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MASTER

Strategic mode of transport optimization at Dow Chemical

Houben, L.T.M.

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Strategic Mode Of Transport Optimization At Dow Chemical

L.T.M. Houben
Identity number: 0629339

February, 2014

School of Industrial Engineering and Management Sciences
Eindhoven University of Technology
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Acknowledgements

This report is the result of my Master thesis project, conducted at Dow Chemical in Terneuzen. The project is the final chapter of my study Operations Management and Logistics at the Eindhoven University of Technology. When I started as a student, more than six years ago, I was not really sure what I wanted to achieve but gradually I became more and more enthusiastic for the field of logistics and operations management. Not only did I learn a lot during this time, but also I met a lot of great people and the experience shaped me for a big part in who I am today.

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Lars Houben

Terneuzen, February 2014
Abstract

The purpose of this study was to investigate how changes in the market of third party logistic providers (3PL) impact strategic supply chain decisions of a chemical company. A mathematical optimization model, considering cost of transportation and inventory holding cost, was constructed to assess the influence of two specific changes in the 3PL market, decreasing tank container availability and increasing parcel sizes of bulk marine tankers, on the mode of transport decisions for an existing supply chain. A qualitative approach, using interviews, was performed to make predictions on these changes. The results reveal that changes in the 3PL market can have a major impact on supply chain cost and optimal mode of transport decisions. Recommendations were given for the specific case study analysed and it was found that investments might be needed to mitigate the changes in the 3PL market.

Key words: Strategic optimization, Transportation, 3PL trends, New production location, Mixed-integer programming.
Management Summary

This report presents the results of a master thesis project conducted at the Supply Chain Operations department of Dow Chemical in Terneuzen. The purpose of the study was to investigate how changes in the market of third party logistic providers (3PL) impact strategic supply chain decisions of a chemical company.

Problem statement

Dow Chemical is currently (re)designing its supply chain for a new production location being build in Saudi Arabia in a joint venture with the Saudi Arabian Oil Company (Saudi Aramco). This joint venture is called The Sadara Chemical Company (Sadara). However, changes in the 3PL market might impact the supply chain in its ability to transport the quantities agreed upon in the Sadara joint venture. Moreover, these changes may influence the cost associated with transportation as a result of the supply chain design.

Dow Chemical identified two key changes in the 3PL market that need to be considered when designing the Sadara supply chain: a decrease in tank container (ISO tank) availability and an increase in parcel size of bulk marine tankers. Dow Chemical wanted to assess the impact of these changes on its current supply chain design for the Sadara project. This led to the following research questions:

How can Dow Chemical optimize on cost of 
transportation and inventory for the distribution of liquid chemicals over sea from Sadara to the hubs in Europe, Africa, Asia, and the Middle-East, by anticipating on the future trends in the logistic service market of larger parcel sizes for bulk marine tankers and ISO-tank availability in the Middle-East, while transporting the required volumes agreed upon with Sadara?

1. What assumptions can be made on ISO-tank availability and future parcel sizes of bulk marine tankers?

2. What is the optimal allocation of modes of transport to the hubs for the different products?

3. How does the ISO-tank availability and future parcel sizes of bulk marine tankers affect Dow Chemicals’ ability to transport the product volumes agreed upon with Sadara?
Optimization model

We developed an integer programming model in order to answer research questions (2) and (3). The model optimizes on cost of transportation as well as inventory holding cost. The model incorporates the mode of transport decision for each origin-destination pair as a decision variable.

The model was programmed in Visual Basic For Application as a Microsoft Excel plug-in. We applied the model to two regions to be supplied by the Sadara production facilities; EMEA (Europe, the Middle-East, Africa) and APAC (Asia, Pacific). Dow Chemical data was used for estimating the model parameters. The model was verified and validated by comparing it with benchmarks at Dow Chemical.

Conclusion

We conclude that the EMEA region is not very sensitive to a decrease in tank container availability and the increase of parcel sizes of bulk marine tankers. Tank container availability is defined as the percentage of tank container journeys that are available of the total number of tank container journeys used in the current supply chain design. A tank container journey is the single transportation movement of a product from origin to destination using a tank container. However, when tank container availability drops below 91.2%, extra inventory capacity has to be requested to be able to transport the volumes agreed upon in the Sadara joint venture.

The APAC region is more sensitive to both changes. A tank container availability level of 90% is still acceptable but lower availability leads to substantial cost increases. Also, extra inventory capacity is needed to anticipate on this decrease in availability. The decreased parcel size availability has no effect on cost for tank container availability levels of 100-80%. However, it does have a substantial effect when tank container availability drops below 80%.

Recommendations Dow Chemical

- Explore options to mitigate against decreasing tank container availability and increasing parcel sizes.

Several options can be explored to mitigate against decreasing tank container availability and increasing parcel sizes. The first option is to add more tank inventory capacity in the hubs. This adds more flexibility to the supply chain in terms of different parcel sizes that can be used to transport products to these hubs. For example, suppose we have a tank inventory capacity of 500 Mg in a certain hub for a certain product. Parcel sizes larger than 500 Mg can certainly not be used for transportation to that hub, because they simply do not fit in the tank. However, by adding more tank capacity larger parcel sizes...
Management Summary

also can be used to transport products to the hub. This adds more flexibility and therefore mitigates against decreasing tank container availability and increasing parcel sizes.

Second, extra flexibility can be added in the operational transportation schedule. Although the supply chain design is modelled as a strategic decision in our model, in reality product volumes and modes of transport can be adjusted on an operational level. For example, if Dow Chemical is not able to transport the products to a hub in location A due to tank containers not being available, they might be sent to location B and redistributed from there. Operational mitigation against the changes is an important option that should be explored more in detail.

Third, it is possible to pack liquid chemicals in drums and ship those drums in a normal box container instead of using tank containers. In the current situation, Dow Chemical only uses this option when the customer asks for the product to be delivered in drums. When the customer requires delivery in bulk, Dow Chemical ships the product to the hubs in bulk (i.e. in a tank container or in a parcel tanker). However, to mitigate against the identified changes it might be possible to ship the products in drums and then at the hub switch the product to bulk again before shipping them to customers requiring delivery in bulk. Naturally, this method is more expensive than shipping directly in bulk but it might be an option Dow Chemical can explore to mitigate against the identified changes.

Finally, Dow Chemical can choose to lease a fleet of tank containers ensuring their guaranteed availability. However, leasing tank containers is a substantial investment and Dow Chemical needs to explore this option further. The results of this project can serve as a benchmark when exploring this option.

- Closely monitor changes in tank container availability and availability of parcel sizes and use the optimization model to continuously assess the impact of these changes in the future.

Changes in the market of 3PLs are common and tank container availability and availability of parcel sizes are subject to change. Our research showed that these changes can have a major impact on cost of transportation, inventory holding cost, and the ability to transport the products. Therefore, it is of paramount importance to continuously keep track of the changes in tank container availability and availability of parcel sizes. The tool of the model developed in this research can be used in the future to continuously monitor the impact of changes in tank container availability and availability of parcel sizes. Therefore, we recommend that Dow Chemical keeps track of changes in the 3PL market and makes forecasts on tank container availability and availability of parcel sizes. These forecasts can be used as input to the model and the impact of the changes can be determined. Finally, appropriate mitigation actions can be determined based on the
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- Use the model to justify investments to mitigate changes in the 3PL market.
  The model proposed in this study can be used to determine cost increases as a result of a decrease in tank container availability and an increase in parcel size of bulk marine tankers. The level of cost increase due to the changes can be used as a benchmark to determine appropriate investment budgets to mitigate against changes in the 3PL market.

Recommendations further research

- Identify and monitor other changes in the 3PL market, and add these to the model.
  Dow Chemical identified the decreasing availability of tank containers and increasing parcel sizes of bulk marine tankers as their key concerns regarding the Sadara project. However, other changes in the 3PL market might also influence their ability to consistently deliver products to the customers at the required service level. Further research may identify which changes are important to consider when making strategic supply chain decisions. The model proposed in our research can be extended with extra constraints in order to incorporate these changes and can be used to determine appropriate mitigation plans. An example of a change that could be included in the model is the availability of normal box containers for the transportation of solid products from Sadara.

- Extend the model with extra decision variables.
  Another recommendation for Dow Chemical from our research is to explore options for mitigation against changes in the 3PL market. Some of these options can be included in the model as a decision variable. For example, one way to mitigate against decreasing availability of tank containers is the option to lease tank containers. Leasing a fleet of tank containers ensures their guaranteed availability. However, leasing tank containers is costly. The number of tanks leased can be added as an extra decision variable to the model. Also, the cost function can be adjusted to incorporate the cost of leasing tank containers.
# List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>3PL</td>
<td>Third Party Logistic Provider</td>
</tr>
<tr>
<td>B.V.</td>
<td>Besloten Vennootschap (similar to Ltd.)</td>
</tr>
<tr>
<td>APAC</td>
<td>Asia, Pacific</td>
</tr>
<tr>
<td>dwt</td>
<td>Deadweight tonnage</td>
</tr>
<tr>
<td>EMEA</td>
<td>Europe, the Middle-East, Asia</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>ISO-tank</td>
<td>Tank container build using ISO standard</td>
</tr>
<tr>
<td>ITCO</td>
<td>International Tank Container Organization</td>
</tr>
<tr>
<td>JCP</td>
<td>Jubail Commercial Port</td>
</tr>
<tr>
<td>LSP</td>
<td>Logistic Service Provider</td>
</tr>
<tr>
<td>Mg</td>
<td>Metric ton (1,000 kg)</td>
</tr>
<tr>
<td>mT</td>
<td>Metric ton (1,000 kg)</td>
</tr>
<tr>
<td>MDI</td>
<td>Methylene diphenyl diisocyanate</td>
</tr>
<tr>
<td>MOT</td>
<td>Mode of Transport</td>
</tr>
<tr>
<td>NGL</td>
<td>Natural gas liquids</td>
</tr>
<tr>
<td>PU</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>PUR</td>
<td>Polyurethane</td>
</tr>
<tr>
<td>Sadara</td>
<td>Joint venture between Dow Chemical and Saudi Aramco</td>
</tr>
<tr>
<td>SC</td>
<td>Supply Chain</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty feet Equivalent Unit</td>
</tr>
<tr>
<td>TDI</td>
<td>Toluene diisocyanate</td>
</tr>
<tr>
<td>VBA</td>
<td>Visual Basic for Applications</td>
</tr>
<tr>
<td>VMI</td>
<td>Vendor Managed Inventory</td>
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1. Introduction

This thesis concerns strategic mode of transport optimization for a chemical company trying to anticipate on changes in the market of third party logistic service providers (3PL). The project was carried out at Dow Chemical Benelux at the Supply Chain Operations department. Section 1.1 describes the problem statement. Section 1.2 states the research questions answered during this project. Section 1.3 summarizes the literature review conducted in advance of the project. Section 1.4 explains the methodology that was used. Finally, section 1.5 provides a company description of Dow Chemical and explains the characteristics of a typical polyurethane supply chain.

1.1. Problem statement

Typically, intercontinental transportation in the chemical industry consists of a sea leg or a rail leg combined with a road leg, i.e. the transportation is inter-modal. Inter-modal transportation is defined as the movement of a load, from its origin to its destination using a minimum of two transport modes (Jones & Turner, 2004). Moreover, on each leg, multiple transportation means can be used. For example, on the sea leg, different vessel types can be used and the product can be transported in bulk or packed. Generally, the transportation of the chemicals is outsourced to 3PLs. However, the chemical company decides which mode of transport should be used.

The mode of transport decision is important in the design of the supply chain of the chemical company, because the 3PL market is constantly changing. These changes affect the supply chain design in its ability to transport the products with the desired service level for the customer. Therefore, it is important to make the mode of transport decision in such way that the supply chain is resilient to changes in the 3PL market.

Dow Chemical is currently (re)designing its supply chain for a new production location that is being build in a joint venture with the Saudi Arabian Oil Company (Saudi Aramco). The joint venture is called Sadara Chemical Company (Sadara). Saudi Aramco is the Saudi Arabian national oil and natural gas company. It is the biggest exporter of crude oil in the world. The total oil production for 2012 was 3.5 billion barrels, about 12% of the global oil production. They are also active in the natural gas liquids market (NGLs), having a natural gas reserve of 284.8 trillion standard cubic feet.

The new production facility will be capable of cracking naphtha and ethane as well as producing specialty chemicals products and performance plastics. A total of 26 manufacturing
1. Introduction

units will be opened at Jubail Industrial City II. The first units are expected to start producing in the fourth quarter of 2014. All units are expected to be fully operational in 2016. The production facility is going to serve markets in Asia Pacific, the Middle-East, Africa, and Eastern Europe. Products will be transported from Sadara to Dow Chemicals’ regional hubs over sea, after which they are further distributed from there.

The Sadara joint venture is going to produce 3.2 million tonnes of chemicals per year, leading to a major increase in demand for means of transportation in the Middle-East. It is apparent that this increase is going to lead to changes in the market of the 3PL serving the market in the Middle-East. Therefore, it is important to design the new supply chain in such way that it is resilient to these changes in the 3PL market. This problem is the subject of our research.

1.2. Research questions

Dow Chemical would like to know what the impact will be of the changes in the 3PL market and how this affects their supply chain design in its ability to transport the volumes required in the Sadara project. They would like to anticipate on these changes by incorporating them in their supply chain design decision.

The research was limited to the transportation of products from Sadara to hubs in Europe, The Middle-East, Africa, and Asia over sea, because this part of the supply chain is currently being designed. The products that are included in the analysis are liquid chemicals, because the transportation market for liquid chemicals seems subject to major changes in the foreseeable future.

One of these changes is the availability of tank containers. Major growth in demand for tank containers is expected in the Middle-East because multiple new production facilities are being build there, including the Sadara project, capable of producing specialty chemicals. As McCune (2013), a specialist on the petrochemical industry in the Middle-East explains: ”As demand for ISO tank containers increases significantly in the GCC 1, the key worry for producers is their guaranteed availability.” The volumes Sadara is going to produce alone will lead to an increase in demand for tank containers of 2,000 per year, about 5% of the total capacity available worldwide. Moreover, the Middle-East has a low amount of import of chemicals which means tank containers have to be repositioned empty from other regions, decreasing its availability even more.

Second, parcel sizes of bulk marine tankers are expected to become larger in the future, as old vessels are continuously being replaced by new vessels with more capacity. These vessels with higher capacity are more profitable for vessel operators than the smaller ones through economies of scale.

Considering the scope of the project and the key changes in the 3PL market identified, the

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1GCC member states are Saudi Arabia, Kuwait, Bahrain, United Arab Emirates, Qatar, Oman
1. Introduction

research questions are defined as follows:

How can Dow Chemical optimize on cost of transportation and inventory for the distribution of liquid chemicals over sea from Sadara to the hubs in Europe, Africa, Asia, and the Middle-East, by anticipating on the future trends in the logistic service market of larger parcel sizes for bulk marine tankers and ISO-tank availability in the Middle-East, while transporting the required volumes agreed upon with Sadara?

(1) What assumptions can be made on ISO-tank availability and future parcel sizes of bulk marine tankers?

(2) What is the optimal allocation of modes of transport to the hubs for the different products?

(3) How does the ISO-tank availability and future parcel sizes of bulk marine tankers affect Dow Chemicals’ ability to transport the product volumes agreed upon with Sadara?

1.3. Literature review

Prior to the research we reviewed literature on transportation in the chemical supply chain in order to get a good feeling of the characteristics of transportation in the chemical industry and to obtain ideas on how to solve our problem. This subsection describes the main conclusions of this literature review.

Logistic decisions are crucial for the performance of the supply chain. This is especially true for the chemical industry, because in this industry the logistic cost usually account for a large part in the total cost. The logistic cost can vary between 3.6% and 20% of the purchase price (Karimi, Sharafali, & Mahalingam, 2005).

In general practice, 3PL are used for the transportation of goods through the chemical supply chain. Outsourcing is defined as the provision of logistic services by a supplier on a contractual basis (Razzaque & Sheng, 1998). For containerized transport a customer of a 3PL can agree a price for a fixed period for all containers it wants to ship. This is called a tender. The period of these tenders is one year for ocean transport. Alternatively, for every individual container a price can be agreed with the carrier at the time of booking. This is so-called spot-freight. Dow Chemical generally does not use this. For bulk transport there are three ways to obtain transportation from a 3PL. The most used method is contract-freight. These contracts are similar to tenders used in containerized transport but usually run longer than 1 year (e.g. for Dow Chemical typically 5 years). Second, shipping trips from origin to destination can be bought on the spot market. The third option is the use of a time-charter, where to customer rents the entire vessel for a prolonged period, usually for a year.
1. Introduction

The international transport of liquid chemicals is carried out using one of five modes of transportation: pipeline, bulk tankers, parcel tankers, tank containers, or drums (Erera, Morales, & Savelsbergh, 2005). Pipeline and bulk tankers are used primarily for the transport of large quantities of a single product. Parcel tankers are smaller vessels with multiple compartments and are used to transport smaller bulk batches of several products. These parcels have capacities varying from 500 Mg to 7500 Mg. Tank containers, or ISO-tanks, are tanks with the form of a cylinder set inside a frame of a box container in such way that they can be handled in the exact same way as standard box containers (Karimi et al., 2005). They can be used for road, rail, and sea transport.

The two modes of transport relevant for our project are parcel tanker shipments and tank container shipments. The research on parcel tankers is limited and mainly focuses on the vessel owner perspective. An example of research done is the fleet size problem by Jaikumar and Solomon (1987). The research on tank containers also focuses on the perspective of the tank container operator. A tank container operator manages a fleet of tanks to transport liquid cargo for various customers around the world. Typically, 60-70% of the fleet is owned by the operator; the remaining tanks are leased, usually for a period of 5-10 years. In order to serve customers, tank containers provide a tank at the customers origin facility and arrange transportation for the tank across multiple modes to its destination. Operators use depots for temporary storage, cleaning, and repair of empty containers (Erera et al., 2005).

Figure 1.1.: Two important modes of transport for liquid chemicals over sea: ISO-tank (left) and bulk marine tanker (right)

The cost associated with our problem are inventory holding cost and cost of transportation. The set of problems considering inventory management as well as vehicle routing and delivery scheduling decision are called Inventory Routing Problems (IRP) (Coelho, Cordeau, & Laporte, 2012). We reviewed the possibility to apply the IRP models to our problem but came to the conclusion that they are not suited because they focus heavily on the operational planning of transportation while we have to focus on the strategic implications of the supply chain design.
1.4. Methodology

To answer the research question, we use the quantitative research model by Mitroff, Betz, Pondy, and Sagasti (1974) (See Figure 1.2) as recommended by Bertrand and Fransoo (2002) in their guidelines for doing quantitative model-based research in operations management. The research consists of five phases: Conceptualization, Modeling, Model Solving, Implementation, and Validation.

![Research model by Mitroff et al. 1974](image)

Figure 1.2.: Research model by Mitroff et al. 1974

Bertrand and Fransoo (2002) interpret these phases as follows:

**Conceptualization:** In the conceptualization phase the researchers observes reality and decides which aspects are relevant and which are irrelevant for his research, thus defining the scope of the research. Decisions are made about what variables need to be included in the model.

**Modelling:** In this phase the actual model is build. Causal relations between variables are defined. The model is build in a software program that is able to solve it.

**Model solving** In this phase to model is applied to data from Dow Chemical and the mathematical solving takes place.

**Implementation:** Implementation means in our case that the solution is projected on the reality. Conclusions are drawn from the model and recommendations are given.

**Validation:** The model should be validated to check its agreement with reality.
1. Introduction

1.5. Dow Chemical Benelux B.V.

Dow Chemical, having around 54,000 employees worldwide, is an American multinational producer of chemicals and plastics. In 2013 their global revenue exceeded $57 billion. Dow Chemical is active in multiple markets including food and food packaging, performance plastics, water purification, basic plastics, basic chemicals, hydrocarbons, coatings, automotive solutions and agricultural solutions. Dow Chemicals’ vision is to be the most profitable and respected science-driven chemical company in the world and it describes its mission as to passionately innovate what is essential to human progress by providing sustainable solutions to their customers. This mission creates two challenges: creating value for customers by providing solutions instead of products, and doing this in an environmentally responsible way.

The biggest production location outside the United States is Terneuzen. The site in Terneuzen contains 26 production plants, owned by the two companies Dow Chemical and Styron, producing plastics and chemicals. Moreover, the Dow Chemical Benelux headquarters is located in Terneuzen along with the biggest Research and Development department of Europe. Finally, the Business Process Services Center is located in Terneuzen. This department provides services to Dow Chemical businesses in the EMEA (Europe, the Middle East, and Africa) region.

Dow Chemical is organized in geographic regions, product groups called ’Businesses’, and function departments. There are four geographic regions: North America, Latin America, Asia Pacific (APAC), and Europe, The Middle East, Africa (EMEA). The Businesses are responsible for marketing and sales of products, production, and purchasing of raw materials. The function departments support the Businesses by providing services. Examples of such functions are human resources, customer services, and finance.

This project is conducted in the supply chain operations department, which is one of the function departments. Their objective is to organize the transportation of products through the supply chain. Moreover, they manage the inventory of Dow Chemical products at storage locations.

1.5.1. The polyurethane supply chain

This subsection describes a typical polyurethane supply chain because the majority of the products involved in our case study belong to this chain. Polyurethane (PU or PUR) is a polymer, formed by reacting an isocyanate with a polyol. PU is a very flexible product that can have many different properties based on the type of isocyanate and polyol used in the production. For example, it can be hard like fiberglass, or soft like foam, or sticky like glue. Therefore, it is used in a wide variety of applications, such as car dashboards, toys, packaging, as adhesive or as coating. Dow Chemical produces the isocyanates and polyols used in polyurethane production. The most commonly used isocyanates are toluene diisocyanate (TDI) and methylene diphenyl diisocyanate (MDI).
See Figure 1.3 for a graphic representation of the PU production process from crude oil to finished product. The products indicated in green in the figure are raw materials for Dow Chemical. Naphtha is made out of oil at an oil refinery. The naphtha is transported from the oil refinery to a Dow Chemical plant. The products indicated in blue are produced by Dow Chemical. Naphtha is cracked in a steam cracker and the products benzene, ethylene, propylene, and butadiene are obtained. As an alternative for naptha ethane can be used. Out of benzene the products MDI and TDI are produced, and out of propylene (and sometimes ethylene) polyol is produced. The polyols are transported to the customer in flexi tanks, ISO-tanks, parcel tankers, or drums. MDI and TDI are transported to the customer in ISO tanks, parcel tankers, or drums, because they are dangerous chemicals and they cannot be transported flexi-tanks, which occasionally leak chemicals. The mixing of polyol with TDI or MDI with polyol to produce the polyurethane is done at an external manufacturer, indicated in the figure with a red color.

1.6. Thesis outline

Chapter 2 contains all the relevant information on the model that was build to answer the research questions and it covers the phases Conceptualization, Modeling, and Validation of the research model by Mitroff et al. (1974). Chapter 3 describes the case study of the two key changes in the market of 3PLs we identified for the Sadara supply chain answering research
1. Introduction

question (1). Chapter 4 describes the results obtained from the analyses run with the model covering the phases Implementation and Model Solving of the research model. This Chapter also answers research question (2) and (3). Finally, Chapter 5 states the conclusions that can be drawn from the analysis and elaborates on the recommendations for Dow Chemical as well as for further research. Moreover, an answer is given to all research question including the main research question.
2. Model

The objective of the model described in this chapter is to support the mode of transport decision for the supply chain design from Sadara to their destination hubs and to assess the influence of changes in the 3PL market on this decision. The model is specifically tailored for two changes in the 3PL market that were identified by Dow Chemical as key changes for the Sadara supply chain: decreasing tank container availability and increasing parcel sizes of bulk marine tankers. However, the model is generic in a sense that it can be used with minor alterations for other companies, regions, or mode of transport.

We chose to model the problem as an optimization problem, because we think it is the goal of the Dow Chemical to design the supply chain in such way that it leads to the lowest cost. This way, we can determine the impact of the changes in the 3PL market not only in terms of the ability of the supply chain to deliver the products but also its influence on cost.

In the remainder of this section we described the model we developed in order to answer research question (2) and (3). The answer to research question (1) was found doing interviews at Dow Chemical internally and will serve as an input to this model (See Chapter 3). Section 2.1 describes the conceptualization phase of modelling. Section 2.3 explains how the cost function is build up. Section 2.4 states the constraints of the cost function. An overview of the assumptions, the model validation and verification is given in section 2.2 and 2.6 respectively.

2.1. Conceptualization

Relevant cost incurred that depend on the mode of transport decision are cost of transportation and inventory holding cost. They should be dependant on a decision variable representing the mode of transport decision for each origin destination combination (in our case the origin is the Sadara facility and the destination is one of the hubs). Moreover, they are dependant on parameters such as vehicle capacity, demand rates, and inventory holding capacity.

2.2. Assumptions

This section describes the assumptions we make use of in our model. Three important assumptions are:

1. Demand and supply in hub are deterministic.
2. **Model**

Dow Chemical agreed in a contract with the Sadara joint venture to accept a fixed yearly volume of product from the new production facility in Jubail. Therefore, we can assume this supply to be deterministic, i.e. we know the exact yearly amount of products that will be supplied from Sadara. Figure 2.1 shows a schematic representation of the supply and demand from Sadara to Dow Chemical. Since the supply is deterministic we assume the total demand to be equal to supply. If this assumption does not hold, the system would become unstable. For example if supply continues to be higher than demand for a long period the inventory levels in the hubs will increase above their capacity. Based on regional demand forecasts, Dow Chemical will divide this supply between their hubs. The Sadara supply chain will use a push-strategy. Under a push-strategy products are ‘pushed’ to the hubs whenever they are available at the production facility (van der Laan, Salomon, & Dekker, 1999). The decision maker has to make a decision on the mode of transport and this decision will result in a one year tender for tank containers and a five year contract-freight agreement for bulk marine tankers. At the moment of the decision, assuming the demand in the hubs to be deterministic and equal to the regional demand forecast is a reasonable assumption. In reality, demand in the hubs is subject to randomness and Dow Chemical will mitigate these differences in supply and demand on an operational level, for example by shipping a small portion of the volume they intended to ship to hub A to hub B instead using bulk marine vessel transportation bought on the spot market. However, since the decision maker has to make a strategic decision on the mode of transport used to the hubs, the most reasonable assumption to make is that demand is deterministic and equal to the regional demand forecasts for the hubs. Note that under this assumption it is reasonable to make a strategic decision but it does not capture the operational dynamics of the transportation process.

2. **One mode of transport is used per lane.**
2. Model

We assume that only one mode of transport can be used per product per hub. We can make this assumption because transportation is outsourced to 3PLs based on tenders which result in a yearly contract or they are based on five year contract-freight. Each year the expected volumes of product for an origin destination pair are determined and the mode of transport is recorded in a contract with the 3PL. On an operational level however, multiple modes of transport might be used to transport the products to their hubs.

3. Transportation can only be done directly from the production facility to one of the hubs and no hubs can be combined into vehicle routes.

Since Dow Chemical is not the owner of the vessel fleet, it cannot make vehicle routing decisions. Dow Chemical can only make the mode of transport decision for an origin-destination pair, called a lane.

2.3. Cost function

Our problem is defined as a set of products \( k = 1, \ldots, K \) that need to be transported to a set of hubs \( j = 1, \ldots, J \). This transport can be done using a set of transport modes \( i = 1, \ldots, I \). The different modes of transport have different loading capacities \( p_i \). Each hub has a yearly deterministic demand for each product \( d_{jk} \) that needs to be satisfied. As explained in section 2.2, transportation can only be done directly from the production facility to one of the hubs and no hubs can be combined into vehicle routes. Moreover, only one mode of transport can be used per product per hub. For example, if the decision maker chooses to use mode of transport \( i = 1 \) to transport product \( k = 1 \) to hub \( j = 1 \), the whole yearly demand for that product and hub will be transported using mode of transport \( i = 1 \). In other words it is not possible to transport a certain product to a certain hub using a combination of different modes of transport.

At the beginning of the year the decision maker has to make a strategic decision on which modes of transport he wants to use to transport the products from the production facility to the hubs.

**Decision variable:** \( x_{ijk} \in \{0, 1\} \): \( x_{ijk} = 1 \) if mode of transport \( i \) is used to transport product \( k \) to hub \( j \), 0 otherwise.

When making the decision, the decision maker needs to consider transportation costs as well as inventory costs. The different modes of transport and products have different transportation costs to all the hubs \( c_{ijk} \). Therefore, the yearly cost of transportation will be:

\[
\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left( \frac{d_{jk}}{p_i} \right) c_{ijk} \cdot x_{ijk}
\]
2. Model

Here, \( \lceil \frac{d_{jk}}{p_i} \rceil \) is the minimum number of units needed to transport the total yearly demand for product \( k \) to hub \( j \) using mode of transport \( i \). Parameter \( c_{ijk} \) is the cost parameter for the cost per unit per mode of transport.

Each product \( k \) has unit inventory holding cost of \( h_k \) per year. The holding cost only depend on the product and not on the storage location in this case because Dow Chemical uses an inventory holding costs of 10% of the selling price to the customers (See equation 2.15). The selling price differs among the regions APAC and EMEA but is generally the same within a region. Since the model was decomposed for the two regions we modelled the inventory holding cost as being dependant on the product but not on the storage location within a geographic region.

Since the decision maker makes a decision based on future yearly demand estimates \( d_{jk} \), and has little knowledge on the variability of the demand during the year, we assume the demand to have a constant rate during the year. Considering this assumptions it is plausible to assume that shipping the products to the hubs on equidistant points in time leads to the lowest average inventory level, and therefore is optimal.

For example, the decision maker has to satisfy a demand of \( d_{11} = 4000 \). He decides to use mode of transport \( i = 3 \) to transport product \( k = 1 \) to hub \( j = 1 \). The capacity of this mode of transport is \( p_1 = 1000 \). His decision, \( x_{311} = 1 \), would lead to 4 shipments of 1000 Mg for product \( k = 1 \) to hub \( j = 1 \). We assumed the demand during the year has a constant rate, so it makes sense to transport 1000 Mg of product on four equidistant points in time over the year as this leads to the lowest possible average inventory level, while still being able to satisfy the demand. This decision would lead to 4 replenishments of 1000 Mg, and since the demand rate at the hub is constant the average inventory level for this product at this hub would be \( 1000/2 = 500 \) Mg.

Now suppose the decision maker decides to use mode of transport \( i = 2 \) to transport product \( k = 1 \) to hub \( j = 1 \). The capacity of this mode of transport is \( p_1 = 500 \). His decision, \( x_{211} = 1 \), now leads to 8 shipments of 500 Mg for product \( k = 1 \) to hub \( j = 1 \). The average inventory level for this product at this hub would now be \( 500/2 = 250 \) Mg.

As this example shows, the average yearly inventory level at a hub is dependent on the number of times a year a shipment takes place from the production facility to the hubs as well as the yearly demand at a hub. The number of times a shipment takes place, in turn, is dependent on the decision on the mode of transport used \( x_{ijk} \). Therefore, the inventory holding cost are dependent on the decision variable, \( x_{ijk} \). This is illustrated in Figure 2.2 with a fictional example in which a product is shipped twice a year versus six times a year. The figure shows that the inventory holding cost are higher when shipping only twice a year compared to six times a year. The expression for the yearly inventory holding cost becomes:

\[
I = \sum_{l=1}^{L} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{d_{jk}}{2} \left\lfloor \frac{d_{jk}}{p_i} \right\rfloor h_k \cdot x_{ijk}
\]  

(2.2)
2. Model

Figure 2.2.: Inventory in a hub location shipping in two large batches versus six small batches

In this equation, yearly demand $d_{jk}$ is divided by the number of units needed to transport the yearly demand $\left\lceil \frac{d_{jk}}{p_i} \right\rceil$. This corresponds with the assumption that the yearly demand will be shipped equally divided over the number of times the product is shipped to the hub. This leads to a maximum inventory level of $\frac{d_{jk}}{\left\lceil \frac{d_{jk}}{p_i} \right\rceil}$ at the hub and an average inventory of $\frac{d_{jk}}{2\left\lceil \frac{d_{jk}}{p_i} \right\rceil}$.

As stated in the research question, the objective of the problem is to minimize the transportation and inventory holding cost, while transporting the volumes requested. The aim of the model should be to optimize on these cost. Therefore, we composed a cost function which is the sum of transportation and inventory holding cost, dependent on the decision variable, as discussed above. An overview of the parameters is given in Table A.

$$\text{TotalCost} = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left( \frac{d_{jk}}{p_i} \right) c_{ijk} \cdot x_{ijk} + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{d_{jk}}{2\left\lceil \frac{d_{jk}}{p_i} \right\rceil} h_k \cdot x_{ijk}$$  \hspace{1cm} (2.3)

2.4. Constraints

The optimization of Formula 2.3 is subject to a number of constraints. The first constraint concerns the fact that only one mode of transport can be used per product per hub:

$$\sum_{i=1}^{I} x_{ijk} = 1; \forall j, \forall k$$  \hspace{1cm} (2.4)

As explained in Chapter 1, there are limits to the availability of the modes of transport. At Dow Chemical for example, mode of transport $i = 1$, transportation using ISO-tanks, is re-
restricted because of its limited availability. Generally, a mode of transport $i$ can be used a limited number of times yearly, $a_i$. We introduce a second constraint to the model to accommodate this fact.

$$\sum_{j=1}^{J} \sum_{k=1}^{K} \left\lfloor \frac{d_{jk}}{p_i} \right\rfloor x_{ijk} \leq a_i; \forall i \tag{2.5}$$

Third, each hub has a limited inventory capacity, $L_{jk}$. Since we assumed a constant demand rate at the hub and shipments on equidistant points in time (Figure 2.2), the size of the shipments as a result of the decision variable are $\sum_{i=1}^{I} \left\lfloor \frac{d_{jk}}{p_i} \right\rfloor \cdot x_{ijk}$. At the moment these shipments arrive the inventory level in the hub will be zero. Therefore, these shipments have to be smaller or equal to the inventory capacity $L_{jk}$. For example, suppose we have a hub with inventory capacity $L_{11} = 900$ Mg and this hub faces a demand of $d_{11} = 4,000$ Mg. The decision to use mode of transport $x_{311} = 1$, would lead to four shipments of $1,000$ Mg according to our model (the capacity of $p_3 = 1,000$ Mg). However, these shipments violate the inventory capacity constraints. We introduce a constraint:

$$\sum_{i=1}^{I} \left\lfloor \frac{d_{jk}}{p_i} \right\rfloor \cdot x_{ijk} \leq L_{jk}; \forall j \forall k \tag{2.6}$$

Fourth, Dow Chemical set a minimum to the number of vessel journeys to the hubs $b$. They did this because this leads to more flexibility on an operational level. For example, suppose we have a demand in a hub for a product of $d_{21} = 2,000$. In theory, this product could be shipped to hub using two shipments of $1,000$ Mg ($x_{311} = 1$ with $p_3 = 1,000$). However, Dow Chemical prefers to make the mode of transport decision is such way, that it leads to at least $b = 4$ shipments. We add a constraint:

$$x_{ijk} \left( \left\lfloor \frac{d_{jk}}{p_i} \right\rfloor - b \right) \geq 0; \forall i \forall j \forall k \tag{2.7}$$

With this constraint the decision $x_{311} = 1$ with $p_3 = 1,000$ Mg would not lead to a feasible solution and the model chooses $x_{211} = 1$ with $p_2 = 500$ Mg which leads to four shipments of $500$ Mg. Without this constraint the demand in the hubs could be satisfied with just one shipment from the production facility to the hub. However, in reality this is not very realistic since Dow Chemical needs the flexibility of multiple shipments to mitigate fluctuations in demand in the hubs.

Finally, we need to add a constraint to ensure that the decision variable is either 0 or 1, representing the fact that a mode of transport is either used or not used to a hub for a specific product:

$$x_{ijk} \in \{0, 1\}; \forall i \forall j \forall k \tag{2.8}$$
2. Model

2.5. Mathematical model

Minimize \[ \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left( \frac{d_{jk}}{p_i} \right) c_{ijk} \cdot x_{ijk} + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left( \frac{d_{jk}}{p_i} \right) h_k \cdot x_{ijk} \] (2.9)

\[ \sum_{i=1}^{I} x_{ijk} = 1; \forall j \forall k \] (2.10)

\[ \sum_{j=1}^{J} \sum_{k=1}^{K} \left( \frac{d_{jk}}{p_i} \right) x_{ijk} \leq a_i; \forall i \] (2.11)

\[ \sum_{i=1}^{I} \left( \frac{d_{jk}}{p_i} \right) \cdot x_{ijk} \leq L_{jk}; \forall j \forall k \] (2.12)

\[ x_{ijk} \left( \frac{d_{jk}}{p_i} - b \right) \geq 0; \forall i \forall j \forall k \] (2.13)

\[ x_{ijk} \in \{0, 1\}; \forall i \forall j \forall k \] (2.14)

This model optimizes on cost of transportation as well as inventory holding cost and will present the decision maker the different modes of transport he needs to use to transport the different products to the different hubs, while satisfying the demand, at the lowest cost. Therefore, the model will be able to answer research question (2). Moreover, the model shows how the optimal solution changes if changes occur in the availability of ISO-tanks as well as future parcel sizes of bulk marine tankers and if that solution is still feasible for Dow Chemical in terms of cost. Therefore, the model will also be able to provide an answer to research question (3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>set of vehicle types</td>
</tr>
<tr>
<td>J</td>
<td>set of hubs</td>
</tr>
<tr>
<td>K</td>
<td>set of products</td>
</tr>
<tr>
<td>c_{ijk}</td>
<td>transportation cost for product k using mode i to hub j (in Euro/unit)</td>
</tr>
<tr>
<td>d_{jk}</td>
<td>yearly demand at hub j for product k (in Mg)</td>
</tr>
<tr>
<td>p_i</td>
<td>loading capacity of mode i for product k (in Mg/unit)</td>
</tr>
<tr>
<td>L_{jk}</td>
<td>maximum tank capacity at hub j for product k (in Mg)</td>
</tr>
<tr>
<td>h_k</td>
<td>holding cost for product k (in Euro/Mg/year)</td>
</tr>
<tr>
<td>a_i</td>
<td>predicted number of yearly journeys available for mode of transport i</td>
</tr>
<tr>
<td>b</td>
<td>minimum number of yearly deliveries to the hubs</td>
</tr>
</tbody>
</table>
2. Model

2.6. Verification and validation

Model verification is "the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model, whereas validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.” (Thacker et al., 2004, p. 2)

We verified the model in three steps:

1. Remove coding errors.
   
The code was run and corrected until no error messages appeared when running the code.

2. Check if results make sense.
   
   We manually checked if the solution proposed by the model was feasible in terms of number of tank containers used. Moreover, we checked if the volumes transported matched with the vehicle and inventory capacities.

3. Compare decisions of the model with current supply chain design.

   Generally, our model made similar decisions compared to the current supply chain design. However, on a number of lanes our model proposes a different solution on some of the lanes.

After the verification procedure we validated the model by comparing the cost our model with projected cost of Dow Chemical. Projections of transportation cost were available. However, projections of inventory holding cost were not available. Therefore, a comparison was made between the transportation cost our model calculated and transportation cost projections made by Dow Chemical. For the EMEA model there was a 3.4% difference between our model and the Dow Chemical’s projections, for the APAC model the difference was 5.5%. To clarify, our EMEA model predicts 3.4% lower costs compared to Dow Chemical’s projections and our APAC model predicts 5.5% lower costs compared to Dow Chemical’s projections.

These differences can be explained by the fact that our model makes different mode of transport decisions on some of the lanes compared with the current supply chain design. For example, our model made a different decision on 4.3% of the lanes for the EMEA region compared with Dow Chemical’s plan (2 out of 47 lanes). Our model makes a different decision on these two lanes, compared with Dow Chemical, because the demand volume does not match with the decision they make. For example, hub \( j = 1 \) for product \( k = 4 \) faces a yearly \( d = 551 \). Dow Chemical plans to use 500 Mg parcel tankers to ship this volumes. Our model on the other hand, makes the decision to transport this volume using ISO tanks. This difference occurs because the volume of 551 Mg is not large enough to achieve the economies of scale needed to justify the use of bulk marine vessels. Therefore, our model chooses to use the cheaper and
2. Model

more flexible tank containers. Dow Chemical might have other incentives than the economic factors contained in our model to make a different decision on theses lanes. For example, specific conditions on these lanes may call for a different decision compared with our model. However, our model made exactly the same decisions compared with Dow Chemical’s plan for the APAC region.

Second, the volumes transported between our model and the projections are slightly different, as shown in Table 2.6. For the EMEA model Dow Chemical projects to transport 0.8% more volume compared to our model and for the APAC region it projects to transport 2.4% less compared to our model.

The difference are relatively small and we can conclude that our model accurately represents the optimization problem we are aiming to solve.

Table 2.2.: Projected transportation cost Dow Chemical compared with our model

<table>
<thead>
<tr>
<th></th>
<th>EMEA</th>
<th>APAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost difference</td>
<td>3.4%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Volume difference</td>
<td>0.8%</td>
<td>-2.4%</td>
</tr>
</tbody>
</table>

2.7. Data collection

This subsection describes how the data used in the analysis was obtained and reflects on the quality of the data.

**Demand data.** For demand data, we used the predictions of the amount of products that will be pushed to the hubs in Europe, the Middle-East, and Asia as described in the MOT-plan version 12.2. This was the most recent data available at the time of the project. Although in reality the predicted amount of products pushed to the hubs will not be strictly equal to the actual demand at the hubs, we were confident to use this data because the decision maker faces a strategic decision. The long term dynamics are still captured using predictions of demand although they might differ in reality.

**Inventory holding cost.** Dow uses formula 2.15 to calculate inventory holding cost. Up to date price information at the time of the project was used to determine inventory holding cost.

\[ h_k = 0.1 \times \text{Product price} \] (2.15)

**Transportation cost.** The transportation cost in the analysis are based on price agreements with 3PL for 2014.

**Tank capacities.** The tanks capable of storing products in the hubs are not owned by Dow Chemical but instead they are leased on a yearly basis. The tank capacity parameters used in the analysis were based on the requested tank capacities for 2014.
3. 3PL Market Changes

This section reports on the internal research performed at Dow Chemical in order to answer research question 1. It explains what reasonable assumptions can be made on future tank container availability and parcel sizes. Section 3.1 describes the assumptions made for tank container availability and section 3.2 describes the assumptions made for parcel size availability.

3.1. Tank container availability

Several sources report an expected tank container shortage in the Middle-East in the near future. The International Tank Container Organization (ITCO) finds that the certainty of tank container availability is a key anxiety amongst producers in the Middle-East 1. McCune (2013) reports that the Middle-Eastern production capacity will increase by 40% 2017 compared with 2012 leading to a major increase in the demand for tank containers in that region. Three chemical production facilities currently under development in the Middle-East are mainly responsible for this increase. Many of the products produced in these facilities will be hazardous liquids, and therefore they rely heavily on the use of tank containers for delivery.

First, the Sadara joint venture discussed in section 1.1 is going to produce 3.2 million tonnes of chemicals per year, leading to a major increase in demand for tank containers in the Middle-East. Dow Chemical’s current supply chain design for Sadara alone leads to an increase in demand for tank containers of 2,000 per year, which is nearly .5% of the total capacity available worldwide.

Second, SABIC is currently building the world’s largest carbonic anhydride purification and and liquefaction plant in Saudi Arabia. The plant will be capable of producing 200 tonnes a day of food-grade liquid carbonic anhydride, which requires tank containers to be delivered to the customer (McCune, 2013).

Third, additional plants are added to Petro Rabigh’s production facility. Petro Rabigh is a joint venture between Saudi Aramco and Sumitomo Chemical, the world’s fourteenth largest chemical company with 2012 sales of $21 billion. The 23 new process units will lead to an increase in demand for tank containers since they will produce several hundred thousand tones of liquid methyl 2-methylpropenoate, propanone and phenylic acid. These are chemicals typically transported using tank containers (McCune, 2013).

1 itco.org
3. 3PL Market Changes

In order to answer what assumption can be made on future tank container availability, we use former research done at Dow Chemical by Boureghda (2012). One of the purposes of this research was to find the key factors affecting a perceived regional container shortage in the Jubail region. Those factors were derived from interviews with tank container operators Hoyer, Stolt-Nielsen and Interbulk. Although the research provides qualitative insights in the drivers impacting the tank container availability in the Middle-East, it does not provide quantitative estimates. Interviews with different employees at Dow Chemical also indicated a lack of knowledge on qualitative estimates for future tank container availability. Because interviews with 3PLs were out of scope of this project we decided not to use estimates of tank container availability but instead conduct a sensitivity analysis on the effect tank container availability on cost of transportation and inventory holding cost. The range of the sensitivity analysis however, is based on the key factors found by Boureghda. The factors are:

1. **The Middle-East has a substantial trade imbalance.**

   The Jubail port is a port that is heavily focussed on export. Figure 3.1 (Boureghda, 2012) shows that more than 85% of the port throughput in 2010 was export. This percentage is expected to increase in the coming years because of three new projects described above in the Jubail area. Therefore, in order to have enough containers available for export, empty containers have to be repositioned from elsewhere to this region. This is a costly operation and this fact decreases the availability of tank containers.

![Figure 3.1: Jubail Commercial Port throughput 2004-2010 (Boureghda, 2012)](image)

2. **Customs sampling regulations cause delays and flexi-tanks are banned.**

   In the Kingdom of Saudi Arabia (KSA), diesel fuel is heavily subsidized and the country is amongst the top ten of countries with the cheapest fuel prices (Alyousef & Stevens, 2011). Because of this very low price, attempts have been made to illegally export the fuel to foreign markets and sell it there with huge profit. As a consequence, Saudi customs
3. **3PL Market Changes**

introduced a rule that each carriage containing liquids should be checked on contents. This rule has large effects on tank container availability in the Jubail region. First, the sampling procedure takes up to 48 hours per container. This increases the turnaround time of the container which in turn decreases the availability of tank containers. Second, another mode of transport for containerized (non-hazardous) bulk liquid would be flexi-tanks. However, flexi-tanks cannot be sampled with the equipment available at the customs. Therefore, they are currently banned in the KSA decreasing the tank container availability even more.

3. **Cleaning facilities near Jubail Commercial Port (JCP) are a bottleneck.**

Finally, the cleaning facilities for tank containers near the Jubail port have limited capacity. Tank container operators believe that current cleaning facilities cannot handle the expected future growth in demand.

| Tank container availability is very uncertain and a decrease can be expected starting from 2015. |

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### 3.2. Parcel sizes

Historical data of the development of the global chemical tanker fleet is presented in Figure 3.2. The figure shows continuous growth of the global chemical tanker fleet in the recent years. However, it also shows that the new ships added to the fleet are mainly large vessels. The small vessels make up a smaller percentage of the total fleet every year (64% in 2002 versus 45% in 2012).

Dow Chemical’s purchasing department sees a decline in the production of “Super Segregator” bulk marine vessels. These are 40 dwt vessels with over 50 segregations, i.e. they were capable of handling many different parcel sizes from 500 Mg to 7,500 Mg. These sophisticated ships were primarily build by Stolt and Odfjell in the 1990s and they have the ability to handle small parcels. Currently, ship owners are primarily building less sophisticated vessels in the 10-25 dwt ranger, with fewer segregations. These vessels have less compartments that will accommodate smaller parcel sizes. As Super Segregators are expired from fleets, charterers are expected to see supply for accommodating parcels under 500 Mg shrink. Dow Chemical believes that in the long term they might even disappear.

Dow Chemical’s Business Process Service Center in Mumbai conducted a research on the drivers for parcel sizes of bulk marine tankers and found that the most important driver for parcel sizes is the total amount of demand for bulk liquid transportation in a specific region. High demand in a region leads to big parcel sizes being prevalent in a region, whereas low

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2Data from Clarkson Fleet Changes database
3. 3PL Market Changes

Figure 3.2.: Number of small and medium/large vessels globally 2002-2013

Demand leads to small parcel sizes being available more. One has to consider the demand in origin region as well as the destination region. Since demand for bulk liquid transportation is expected to grow rapidly in the Middle-Eastern region the availability of small parcel sizes is expected to decrease in the Middle-East.

In the current supply chain design, parcel sizes of 500, 1000, 1500, and 2500 Mg are used. However, the majority of the employees interviewed at Dow Chemical expect that the parcel size of 500 Mg will not be available any more in the future. Therefore, we assume that the 500 Mg parcels will be unavailable in the future and this assumption serves as an input for the calculations done in Section 4.

In the future it can be expected that the 500 Mg parcel size will dissapear from the bulk chemical transportation market.
4. Results

In this section we attempt to answer research question 2 by calculating the optimal solution for the model described in Section 2 under the assumptions made on future tank container availability as well as parcel sizes of bulk marine tankers based on the data available at Dow Chemical. Moreover, we conduct a sensitivity analysis to assess the influence of tank container availability on the total inventory holding cost and cost of transportation and thereby we answer research question 3.

We define tank container availability as the percentage of tank container journeys that are available of the total number of tank container journeys used in the current supply chain design. A tank container journey is the single transportation movement of a product from origin to destination using a tank container. For example, suppose Dow Chemical uses 1,000 tank container movements in its current supply chain design. Predictions are made that in the future only 900 tank container movements will be available for Dow Chemical. In this case the tank container availability is 90%.

In Section 3 we found that availability of tank containers and parcel sizes of bulk marine tankers are region dependant. Therefore, the model is decomposed by region into two different models for the EMEA and APAC region.

4.1. Optimal solution

The model discussed in Section 2 was programmed using Visual Basic for Applications (VBA). We chose to use VBA since every Dow Chemical workstation has Microsoft Office installed and therefore, our tool will be easily accessible for use by all Dow Chemical employees that have interest in the tool without installing additional software packages. We made a Microsoft Excel plug-in and wrote a manual on how to use it for optimization. The results in this section are obtained from analysis using this tool. The values for the model parameters can be entered in Excel. The values we used for the parameters are based on Dow Chemical data. For example, demand parameter $d_{jk}$ is based on forecasts of demand made by Dow Chemical.

First, we calculated the optimal solution for the case where the number of tank containers available is $a = \infty$. Table 4.1 shows the optimal solution of our model compared with the current supply chain design plans. For the EMEA region we find that a slightly lower number of tank containers should be used compared to current plans. This might be due to the fact our model is an abstraction, which is needed to solve the problem due to complexity, but does
4. Results

not necessarily capture all the details of reality. For the APAC region our solution is equal to current plans with 1,241 tank containers used.

Table 4.1.: EMEA results (all MOTs available)

<table>
<thead>
<tr>
<th></th>
<th>Tank containers used</th>
<th>Total cost (% of optimal solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current plan</td>
<td>1,195</td>
<td>...</td>
</tr>
<tr>
<td>Model $a = \infty$</td>
<td>1,149</td>
<td>100%</td>
</tr>
<tr>
<td>Model $a &lt; \infty$</td>
<td>1,090 (91.2%)</td>
<td>100.69%</td>
</tr>
</tbody>
</table>

Table 4.2.: APAC results (all MOTs available)

<table>
<thead>
<tr>
<th></th>
<th>Tank containers used</th>
<th>Total cost (% of optimal solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current plan</td>
<td>1,241</td>
<td>...</td>
</tr>
<tr>
<td>Model $a = \infty$</td>
<td>1,241</td>
<td>100%</td>
</tr>
<tr>
<td>Model $a &lt; \infty$</td>
<td>1,241 (100%)</td>
<td>100%</td>
</tr>
</tbody>
</table>

Second, we gradually decreased tank container availability $a$ to calculate the value for which the model becomes infeasible. As Table 4.1 shows, the margin for tank container availability in order for the model to become infeasible is very narrow with 91.2% for EMEA. In APAC there is no margin at all. This implies that future tank container availability strongly affects Dow Chemicals ability to transport the volumes agreed upon in the Sadara joint venture. The reason for this narrow margin is the fact that with the current supply chain design limited extra inventory capacity is available at the hubs, especially in the APAC region. Therefore a shortage of tank containers cannot be mitigated by using bulk marine tankers instead. For example, suppose that the mode of transport with the lowest cost for a product to a certain hub is tank containers. However, when the availability of tank containers decreases another mode of transport has to be used in order to satisfy the tank container availability constraint (2.5).

The model will try to use bulk marine tankers as mode of transport. However, if no inventory capacity is available for that product in the hub, the inventory capacity constraint (2.6) will be violated and the model becomes infeasible.

Figure 4.1 shows that in the optimal solution, the majority of the costs are transportation cost (87% for EMEA and 85% for APAC), with only 13-15% of the cost being inventory holding cost. Therefore, we conclude that costs of transportation are decisive in the decision for mode of transport.

4.2. Sensitivity analysis

In order to assess the influence of tank container availability and future parcel sizes of bulk marine tankers on the ability of Dow Chemical to transport the volumes agreed upon in the
4. Results

Sadara joint venture, it is important to know what the impact of these changes will be on the inventory holding cost and cost of transportation. We expect a cost increase, because if fewer transportation options are available, suboptimal modes of transport have to be used to transport the products to the hubs, leading to higher cost. The amount of cost increase determines whether the change is acceptable for Dow Chemical and if action is required to mitigate the increase. This in turn determines how the changes influence Dow Chemical’s ability to transport the product volumes agreed upon in the Sadara joint venture.

In order to calculate the cost increase as a result of the changes we conduct a sensitivity analysis on the cost by changing the tank container availability and the sizes of parcels for bulk marine tankers. However, to be able to perform this sensitivity analysis, we relaxed the assumption on inventory capacity constraints in the hubs by assuming infinite capacity ($L_{jk} = \infty$). There are two reasons for this. First, as section 4.1 shows, the model quickly becomes infeasible for lower tank container availability; 92.2% availability for the EMEA model, 100% availability for the APAC model. Therefore, it makes no sense to calculate cost increase for lower tank container availabilities if the inventory capacity is limited because the model will be infeasible. Second, inventory capacity in the hubs is a design decision and can easily be adjusted during the years. Extra tank capacity can and will be requested by Dow Chemical to the hub operators if transportation becomes infeasible.

We ran the two models EMEA and APAC both twice; with all parcel sizes available (denoted with ’all’ in the figures in this paragraph) and without the 500 Mg parcel sizes (denoted with no500) as was suggested in Section 3. Moreover, we varied the availability of tank containers between 100% and 60% as suggested in Section 3.

As Figure 4.2 and Figure 4.3 show, lower tank container availability does not lead to a substantial increase in costs for the EMEA model. However, the model without 500 Mg parcel sizes, leads to higher cost of approximately 600,000 €. Therefore, we conclude that the EMEA supply chain is resilient to changes in tank container availability and parcel size of bulk marine tanker and these changes will not greatly affect Dow Chemical’s ability to transport the volumes agreed upon in the Sadara joint venture.

As Figure 4.4 shows, lower tank container availability drastically increases cost when tank
4. Results

Figure 4.2.: Sensitivity tank container availability EMEA

Figure 4.3.: Sensitivity tank container availability EMEA zoomed in
4. Results

Figure 4.4.: Sensitivity tank container availability APAC

container availability drops below 80% for the APAC region. The reason for this drastic change in cost when availability of tank containers decreases below 80% is the fact that modes of transport with high capacity (> 500 Mg) have to be used on lanes with very small demand. Without the tank container availability constraint (2.5), the model would choose to transport these small volumes using tank containers, because they have the smallest capacity and are most cost effective to transport small volumes. However, when tank container availability decreases below 80% modes of transport with a relative high capacity are used to transport small volumes, which is not very cost effective. This explains the major increase in cost when tank container availability decreases below 80%.

Figure 4.5 shows that a tank container availability of 90% does not lead to a significant increase in cost but an availability of 80% leads to a cost increase of 1 M €. Even lower availabilities (<80%) lead to unacceptable increases in cost of more than 90%. Therefore, we conclude that a tank container availability level of 90% is still acceptable. An availability level of 80% needs consideration and lower availability levels need mitigation actions. Tank container availability can greatly affect Dows Chemical’s ability to transport the volumes agreed upon when the level of availability drops below 80% for the APAC region.

Moreover, the model without 500Mg parcel sizes shows no cost increases for availability levels 100%-90%. However, it does show increases for availability levels of 80% and less (See Figure 4.5).

There are two reasons for the relative insensitivity of the model to the unavailability of the
4. Results

Figure 4.5.: Sensitivity tank container availability APAC zoomed in

500 Mg parcel. First, as Figure 4.6 and Figure 4.7 show, a relative small portion of the lanes are served using 500 Mg parcels as mode of transport. In the EMEA region the model uses the 500 Mg parcel on only 15% of the lanes. In the APAC region only 7% of the lanes are served using 500 Mg parcels. Second, on many of the lanes the cost difference between using a 500 Mg parcel and using a 1000 Mg parcel are very little. Therefore, the unavailability of the 500 Mg does not have much influence on the total cost.
4. Results

Figure 4.6.: Optimal MOT breakdown EMEA

Figure 4.7.: Optimal MOT breakdown APAC
4. Results

4.3. Conclusion

- The EMEA model is not very sensitive to changes in tank container availability and the expected retirement of the 500 Mg parcel. However, when availability drops below 91.2%, extra inventory capacity has to be requested to be able to transport the volumes agreed upon in the Sadara joint venture.

- The APAC model is more sensitive to these changes. A tank container availability level of 90% is still acceptable but lower availability leads to substantial cost increases. Also, extra inventory capacity is needed to anticipate on this decrease in availability. The decreased parcel size availability has no effect on cost for tank container availability levels of 100-80%. However, it does have a substantial effect when tank container availability drops below 80%
5. Conclusion and Recommendations

This chapter describes the conclusions made and provides an overview of the answers to the research questions (section 5.1). Moreover, section 5.2 describes the recommendations for Dow Chemical and section 5.3 the recommendations for further research.

5.1. Conclusion

In this master thesis we investigated how Dow Chemical can optimize on cost of transportation and inventory holding cost for the distribution of liquid chemicals over seas from the new production facility currently being built in Jubail to hubs in Europe, Africa, Asia, and the Middle-East. The supply chain design and the mode of transport decisions made in this design are of strategic importance because the 3PL market is subject to changes such as mode of transport availability and cost. Therefore, it is important to consider these changes when making the mode of transport decision instead of solely focusing on transportation and inventory holding cost. The most important changes are identified by Dow Chemical as decrease in tank container availability and an increase in parcel sizes of bulk marine tankers. This led to the first research question:

1. What assumptions can be made on ISO-tank availability and future parcel sizes of bulk marine tankers?

Several sources report an expected tank container shortage in the Middle-East as a result of multiple new production facilities for chemicals requiring tank containers for transportation currently under construction in the Middle-East. The new facilities are expected to lead to an increase in production capacity of 40% in 2017 compared with 2012. Interviews with employees at Dow Chemical showed that a decrease in tank containers can be expected but the amount of decrease is very uncertain. Boureghda (2012) found three key drivers for the expected tank container shortage. First, the Middle-East has a substantial trade imbalance. Second, custom sampling regulations cause delays and flexi-tanks are banned. Third, cleaning facilities near JCP are a bottleneck. We conclude that tank container availability is very uncertain, and a decrease of up to 60% can be expected.
5. Conclusion and Recommendations

The availability of parcel sizes is dependant on the total demand in the origin and destination region of the transportation. Since demand for bulk liquid transportation is expected to grow rapidly in the Middle-Eastern region the availability of small parcel sizes is expected to decrease in the Middle East. Interviews conducted at Dow Chemical show that the majority of employees interviewed at Dow Chemical expect that the parcel size of 500 Mg will not be available any more in the future.

2. What is the optimal allocation of modes of transport to the hubs for the different products?

We used an integer programming model to find the optimal allocation of modes of transport for liquid chemicals from Sadara to the hubs. The model was programmed using VBA in order to make the tool easily accessible for further use at Dow Chemical. For the APAC region our solution is equal to the current supply chain design. For the EMEA region our solution slightly differs compared with the current supply chain design.

3. How does the ISO-tank availability and future parcel sizes of bulk marine tankers affect Dow Chemicals’ ability to transport the product volumes agreed upon with Sadara?

The EMEA model is not very sensitive to changes in tank container availability and the expected retirement of the 500 Mg parcel. However, when availability drops below 91.2%, extra inventory capacity has to be requested to be able to transport the volumes agreed upon in the Sadara joint venture.

The APAC model is more sensitive to these changes. A level of 90% is still acceptable but lower availability leads to substantial cost increases. Also, extra inventory capacity is needed to anticipate on these changes.

5.2. Recommendations Dow Chemical

- Explore options to mitigate against decreasing tank container availability and increasing parcel sizes.

We concluded that the identified changes in the 3PL market have an impact on Dow Chemicals ability to transport the required volumes agreed in the Sadara joint venture. For example, when tank container availability drops below 91.2%, extra inventory capacity has to be added to be able to transport the required volumes in the EMEA region. Moreover, in the APAC region, extra inventory capacity has to be added when tank container availability drops below 100%. Therefore, it is important that Dow Chemical explores options to add extra inventory capacity to the hubs in the EMEA region, but especially in the APAC region, in order to mitigate against the key changes identified in the 3PL market. Adding more tank inventory to the hubs mitigates against decreasing
tank container availability and increasing parcel sizes because it adds more flexibility to the supply chain in terms of different parcel sizes that can be used to transport products to these hubs. For example, suppose we have a tank inventory capacity of 500 Mg in a certain hub for a certain product. Parcel sizes larger than 500 Mg can certainly not be used for transportation to that hub, because they simply do not fit in the tank. However, by adding more tank capacity larger parcel sizes also can be used to transport products to the hub. This adds more flexibility and therefore mitigates against decreasing tank container availability and increasing parcel sizes.

Another possible way to mitigate against the changes is to add extra flexibility in the operational transportation schedule. Although the supply chain design is modelled as a strategic decision in our model, in reality product volumes and modes of transport can be adjusted on an operational level. For example, if Dow Chemical is not able to transport the products to a hub in location A due to tank containers not being available, they might be send to location B and redistributed from there. Operational mitigation against the changes is an important option that should be explored more in detail.

Third, it is possible to pack liquid chemicals in drums and ship those drums in a normal box container instead of using tank containers. In the current situation, Dow Chemical only uses this option when the customer ask for the product to be delivered in drums. When the customer requires delivery in bulk, Dow Chemical ships the product to the hubs in bulk (i.e. in a tank container or in a parcel tanker). However, to mitigate against the identified changes it might be possible to ship the products in drums and then at the hub switch the product to bulk again before shipping them to customers requiring delivery in bulk. Naturally, this method is more expensive than shipping directly in bulk but it might be an option Dow Chemical can explore to mitigate against the identified changes. The reason this option mitigates against decreasing tank container availability and increasing parcel sizes is because the total volume of products to be transported in bulk increases. Larger volumes of products allow for larger parcel sizes to be used which is more cost efficient through economies of scale. The use of larger parcel sizes decreases the number of small parcel sizes and tank containers that need to be used. Therefore, this option mitigates against decreasing tank container availability and increasing parcel sizes of parcel tankers.

Finally, Dow Chemical can choose to lease a fleet of tank containers ensuring their guaranteed availability. However, leasing tank containers is a substantial investment and Dow Chemical needs to explore this option further. The results of this project can serve as a benchmark when exploring this option.

- Closely monitor changes in tank container availability and availability of parcel sizes and use the optimization model to continuously assess the impact of these changes in the future.
5. Conclusion and Recommendations

Changes in the market of 3PLs are common and tank container availability and availability of parcel sizes are subject to change. Our research showed that these changes can have a major impact on cost of transportation, inventory holding cost, and the ability to transport the products. Therefore, it is of paramount importance to continuously keep track of the changes in tank container availability and availability of parcel sizes. The tool of the model developed in this research can be used in the future to continuously monitor the impact of changes of tank container availability and availability of parcel sizes. Therefore, we recommend that Dow Chemical keeps track of changes in the 3PL market and makes forecasts on tank container availability and availability of parcel sizes. These forecasts can be used as input to the model and the impact of the changes can be determined. Finally, appropriate mitigation actions can be determined based on the analysis made with the model.

- **Use the model to justify investments to mitigate changes in the 3PL market.**

  The model can be used to determine cost increases as a result of changes in the 3PL market. The level of cost increase due to the changes can be used as a benchmark to determine appropriate investment budgets to mitigate against changes in the 3PL market.

### 5.3. Recommendations further research

- **Identify and monitor other changes in the 3PL market, and add these to model.**

  Dow Chemical identified the decreasing availability of tank containers and increasing parcel sizes of bulk marine tankers as their key concerns regarding the Sadara project. However, other changes in the 3PL market might also influence their ability to consistently deliver products to the customers at the required service level. Moreover, these changes can have a major impact on cost of transportation. Further research may identify which changes are important to consider when making strategic supply chain decisions. The model proposed in our research can be extended with extra constraints in order to incorporate these changes and can be used to determine appropriate mitigation plans.

  An example of such other change in the 3PL market is the availability of normal box containers. As Boureghda (2012) showed a shortage of box containers is to be expected in the Middle-East starting in 2015. The model could be extended to include solid products that need to be transported from Sadara to the regional hubs. The availability of box containers can be modelled in a way similar to the method we used to model availability of tank containers.

- **Extend the model with extra decision variables.**

  Another recommendation for Dow Chemical from our research is to explore options for mitigation against changes in the 3PL market. Some of these options can be included in
the model as a decision variable. For example, one way to mitigate against decreasing availability of tank containers is the option to lease tank containers. Leasing a fleet of tank containers ensures their guaranteed availability. However, leasing tank containers is costly. The number of tanks leased can be added as an extra decision variable to the model. Also, the cost function can be adjusted to incorporate the cost of leasing tank containers.

A second example of an extra decision variable that could be added to the model is the decision to either do the drumming of products in Saudi Arabia or at the hubs. As explained in section 5.2, drumming of products that need to be delivered to the customer in drums will be done at the Sadara facility according to current plans. However, for some hubs it might also be possible to do the drumming at the hubs. This decision can also be modelled and added to the strategic optimization model proposed in Chapter 2.
A. Model and Declarations

Minimize \[
\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left\lceil \frac{d_{jk}}{p_i} \right\rceil c_{ijk} \cdot x_{ijk} + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \frac{d_{jk}}{2p_i} h_k \cdot x_{ijk}
\]

\[
\sum_{i=1}^{I} x_{ijk} = 1; \forall j \forall k
\]

\[
\sum_{j=1}^{J} \sum_{k=1}^{K} \left\lceil \frac{d_{jk}}{p_i} \right\rceil x_{ijk} \leq a_i; \forall i
\]

\[
\sum_{i=1}^{I} \frac{d_{jk}}{p_i} \cdot x_{ijk} \leq L_{jk}; \forall j \forall k
\]

\[
x_{ijk} \left(\left\lceil \frac{d_{jk}}{p_i} \right\rceil - b\right) \geq 0; \forall i \forall j \forall k
\]

\[x_{ijk} \in \{0, 1\}; \forall i \forall j \forall k\]

Table A.1.: Description of parameters used in the model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I$</td>
<td>set of vehicle types</td>
</tr>
<tr>
<td>$J$</td>
<td>set of hubs</td>
</tr>
<tr>
<td>$K$</td>
<td>set of products</td>
</tr>
<tr>
<td>$c_{ijk}$</td>
<td>transportation cost for product $k$ using mode $i$ to hub $j$ (in Euro/unit)</td>
</tr>
<tr>
<td>$d_{jk}$</td>
<td>yearly demand at hub $j$ for product $k$ (in Mg)</td>
</tr>
<tr>
<td>$p_i$</td>
<td>loading capacity of mode $i$ for product $k$ (in Mg/unit)</td>
</tr>
<tr>
<td>$L_{jk}$</td>
<td>maximum tank capacity at hub $j$ for product $k$ (in Mg)</td>
</tr>
<tr>
<td>$h_k$</td>
<td>holding cost for product $k$ (in Euro/Mg/year)</td>
</tr>
<tr>
<td>$a$</td>
<td>predicted number of yearly ISO-tank journeys available</td>
</tr>
</tbody>
</table>
### Table A.2.: Declaration modes of transport

<table>
<thead>
<tr>
<th>i</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>ISO-tank</td>
</tr>
<tr>
<td>2</td>
<td>500Mg Parcel</td>
</tr>
<tr>
<td>3</td>
<td>1,000 Mg Parcel</td>
</tr>
<tr>
<td>4</td>
<td>1,500 Mg Parcel</td>
</tr>
<tr>
<td>5</td>
<td>2,500 Mg Parcel</td>
</tr>
<tr>
<td>6</td>
<td>7,500 Mg Parcel</td>
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</table>
B. Global Tank Container Fleet Overview

Taken from the ITCO Tank Container Fleet Survey of 2013.

Table B.1.: Global Tank Container Fleet: Overview

<table>
<thead>
<tr>
<th>Operator Fleets</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Owned</td>
<td>140,460</td>
</tr>
<tr>
<td>Leased</td>
<td>88,000</td>
</tr>
<tr>
<td>Total</td>
<td>228,460</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Leasing Companies Fleet</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Idle</td>
<td>15,000</td>
</tr>
<tr>
<td>Leased to operators</td>
<td>88,000</td>
</tr>
<tr>
<td>Leased to producers and others</td>
<td>47,700</td>
</tr>
<tr>
<td>Total</td>
<td>150,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Producer and Others</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Owned</td>
<td>47,400</td>
</tr>
<tr>
<td>Leased</td>
<td>47,400</td>
</tr>
<tr>
<td>Total</td>
<td>94,800</td>
</tr>
</tbody>
</table>

| Estimated Grand Total  | 338,260 |
| Estimated manufacture 2012 | 39,700 |
References


