS – CO – SI
5	SI – SH – SI – CO – PS – GT – VA – RO – VA – GT – PS – CO – SI
6	SI – SH – SI – CO – PS – VA – RO – VA – PS – CO – SI
7	SI – HK – SI – CO – PS – VA – RO – VA – PS – CO – SI
8	SI – HK – SI – CO – PS – VA – HA – VA – PS – CO – SI
9	SI – TO – SI – CO – PS – VA – HA – VA – PS – CO – SI
10	SI – SH – SI – CO – PS – VA – SO – VA – PS – CO – SI
11	SI – HK – SI – PK – CO – PS – IS – VA – LH – VA – IS – PS – CO – PK – SI
12	SI – PK – CO – PS – IS – GT – VA – AN – VA – GT – IS – PS – CO – PK – SI
13	SI – PK – CO – PS – VA – RO – VA – PS – CO – PK – SI
14	PK – CO – PS – VA – HA – VA – PS – CO – PK
15	PK – CO – PS – VA – PS – CO – PK
16	PS – VA – PS
17	PS – IS – GT – VA – GT – IS – PS
18	IS – GT – VA – GT – IS

We see a lot of fluctuations in number of ports been visit on the 18 routes. This results in the following distances and weeks that ships has to sail on every route.

Table 5.2.3: For each route the total distance is been determined together with the number of weeks, this route will sail with a speed of 28 nautical miles per hour.

Route	Distance	Weeks	Route	Distance	Weeks
1	24686	8	10	20778	5
2	23762	8	11	20716	5
3	24176	8	12	18324	6
4	21276	7	13	16918	5
5	21276	7	14	17018	4
6	21180	7	15	13050	4
7	19730	6	16	3328	2
8	20226	6	17	4748	3
9	23218	5	18	3158	2

The information about the cost are given in table 5.2.4, followed by some general information about this set of routes in table 5.2.5.

Table 5.2.4: Description about the revenue and costs, together with the amount in US dollars ($).

Revenue and cost description	$
Revenues per TEU transported	$500
Capital and operating costs per ship per year	$18,000,000
Fuel costs per nautical mile	$100
Port charges per port	$200,000
Transshipment costs per handling	$100,000

Table 5.2.5: Description about the revenue and costs, together with their amount.

Description	amount
Number of TEU transported per year	17.717,000
Number of ships per year	106
Total amount of nautical miles travelled	16,513,536
Number of times per year ports are visit	9828
Number of transhipment handlings per year	6136

These results will lead to the revenues, costs and profits given by table 5.2.6.

Table 5.2.6: Total revenue, costs and profit in US dollars ($).

Total revenue	$ 8,858,500,000
Total capital and operating costs	$ 1,908,000,000
Total fuel costs	$ 1,651,353,600
Total port charges	$ 1,965,600,000
Total transshipment costs	$ 613,600,000
Total costs	$ 6,138,553,600
Total profit	$ 2,719,946,400

More than 1/3 of the total revenues will be kept as profit. Because this is a new made example, this result can not be compared with the method of Ka Wang Man. There can only be looked if the algorithm from paragraph 4.7 can improve these results. Table 5.2.7 will show the profits per route how it is now.

Table 5.2.7: Profit (in US $) and effectiveness per route.

Route	Profit	Effective?	Route	Profit	Effective?
1	$ 642,932,800	Yes	10	$ 476,454,400	Yes
2	$ 753,037,600	Yes	11	$ 355,176,800	Yes
3	$ 837,084,800	Yes	12	$ 160,315,200	Yes
4	$ 578,064,800	Yes	13	$ 113,726,400	Yes
5	$ 201,064,800	Yes	14	$ 312,906,400	Yes
6	$ 537,364,000	Yes	15	- $ 76,460,000	No
7	$ 743,904,000	Yes	16	- $ 76,905,600	No
8	$ 560,824,800	Yes	17	-$ 139,389,600	No
9	$ 520,266,400	Yes	18	- $ 86,421,600	No

Just like in the example of Ka Wang Man's, the smallest routes, from the set of routes found by the algorithms discussed in paragraph 4.2 to 4.5, have a negative effect on the total profit. According to the allocation schedule, the last three routes are not used to ship containers. This means that they will only cost money while they are not gaining revenues. Route 15 is only filled up at most by 36 % of the ship capacity on this route. Some other point to mention is that not all containers are handled. There are 438,000 containers that stay at there original place and will not reach there destination.

Now there will be looked to the algorithm from paragraph 4.7 if the routes can be improved to a set of routes where all routes are profitable. The new set of routes that is found is shown in table 5.2.8.

Table 5.2.8: Set of routes found by the algorithms in this thesis. The routes are numbered from 1 till 15. All ports on the route are ordered alphabetically from A till M. Port A will be visit first, port B will be next and so on.

Route	Ports on route
1	SI - TO - CO - NS - PS - IS - VA - LH - IS - PS - NS - CO - SI
2	SI - TO - SI - CO - JE - PS - IS - VA - SO - GT - JE - CO - SI
3	SI - SH - SI - CO - NS - JA - PS - GT - PS - JE - JA - CO - SI
4	SI - SH - GT - VA - RO - VA - PS - CO - SI
5	SI - SH - SI - CO - PS - VA - GT - PS - CO - SI
6	SI - SH - SI - CO -PS - VA- SI
7	SI - HK - SI - PS - VA - SI
8	SI - HK - SI - CO - PS - VA - HA - PS - SI
9	SI - TO - SI - CO - PS - VA - SI
10	SI - SH - SI - CO - PS - VA - SI
11	SI - PK - CO - PS - VA - LH - IS - SI
12	PS - IS - GT - VA - AN - VA - GT - IS
13	PK - PS - VA - RO - VA - PS - CO - SI
14	CO - PS - VA - PS
15	PK - PS - CO - PK

First thing to notice is that there are three routes missing. The last three routes of the starting set of routes are skipped, what is logical because they do not handle any containers. Furthermore, all routes have been decreased in the number of ports on their route.

This new set of routes will give the results given by table 5.2.9 and table 5.2.10.

Table 5.2.9: Description about the revenue and costs, together with their amount.

Description	amount
Number of TEU transported per year	16,329,000
Number of ships per year	82
Total amount of nautical miles travelled	13,497,328
Number of times per year ports are visit	6552
Number of transhipment handlings per year	4368

Table 5.2.10: Total revenue, costs and profit in US dollars ($).

Total revenue	$ 8,164,500,000
Total capital and operating costs	$ 1,476,000,000
Total fuel costs	$ 1,349,732,800
Total port charges	$ 1,310,400,000
Total transshipment costs	$ 436,800,000
Total costs	$ 4,572,932,800
Total profit	$ 3,591,567,200

While in the example of Ka Wang Man the algorithm of paragraph 4.7 does not change the total profit that much, this time the total profit has increased by more than 30 %. Which means that this is a really effective change. While again the number of unhandled containers has grown to 1,826,000 containers, this time the decrease of total revenues will be overshadowed by the decrease of the total costs. Looking to the percentage of used ship capacity, there can be concluded that ships are filled almost the whole route by more than half their capacity. The total profits per route are now given by table 5.2.11.

Table 5.2.11: Profit (in US $) and effectiveness per route.

Route	Profit	Effective?	Route	Profit	Effective?
1	$ 1,605,500,000	Yes	9	$ 796,290,000	Yes
2	$ 1,106,300,000	Yes	10	$ 805,810,000	Yes
3	$ 809,490,000	Yes	11	$ 748,230,000	Yes
4	$ 1,084,700,000	Yes	12	$ 678,100,000	Yes
5	$ 1,261,000,000	Yes	13	$ 456,620,000	Yes
6	$ 1,037,300,000	Yes	14	$ 562,290,000	Yes
7	$ 1,158,000,000	Yes	15	$ 281,820,000	Yes
8	$ 963,430,000	Yes			

As shown in table 5.2.11, all routes have a positive effect on the total profit. This means that skipping one of these routes, the total profit will decrease. If we compare these profits per route together with the same profits each route had in the situation of the starting set of routes in table 5.2.7, that the profits of almost all routes are increased in the new set of routes.

6 Conclusion

Now all algorithms are tested with two examples and one been compared with an earlier study, there can be made some conclusions about the methods used in this thesis. The main goal of this thesis is to solve the route scheduling problem for the trading line between Europe, the Middle-East and Asia. There have been a few points to deal with in finding a method which makes a set of routes that will handle the trade on this line in a profitable way. All these points will be discussed in this chapter.

Earlier studies have shown that it is best to avoid complexity in solving the main goal of route planning. This means that the total costs does not have to exist out off too much components. The total costs in this thesis are split up in capital and operating costs, fuel costs, port charges and transhipment costs. All these costs must be tried to minimized in such a way that these costs together will reach a minimum. First of all the fuel costs can be minimized by minimizing the distance a ship must sail on his route. This can by achieved by solving a Travelling Salesman Problem for each route. There is only one problem in finding the optimal route (in MATLAB code) which is that there is a limit of 8 ports on one route. That is why there is been decided in this thesis to make use of the Nearest Neighbour algorithm. The solution will not always be optimal, but the results of this algorithm will be close to optimal.

Next point to be minimized will be the port visits. In that way, the total port charges are minimized. Combining the total distance together with the number of port visits, also the number of ships needed can be minimized. Which means that the total capital and operating costs are minimized. In order to minimize the number of port visits, there will be made use of an adjusted set covering problem. The set covering problem will result in an optimal solution for assigning ships to ports in a way that all demand is covered. Because it is to complicated to formulate all restrictions for this problem, an adjusted version of the set covering problem is used this thesis. This problem formulation will only works when there are hubs been assigned on the route and when there is no mutual trade between the ports on the route from the first to the second hub. Routes between two hubs where is mutual trade will be easily generated according a method which will assign a port on a route, when there is still some ship capacity left and otherwise make a new route when none of the routes have some ship capacity left. These methods will not find an optimal set of routes, but will find a set of routes which are close to optimal according own assumptions.

Some other discussion point is the use of hubs on the routes. Will it have a positive or negative effect on the final outcome. As can be seen in Ka Wang Man his example from the previous chapter, the use of more than one hub will have a positive effect on the total profit. The use of two hubs in that example will work better than only using one hub. In the other example there will be used four hubs, which leads to a profit of more than 1/3 of the total revenue. Only problem is that from this example there can not be said if the use of hubs will be effective comparing this results with an other method. Using the algorithm from paragraph 4.7 on this outcome, have resulted in a total profit which is even better than with the starting set of routes. Looking to the new set of routes, there can be seen that the majority of the ports on the routes, are still the ports which are selected as hub. Concluding from this result, there can be said that hubs are having a positive effect on the total profit.

Last point that will be discussed is the allocation process. The methods used in this thesis are not optimal, but will assign allocation to routes according to own assumption. Containers will first be assigned to ships which sail a route on which the port of final destination is visit. If this is not possible any more, than assign the containers on ships with a route which can shipped the containers to the next hub. There can be looked at the hub to reload the containers to an other ship which can ship these containers to their destination. This allocation method will assign as much of the demand to ships as it can. Only remark is that this method will not take all possible allocation schedules into account. That is why in larger problems/examples it is more difficult to assign all containers to a ship, but there will be some demand left which will not be handled. However the algorithm from paragraph 4.7, which tests the starting set of route found by the algorithms from paragraph 4.2 to 4.5, shows that it could be more profitable to let some demand unhandled.

The results of the methods used in this thesis are different from that in the earlier study from Ka Wang Man. There can not be said that the results are better while there are made some different assumptions, but the total profit that is found are higher. However the methods used in this thesis will not find the optimal solution, there still is room for improvements.

7 Further research

As said before, there is still some room for new theories about route scheduling. Some points for further research are already shortly been discussed in earlier chapters. In this thesis hubs are selected without checking if it is possible to extend this port to a hub. However some ports do not have room to extend. Or maybe it is not profitable for some ports to extend into a hub.

Another point is doing some research about the revenue determination. This is more an economical issue. When the profits are calculated for each single route, it is difficult to say what part of the revenue will go to a route, when a container is handled by more than one route.

In this thesis, hubs are used as transhipment points on every route. An other thought about the use of hubs could be to use them as a central point in their region. That way all demand will be shipped by feeder lines from the smaller ports to the hub in every region. Eventually you can make a few main lines between the hubs, which connect the regions to each other. This is a theory that already is been used in the research of Hsu and Hsieh (2006). But there has to be taken into account that the difference in capital and operating costs between small and large ships is almost nothing. Which means that all ships still can be seen as equal, so still the number of ships must be minimized.

The algorithm from paragraph 4.5 used to making the routes can be improved, because only the regions without mutual trade will use the adjusted set covering problem. Regions with mutual trade will be solved by an approximative method. There can be found a better starting set of routes, when there can be found an adjusted version of the set covering problem to solve the regions with mutual trade.

The allocation method was not optimal. There can be looked for a Linear Programming formulation in stead of the use of algorithms. Although algorithms are mostly handy methods to get a quick close to optimal solution, it will be rather coincidence to find the optimal solution. If there can be found a LP formulation which can be solved by for example the software AIMMS, resulting in the optimal solution. In that way, the set of routes can be made variable. In stead of a fixed set of routes, all possible routes can be taken into account.

Last struggle point in this thesis was the algorithm from paragraph 4.7. In this thesis the algorithm will only look to improvements in profit, what means that the solution this method will found, is not directly optimal, but will mostly be a local optimum. As already been stated in paragraph 4.7, combination of solutions can be used to grow out of a local optimal. Another idea is looking to a method which will accept deteriorations in order to go past a local optimum and finds the optimal solution. But there has to be made sure that such a method will not grow into a loop.

8 References

Dekker, R. (2009) *Personal communication*

Wikipedia.com (2001). *Free encyclopedia*. Viewed in the period May-July, 2009, www.wikipedia.com

SeaRates.com (2006). *Port Distance*. Viewed in June/July, 2009, from www.searates.com

Bachelor thesis Man, K.W. (2007), Routing and Scheduling Container Liners between Asia and Europe. *BSc thesis*, Econometrie & Besliskunde, Erasmus University, Rotterdam.

Wolsey, L.A. (1998). *Integer Programming*. New York: John Wiley & Sons, Inc..

Hsu, C.I. & Hsieh, Y.P. (2006). Routing, Ship Size, and Sailing Frequency Decision-Making for a Maritime Hub-and-Spoke Container Network. *Mathematical and Computer Modelling*, *45,* 899-916.

Lagoudis, I.N. & Litinas, N.A. & Fragkos, S. (2006). Modelling container fleet size: The case of a medium size container shipper company. *International Conference: "Shipping in the era of Social Responsibility",* In Honour Of The Late Professor Basil Metaxas (1925-1996), Argostoli, Cephalonia, Greece, 14-16 September 2006.

Ting, S.C. & Tzeng, G.H. (2003). Ship Scheduling and Cost Analysis for Route Planning in Liner Shipping, *Maritime Economics & Logistics, 2003, 5*, 378-392.

Alvarez, J.F. (2008). Optimization Algorithms for Maritime Terminal and Fleet Management: Joint Routing and Deployment of a Fleet of Container Vessels, 7-28, *Doctor of Philosophy Thesis*, Economics, Management and finance, University Popeu Fabra, Barcelona.

Ronen, D. (2002). Marine Inventory Routing: Shipments Planning. *Journal of the Operational Research Society*, 53, 108-114.

Christiansen, M. & Fagerholt, K. & Hasle, G. & Minsaas, A. & Nygreen, B. (2009). Maritime Transport Optimization: An Ocean of Opportunities. *OR/MS Today,* April 2009, viewed in June 2009 from http://www.lionhrtpub.com/orms/orms-4-09/frmaritime.html

Christiansen, M. & Fagerholt, K. & Haugen, Ø. & Helleberg Lund, E (2008). Ship routing and scheduling with inventory and stowage constraints. Department of Industrial Economics and Technology Management, Norwegian University of Science and Technology, Trondheim, viewed in June 2009, from http://transp-or2.epfl.ch/tristan/FullPapers/042Christiansen.pdf

Korsvik, J.E. & Fagerholt, K. & Laporte, G. (2009). A tabu search heuristic for ship routing and scheduling. *Journal of the Operational Research Society,* 11 March 2009, viewed in June 2009, from http://transp-or2.epfl.ch/tristan/FullPapers/091Korsvik.pdf