Master's degree thesis

LOG950 Logistics

Title: Fleet design for maritime distribution of stone products in NorStone

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Number of pages including this page: 96

Molde, May 25, 2010

Molde University College

Publication agreement

Title: Fleet design for maritime distribution of stone products in NorStone

Author(s): Apetorgbor, Robert Kodjo
Lin Jing

Subject code: LOG 950

ECTS credits: 30

Year: 2010

Supervisor: Associate Professor Johan Oppen

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Date: May 25, 2010

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Preface

This thesis was written by Apetorgbor Robert Kodjo and Lin Jing in the final year of the MSc program at Høgskolen i Molde. We are majoring in Industrial logistics and Supply chain management respectively. This master thesis is developed by Møreforskning AS and Høgskolen i Molde which constitutes a part of a main project “Ny logistikk løsning for NorStone”. Our thesis is based on vehicle routing; applied to maritime transportation. Our goal has been to obtain a better understanding of the concept of vehicle routing and exploiting fleet design/composition in dealing with improved logistics activities.

The main purpose of this master thesis is to carry out an analysis to determine an optimal fleet design for the transportation and distribution of the various sand and stone products to the customers of NorStone to improve logistics activities within the Hordaland and Rogaland region.
This report is a product of our own ideas, research and efforts. Working with the thesis has given us many important insights. Additionally, we appreciate the value and the payback of appropriate planning and project management even when executing a thesis project.

This paper and the oral presentation on June 10, 2010 constitute the course LOG 950. This is considered as a development of the proposal carried out during the fall of 2009.

Summary

The topic for this thesis is **Fleet design for maritime distribution of stone products in NorStone**. The main project is aimed at finding new logistics solutions for the distribution of products for NorStone AS. Our study is focused on developing a fleet design for the transportation of products to customers within the Hordaland and Rogaland region using traditional bulk vessels from the current fleet in operation. A fleet composition is also determined for the same problem instances using tugboats and barges as an alternative vessel type. The solution from both vessel types are compared in terms of their fleet composition and size, their productivity in terms of the number of orders which can be served daily/weekly, flexibility and the elimination of waiting time.

Research method

In undertaking this research, a solver being developed by Associate Professor Johan Oppen as part of the "Ny logistikk løsning for NorStone" project was used in solving problem instances. Customers were divided into three clusters based on the location relative to the production plants. Relevant data were extracted in collaboration with NorStone AS.

Research findings

Based on our analyses we can conclude that the current fleet can be optimized for transportation in the region. More gains through the elimination of waiting time at customer ports can be achieved through the use of tugboats and barges.

- Waiting time at ports can be eliminated to a large extent by using tugboats/barges. The advantages gained when using this vessel type include increased flexibility, increase in the level of productivity, reduction in the amount of idle time and a reduced number of crew.

- The application of tugboats/barges as an alternative is of major significance in Cluster 1. This is a result of the relatively short distances between all the ports in the cluster and the high number of customers and orders received.

- Traditional bulk vessels are a better option in instances where the distances are long as was seen in Cluster 3. In such instance, flexibility from the tugboats/barges is lost and their operation becomes similar to the bulk vessels.

- A fleet composition for the region would consist of a mix of traditional bulk vessels and tugboats/barges. The bulk vessels are applicable in areas with long distances and less demand while tugboats/barges can serve areas with relatively short distances with high demand.

- The solution anticipated by NorStone was expected to have few tugboats handling a lot of barges. Contrary to this, our analysis shows that more tugboats are required than expected and these would be handling a fewer number of barges.

In all, we hope the findings of this research will provide additional information to NorStone AS by helping them to make more informed decision regarding implementation of an appropriate fleet design for increased logistics performance.

Acknowledgements

We would like to thank all those people who have helped us from the beginning to the completion of this thesis.

First we would to express our sincere appreciation to our supervisor Associate Professor Johan Oppen. Without his support and constructive instructions, it would not be possible for us to finish this thesis.

Secondly, our heartfelt gratitude goes to Knut Olav Horsberg (Sales and Logistics Manager, NorStone AS) for taking his time to provide data for this study.

Our special thanks goes to Østergaard Jens Erik for his contribution by providing us with maps of the Hordaland and Rogaland region used in the study.

Lastly, we would extend our special acknowledgement to two very important people whose inputs, time and proof-reading effort have had a significantly positive impact on the study. They are Halvard Arntzen, Associate Professor and Program Manager, MSc. Logistics Program (Molde University College) and Peter Houngo Apetorgbor, MSc. Supply Chain Management (Molde University College).

During the work with the thesis we have gained new knowledge and a more detailed perspective of logistics activities. Although our new won knowledge cannot decisively help us address all transportation challenges, it might make us more conscious of the most important issues to focus on as we enter the corporate world.

CHAPTER ONE

1.0 Introduction

Maritime transportation is the major means of international trade; by this, efficient transportation is becoming more and more important to companies which rely on the sea trade. There are great costs related to transportation; some of which include fuel expenses, repairs, maintenance and wages, with the maximum utilization of transportation equipment and high level of customer service being a major priority. This has consequently led to the need for effective logistical planning and distribution with the aim of achieving a relatively cost effective result while maintaining desirable service levels and thus customer satisfaction.

During 2008 until now, there has been an unexpected financial crisis which raided the whole global economy. Therefore to regain market competitiveness it is crucial for industries to improve delivery performance. Cost saving and reduction in the Supply Chain is one of the best strategies to improve profitability for the companies. This is especially more relevant in maritime transportation area, where transportation cost accounts for very large proportion of the total cost. These are ways to reduce transportation costs such as finding alternative distribution systems, improving effectiveness of fleet, and reducing vessels' waiting time in port. In this thesis, the terms vessel and vehicle are used interchangeably to refer to the same thing.

Fleet design for maritime transportation is a problem analysis of alternative vessel sizes and vessel types, including loading and unloading equipment both on board the vessels and ashore in which a fleet of delivery vessels must service known customers that have a demand for frequent service. The fleet design is also a fleet size and mix routing problem, where one has to decide how many vessels of each type to use given a mix of vessel types which differ in capacity and cost and then planning their routing. A set of routes are predefined between the production sites and the customers, demands are assigned to any of the available vessels which has the needed capacity to serve the demand. More than one order can be assigned to a vessel depending on its capacity and a route determined for the demands it has to serve. Consequently, some the predefined routes may not be used after the actual route planning[1].

In this thesis we focus on determining an optimal fleet design i.e. how large the fleet should be, the types of the vessels to be used and the number of each type taking into account their capacities and costs. Here the fleet typically consists of multiple vessels and economic dependencies may exist among the vessels in the form of economies of scale in the cost of replacement, and diseconomies of scale in maintenance costs[2]. And one more complicating factor is that the vessels are under different types of contract leading to variation in cost as extensively discussed in section 3.4 in Chapter 3.

The background for our master thesis is based on the project “Ny logistikk løsning for NorStone” which is being carried out by Møreforskning AS and Molde University College. The main project is aimed at finding new logistics solutions for the distribution of products for NorStone AS. The master thesis by Ormåsen and Haug from 2009 is a starting point for this thesis, and provides a description of the company NorStone and the value chain for stone products. Ormåsen and Haug[3] also describe and model a distribution and inventory problem dealing with seaborne transportation of NorStone’s products from plants to customers and the company’s own terminals in Rogaland and Hordaland in the southwestern part of Norway.

The solver to be used in this thesis has been provided by our supervisor Associate Professor Johan Oppen. The solver is currently an early version which is to be further developed as part of this study and is expected to be used in the future for the maritime project being run by NorStone. The solver will be tested on how the solution quality changes with different vessel types using selected and modified problem instances. Small instances of the problem which can be solved by hand would be tested on the solver. The solution from the solver would be evaluated for correctness and the ability of the solver to produce feasible solutions by comparing it with the hand solved solution.

The main research objectives:

- ✓ An analysis to determine an optimal fleet design for the transportation and distribution of the various sand and stone products to the customers of NorStone. The fleet design refers to the types of the vessels to be used and the numbers of each type (the fleet mix) taking into account their capacities and costs.

- ✓ Possibilities of using alternative vessels e.g. larger vessels which give a reduced unit cost compared to smaller vessels.

The different contracts would also be taken into consideration, capacities of the vessels and efficiencies when these objectives are being analyzed.

1.1 Structure of study

This study is organized into eight chapters. Chapter one of this study is an introduction to the importance of transportation as well as its relevance to the maritime and the need to reduce costs through the application of cost efficient measures.

The remaining chapters are organized as follows:

Chapter two presents some background information about NorStone AS, the firm on which this study is being conducted. The chapter also reviews the production process, product groups, customers, demands, fleet and the contracts under which they operate and also a description of the problem being studied.

Chapter 3 reviews the relevant literatures concerning the study area. This covers maritime transportation, vehicle routing problem and some special extensions the VRP. The mixed fleet vehicle routing problem, the inventory routing problem as a special variant of the VRP, contract evaluation and optimization are reviewed in this study. A model is also described which covers relevant cost elements associated with vessel management.

Chapter four is dedicated to the analysis of data for the study and Chapter five gives an overview of the solver used for the study.

An overview of the solver used for data testing is presented in Chapter five and small problem instances tested to validate the solutions.

The main part of the thesis is covered in Chapter six. In this chapter, different problem instances are tested using two vessel types. The solution obtained are analysed and a comparison of the various solutions made.

In Chapter seven is a summary of the study and includes some conclusions made and recommendations are also outlined. Finally, areas of further research are presented in Chapter eight.

CHAPTER TWO

BACKGROUND INFORMATION

2.0 NorStone AS

With the rights acquired to explore the quality rock and stone reserves of the Norwegian mountains the company ships about 8 million tons of stone products per year to customers within Norway and northern Europe. Shipping of the stone products is done from six production sites in south-western Norway to different customers including three terminals. Currently, this shipping is done by traditional bulk vessels with capacities between 500 and 5000 tons deadweight (dwt), which are normally equipped with a mechanical digger for discharging.

2.1 Products

The products produced by the company fall within four main groups namely asphalt aggregates used for motorways concrete aggregates, offshore products for covering underwater pipes and preparing sea-beds for installations and railway track ballasts. These are all obtained from the same raw material base. However, the production process determines the product at different stages resulting in a wider product range.

Examples of the products/fractions (size ranges): 0-16mm, 16-32mm, 11-16mm, 0-2mm fractions which are the least profitable due high production cost are obtained from later crushing process but there is a market for this fraction hence it has been added as one of the products from NorStone. Fractions used for railway truck ballasts are most profitable as they are obtained in the first stages of crushing i.e. 30-60mm.

2.2 Production sites and Terminals

Data from 2008 indicate that NorStone serves its customers from a total of nine sites; six of which are productions sites and the other three being terminals. The terminals are used to supply customers inland who have relatively small demands by trucks. The terminals are treated as customers and they receive supplies from the production sites.

The production process varies at the different sites based on the type of product obtained from the site. However all the production activities follow a process sequence as illustrated in Figure 2.1.

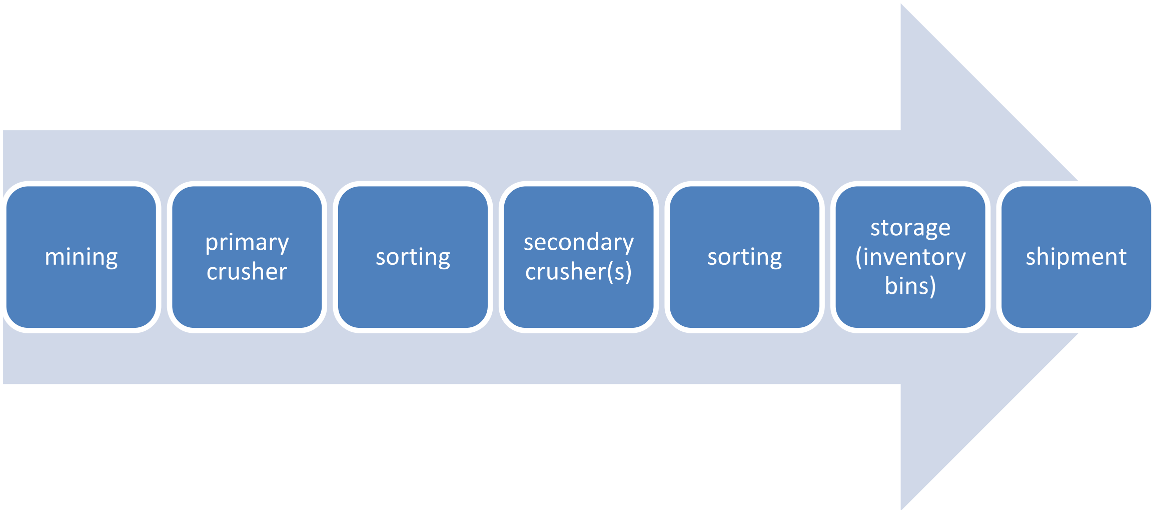

Figure 2.1: Generalized production process

Explosives are used to mine the rocks and only the finest quality is used for production. In the mountains where NorStone has acquired contractual rights, explosives are used to mine the rocks and only the finest quality is used for production. These are transported via trucks from the mine sites to production facility; a primary crusher is used to crush the rocks and taken up by a conveyor belt for sorting. This initial product may be a final product or further crushing is done with a secondary crushing and sorting continues. The final products in different fractions (size ranges) are stored in specific compartments with capacities ranging from 2500 to 50000 tons which serve as inventories. Customers are supplied based on their preferences i.e. a mix of fractions which is referred to as a formula or as individual fractions.

Figure 2.2 shows the locations of the production sites and terminals in the Hordaland and Rogaland region as at June 2008. The location of production sites are indicated their names in green font; terminals are illustrated with the blue font and the customers locations with red font.

Figure 2.2: Production sites and terminals (Hordaland and Rogaland region)

2.3 *Customer Distribution*

NorStone supplies products throughout Norway and some European countries. Figure 2.3 taken from [3] is the percentage of demand delivered to various customers within Hordaland and Rogaland. This is the representation of customers for the month of June, 2008 which carries the most demand. The data for this period shows that about 40% of the demand comes from the terminals i.e. Laksevåg, Forusstranda and Bøneset.

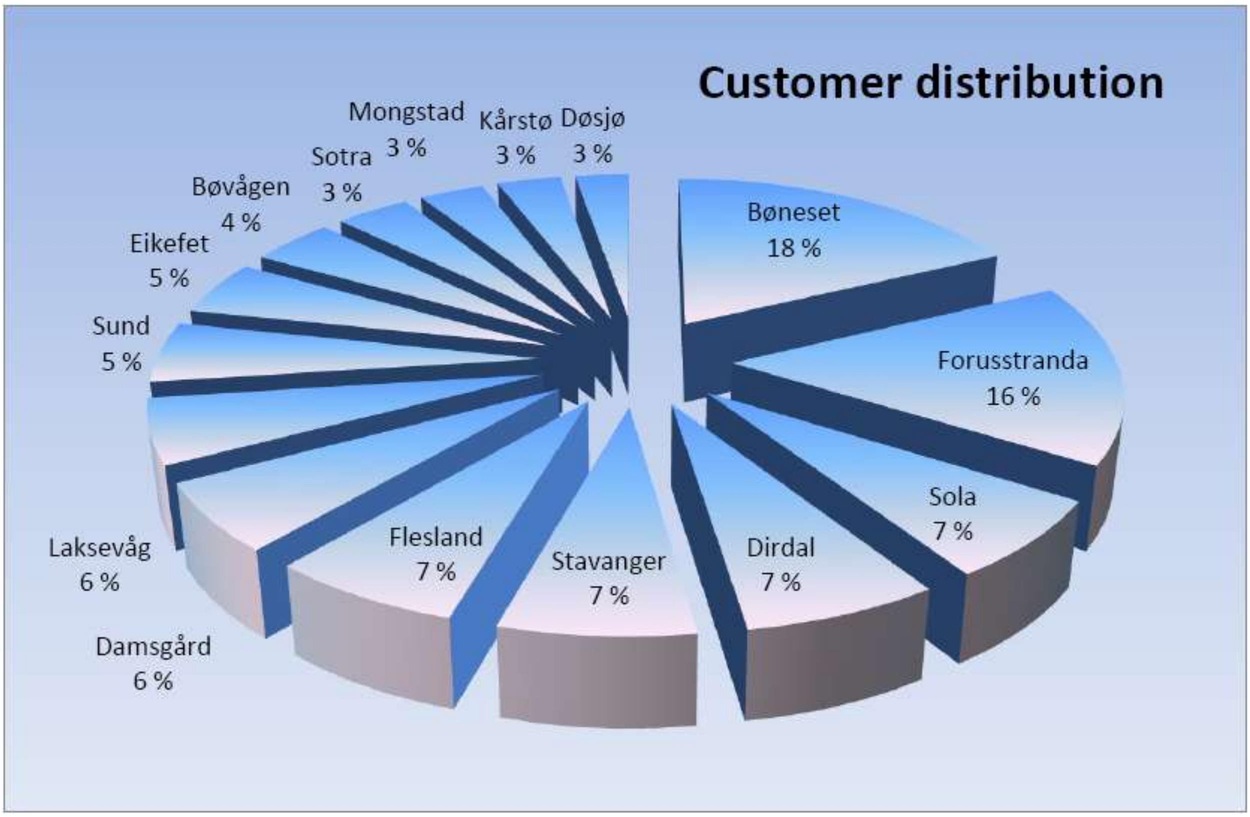

Figure 2.3: Customer distribution within Rogaland and Hordaland; taken from [3]

2.4 *Demand Pattern*

Figure 2.4 presents the monthly distribution of demands from January to December in 2008. The figure indicates a relatively smooth pattern of demand between the months of July to March of approximately 150000 tons but an increase in the months of April to June. The relatively smooth demands are characteristic of the off-peak season using mostly vessels on time charter and contract of affreightment. Demands between April and June are characteristic of the peak season where capacity of vessels on time charter and contract of affreightment is not sufficient. NorStone resorts to the spot market to obtain the extra capacity to meet increased demand. The graph illustrates the demand within the Hordaland and Rogaland region only.

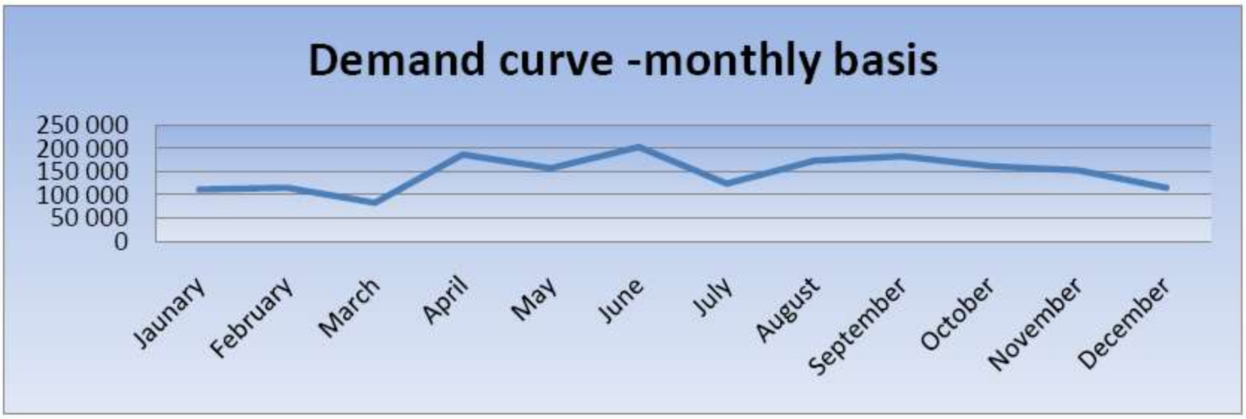

Figure 2.4: Monthly distribution of demand for 2008; taken from [3]

2.5 Order Processing and Fulfilment

Orders are received on a daily basis from different customers some of which are regular customers. However, the destinations are not always the same i.e. a customer may place orders which have to be sent to different destinations. Hence, the number of customers is less than the number of destinations. Information required for the successful processing of any order includes the name of the customer, product required and its quantity and the destination to which the product is to be delivered.

Planners at NorStone are responsible for determining production site or terminal that is nearest to the destination and also has the required product and quantity demanded. If a vessel owned by NorStone is not available for the shipment, a charterer is responsible for assigning a vessel to serve the order within the time window in order to optimize fleet utilization. In assigning a vessel with least capacity that can serve the demand once, delivery is made within one-three days. The high customer service is coupled with the superior quality of their products which have been used in a number of projects within and outside Norway.

2.6 Current Fleet

NorStone has about 15 vessels at their disposal for transportation within Rogaland and Hordaland. The vessels are chartered under three types of contract; the contracts are discussed later in section 2.9. As mentioned earlier, orders are processed and logistical planners determine which production sites have to process the orders. The vessel charterer through experience and knowledge assign the vessels to serve the order.

The heterogeneous mix of vehicles/vessels enables different customers to be served due to physical restrictions or constraints which are usually at the customer end. The different capacities and multiple compartments of the fleets also allow for flexibility in serving the varying demands thus the transportation of different products types or mix in different compartment.

A landside cargo handling equipment or discharger is used for loading vessels with the stone products as they are delivered from the inventory bins over a conveyor belt. Delivery from the discharger into the vessel is approximately one thousand tons per hour (1000 tons/hr). Some vessels are equipped with a discharger for unloading the cargo at the customer end. The rate at which this discharger operates is limited by the rate at which the machinery of the customer operates. Vessels without an onboard discharger have their cargo unloaded with land-side equipment.

2.7 Time Consumption

The central part of any routing problem is saving costs or covering all routes at the least cost but another aspect which could be influenced in relation to cost and is time. If there is more time, then quite more assignments can be covered within the same time frame which would have otherwise not been possible. There are time constraints that affect the vessel operation. These include loading, offloading, length of tour, weather conditions, legal speed limits, age of vessel and waiting time.

As mentioned earlier, the loading is done at approximately 1000 tons/hr. The total time which it takes to load a vessel therefore is a ratio of the order quantity to the loading rate. Similarly, the total time for unloading/offloading is the ratio of the order quantity to the rate of unloading.

It is necessary to identify the tour duration, loading and unloading time for the whole transport process. This provides knowledge of how long it will take to serve any order and the possible number of orders that can be served in a day or in the planning horizon. The tour duration is a measure of the route length which is the distance between the production site and the customer or terminal. Unlike roads which may be constrained with rush hours, maritime time transportation is not. On the other hand, there are restrictions on speed which have to be considered when carrying cargo. The maximum speed is lower when there is cargo onboard as compared to an empty vessel. The travel time is also affected by weather conditions and as a regulation; the speed limit is lower in winter as compared to summer. Saving time on the tour duration would require that vessels are equipped with stronger engines or newer vessels which are robust. Another option is to combine more than one route i.e. serving more than one customer on a trip with a single vessel where possible which is not often applied at NorStone.

Lastly to be considered are waiting times. Customers provide time windows within which ports would be free to receive products from NorStone. If this time is missed, there is the possibility of having to wait for several hours because the port may be busy. Another time window is the number of days within which an order has to be served. Time windows play a significant role in VRPs (vehicle routing problems) and in the real world it gives flexibility so that an order could be served on a different day to give better solution as long as it is within the time window.

2.8 Types of Contract

Vessels with different capacities and specifications used by NorStone for transporting products are hired from external ship owners. The vessels are chartered under three types of contract; Time charter (TC), Contract of Affreightment (COA) and SPOT contracting.

Time charter (TC) vessels are based on long term contracts, usually from one to three years where a fixed amount is paid on a daily basis and an accumulated cost of bunker per shipment.

Contract of Affreightment (COA) is about two times as expensive as TC. Under COA, a predefined quantity of product is carried between specified ports within a set time frame. The price therefore is factor of the distance and quantity of cargo transported.

SPOT rate/contract is used when customer demand exceed supply capacity usually in the peak season. The rate is about four times expensive as the TC contract.

In general, the type of contract under which a vessel is chartered contributes a fixed cost and associated variable costs which is dependent on the distance, product weight and sometimes the region or location of the customer. This aspect becomes important when vessels are to be replaced and when contracts are being reviewed which takes place usually after a year or more. This is done in view of the anticipation of future demand and current demand such that these demands can be served as well as the long run benefit to the company in terms of cost savings with a balance to customer satisfaction[4].

Among the factors contributing to the cost in a contract include the year which the vessel is made and its operating costs, the purpose which it will serve i.e. type of cargo to be carried, the size and capacity of the vessel. Prices are also influenced by the market and season. In the anticipation of low demands during the year, vessel owners would prefer to have more of their vessels utilized and put them on long term contracts and spot rates fall. In contrast, when demands are high in the peak season, spot rates rise and vessel owners would prefer to have just a few of the vessels operating under long term contracts.
Other factors are the negotiating ability of individuals, prior relations with vessel owners and possibility of having confidential contracts where different shippers are charged different prices[4].

CHAPTER THREE

LITERATURE REVIEW

3.0 Literature Review

The interest of research in maritime transportation has been increasing rapidly during the last decades. An early account was given by Ronen[5], who published the first review of operational research work in ship routing and scheduling.

Crainic and Laporte[6] discuss the main issues in freight transportation and operations and present operations research models and methods. Usually strategic decisions cover ship design, fleet size and mix, market selection, and port or terminal.

Relevant literature for this thesis would include the vehicle routing problem with extensions into capacity and inventory constraints as well as the fleet size and mix as applied to maritime transportation.

3.1 Maritime Transportation

Shipping industry has been one of the critical stepping stones to economic growth and prosperity throughout history. Since 5000 years ago when the first cargoes were moved by sea it has been at the forefront of global development. In 2004, the great shipping boom swept the industry from rags to riches. In not more than one year, the shipping boom made its fortunate investors some of the wealthiest people in the world. The shipping industry is a truly global industry which transported 7.0 billion tons of cargo between 160 countries in 2005. All maritime industry's annual turnover was over $1 trillion in 2004[7]. Data gathered from United Nations Conference on Trade and Development (UNCTAD) for 2003 and 2004 indicated that the total international seaborne trade has increased by 67% in terms of weight since 1980 with dry bulk cargo increasing by 85%[4]. Trade and transportation over the years has shifted a lot to the maritime sector; playing a significant role in international as well in domestic trades and especially for countries that have long shorelines or navigable rivers, or in countries consisting of multiple islands with Norway being a typical example.

Four factors which determine cargo shipment as outlined below include [7];

Price: Transportation cost is always important and has taken a large proportion of total logistics cost. Reducing the cost of transportation to an acceptable level is a critical issue for companies as it impacts directly the profitability. This situation is no different from what is observed at NorStone AS when the cost allocation across the value chain is analysed as illustrated in Figure 3.1. From this, the cost of obtaining raw materials at the quarries is the least expensive. Activities at the quarry basically involve clearing the land surface of plant based materials together with some top level rocks, use of explosives to break down the rock materials and finally loading and transporting with heavy tractor equipment to the production facility. The production process which is the second most expensive in the value chain is approximately twice the cost of obtaining the raw materials. Finally, the shipment of products to customer destination ports contributes the greatest percentage of costs within the value chain.

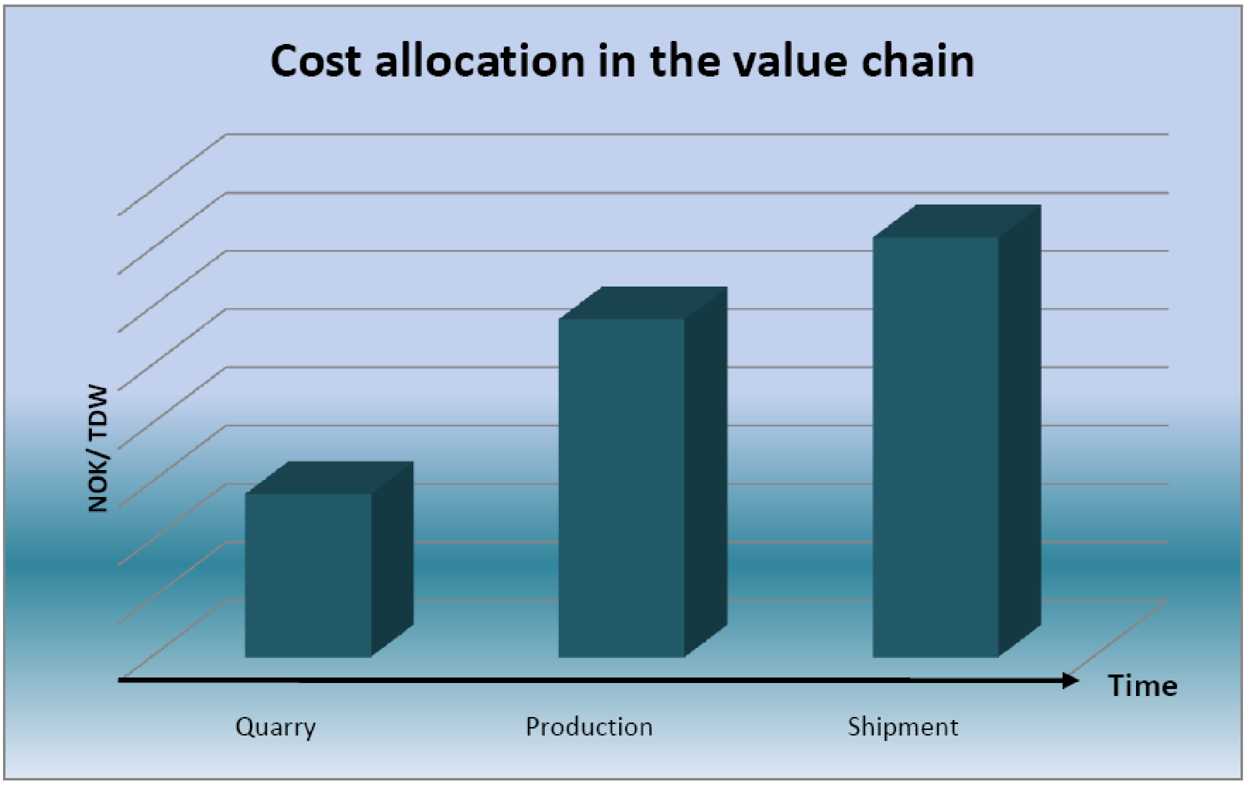

Figure 3.1: Cost allocation in value chain, NorStone AS[3]

According to European Commission report, in the early 1980s, 20% of transport cost was accounted for by dry bulk cargo delivered to countries within the community[8].

Speed: Time is money, especially with the knowledge that delivery time directly affects customer service and satisfaction. Also, time in transit incurs an inventory holding cost.

Reliability: Reliability is a possible way of demonstrating competitive differentiation. Transport reliability has taken on a new significance after “Just in time” stock control systems and to this effect, some shippers are willing to take on a few extra costs to ensure delivery of shipments and maintain competitiveness.

Security: Shippers will prepare to pay more attention to secured transportation in order to reduce risks such as damage, thefts, and piracy. Transport security has received a lot of attention within the past few decades especially with the threats of hijacking by pirates. In the context of this study, the Norwegian Sea offers much more security in comparison to that of the coast of Somalia where there has been reports of pirate attacks on shipping vessels.

In recent years, the shipping sector has expanded considerably. Before 2008, the number of ships increased in operation for the international trades for short sea trades. In 2008, the unexpected financial crisis affected all kinds of industries all over the world. Therefore, following the global economic downturn, the maritime transport met some challenges within the industry and international seaborne trade. After the 2008 economic crisis, dry bulk trade by the shipping industry slowed down with a 4.7% growth rate as compared to 5.7% in 2007; the total volume of dry bulk cargo loaded in 2008 stood at 5.4 billion tons[9].

From the report given by the UNCTAD in 2009, the world merchant fleet reached 1.19 billion deadweight tons, compared to January 2008, an increased growth of 6.7 percent. During the economic downturn, the world’s shipping capacity continued to increase consequently leading to a surge in oversupply and tumbling charter in the industry. This growth resulted from the fact that many new vessel orders placed prior to the global economic crisis which is delivered throughout 2009 as indicated in the Figure 3.2.

World fleet size by principal types of vessel, 2008–2009[a] (beginning-of-year figures, thousands of dwt)			
Principal types	**2008**	**2009**	**Percentage change 2009/2008**
Oil tankers	407 881	418 266	2.5
	36.5	*35.1*	*-1.4*
Bulk carriers	391 127	418 356	7.0
	35.0	*35.1*	*0.1*
General cargo ships	105 492	108 881	3.2
	9.4	*9.1*	*-0.3*
Container ships	144 655	161 919	11.9
	12.9	*13.6*	*0.6*
Other types of ships	68 624	84 895	23.7
	6.1	*7.1*	*1.0*
Liquefied gas carriers	30 013	36 341	21.1
	2.7	*3.0*	*0.4*
Chemical tankers	8 236	8 141	-1.2
	0.7	*0.7*	*-0.1*
Offshore supply	20 687	22 567	9.1
	1.9	*1.9*	*0.0*
Ferries and passenger ships	5 948	6 083	2.3
	0.5	*0.5*	*0.0*
Other/ n.a.	3 740	11 762	214.5
	0.3	*1.0*	*0.7*
World total	1 117 779	1 192 317	6.7
	100.0	*100.0*	

Figure 3.2: World fleet size by principal types of vessels [9]

Among the three planning levels i.e. strategic, tactical and operational, the fleet design problem is considered to be at the strategic level as it covers a longer time and is a major capital investment and also when long term contracts are considered.

The strategic decisions include fleet size and mix, transportation network design and maritime logistic system design. Operational cost can be reduced through proper planning of fleets. Industry actors are then faced with the problem of reducing operational costs in order to remain competitive in a continuously growing industry [4].

3.2 The Vehicle Routing Problem

The vehicle routing problem is at the core of most organizational units or settings and in the area of logistics where distribution and transportation activities are needed. The vehicle routing problem consists of a set of vehicles which must be assigned to a number of orders. These must then be routed such that each customer is visited on a single route and only once.

In [10], page 3214, the classical VRP is defined as follows:

”The classical VRP is defined on a graph $G = (N, A)$ where $N = \{0 . . . n\}$ is a vertex set and $A = \{(i, j): i, j \in N\}$ is an arc set. Vertex 0 is the depot; the other vertices are the customers. The travel cost between customer i and j is defined by $c_{ij} \geq 0$ and d_i is the demand for customer i”.

The vehicles are assumed to be homogeneous with capacity q. The objective is to plan a route for the vehicles such that each customer is visited only once. The route plan must also originate from the depot and end at the depot using the least cost. The vehicle capacity imposes a constraint which has to be satisfied for every route i.e. the total demand of all customers on a route must not exceed the capacity q. This classical formulation with capacity constraints is often referred to as the Capacitated VRP or CVRP.

As a consequence of variation in organizational settings, a VRP model may not necessarily be useful to other organizational settings. It can only be possible when the model is more generalized but would fail to capture most of aspects of the problem. Alternatively, a model can be used as a black box and modification done and extensions added to capture the relevant aspects of a problem.
Other objectives which may be also considered for their optimization include the following or a combination of them[11]

- ✓ Minimizing the number of vehicles to serve all demands/customers i.e. fleet sizing problem
- ✓ Balancing routes for travel time and loads
- ✓ Minimizing penalties associated with partial service of customers

3.2.1 Extensions of VRP

Figure 3.3 illustrates the basic extensions of the VRP. These extensions stem from the capacitated vehicle routing problem **(CVRP)** which is the result of including capacity constraints on the vehicles.

Distance-Constrained VRP (DCVRP) is an extension obtained when a constraint on route length is considered together with the capacity constraint in which the optimal solution minimizes the route length.

The other extensions illustrated include **VRP with Backhauls (VRPB)**; **VRP with Pickups and Deliveries (VRPPD)** with can be extended into a **Travelling Salesman Problem with Pickups and Deliveries (TSPPD)**.

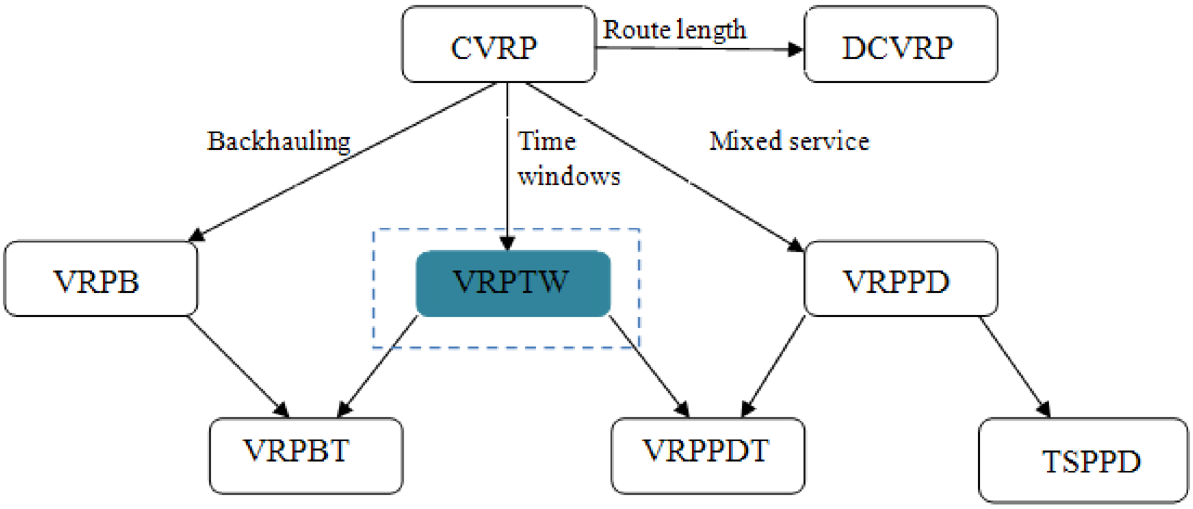

Figure 3.3: The basic problems of the VRP class and their interconnections [11]

An essential part of these extensions is the **VRP with Time Windows (VRPTW)** which forms the basis of this study. In addition to the capacity constraint, the VRPTW incorporates another constraint which determines when each customer has to be serviced. Each customer *i* has to be served between the time $[a_i,b_i]$ where a_i is the earliest time when service can begin and b_i is the latest time to begin service and after which service is not allowed. This time interval is what is referred to as the Time window.

3.2.2 Special Extensions of the VRP

In Section 3.2.1, some basic extensions of the VRP are briefly outlined. Section 3.2.2 is devoted to other special extensions of the VRP which are more related and relevant to this study. These areas include the Fleet size and Mix Vehicle Routing Problem (FMVRP), transporting Multiple Products and the Inventory Routing Problem.

3.2.2.1 The Fleet size and Mix Vehicle Routing Problem (FMVRP)

The FMVRP is a variant of the vehicle routing problem. The VRP consists of tasks which are assigned to a set of available vehicles. The assigned vehicles are then routed. As already described, the classical VRP is constrained by vehicle capacities and route length or tour duration[12]. The fleet size and mix routing problem as a variant of the VRP is made up of a fleet of vehicles with the same or different capacities and costs i.e. homogeneous or heterogeneous. The mix of vehicles (heterogeneous fleet) enables different customers to be served due to load/docking/port constraints (physical restrictions). The different vehicle capacities also allow for flexibility in serving the varying demands of customers[13].

Similar to the classical VRP, the best mix of vehicles/vessels have to be determined to serve demand between several production sites and customer locations. The vessels (mix) to be used have to be decided and the routes determined simultaneously given the demand.

The fleet size relates to the number of each vehicle type that has to be included to make up the entire fleet. In other words, the minimum mix of vehicles that gives flexibility in serving all customer demands becomes a preferred solution while minimizing costs as well.

In the studies relating to VRPs, the fleet size and mix vehicle routing problem has received much attention and has been studied by several authors. A variation of the problem includes the addition of time windows which only allocates time frames within which each order has to be served.

3.2.2.2 Multiple Products / Demand

Demand patterns for products are relatively stable throughout the year with the only variation being in the peak seasons as shown in Section 2.5 (Figure 2.4). The cost efficient use of vessels is to serve or associate demands with vessels which give the minimum cost per unit of their capacity i.e. utilization of maximum capacity. Some products allow for mixing and vessels can have multiple compartments to carry multiple products or the stone products can alternatively be loaded as separate piles on a single vessel. In this way, a customer order with different fractions of stone products could be served on fewer vessels. Also, customer locations which are within close proximity can have their orders shipped together if the vessel has enough capacity to serve the combined demand.

In literature, combining demands onto a single route is supported by the savings algorithm. An initial solution is a route from a production site (*o*) to the customer (*i*) and back (*o*), and is the same for all other demands to be served. The savings algorithm combines any two routes where possible i.e. feasibility, to yield a saving[14].

$$s_{ij} = c_{io} + c_{oj} - c_{ij}$$

It should be noted however that the savings algorithm by Clarke and Wright does not always give very good solutions compared to other algorithms which have been developed in recent years. The application of the concept to this thesis is the simplicity of the savings algorithm and how it fits quite well for the problem.

Christiansen et al.[4]; present a mathematical model dealing with multiple products on a vessel, where the cargo are either mixable or non-mixable. Applications of this have mostly been in the oil and gas industry where products are usually in containers unlike the problem which is being presented in this study.

3.2.2.3 The Inventory Routing Problem (IRP)

NorStone AS has three terminals which serve products to inland customers. Presently, these terminals are served in the form of customers i.e. orders are received from the terminals, processed and deliveries made from the plants. Alternatively, these terminals could be taken as inventories for their local customers and as such it can be considered as an inventory routing problem. This is supported by the economical benefits that could be gained, increased flexibility and robustness through the coordination of the inventory management and routing[15]. The timing of the replenishment and its size must be considered with other customer routes in mind so that the inventory holding cost and transportation are both reduced[16].

The objective of the IRP is to determine a distribution plan that minimizes average distribution and inventory costs without causing any stock-out for the customers. Under this principle, the terminals are monitored using a preferred inventory management system such as Periodic review (*R, s, S*) system. Archetti et al[17] studied the IRP over a time horizon adopting an order-up-to inventory policy. The solution they proposed was based on the branch-and-cut algorithm in which, as in other IRPs studied, they determine how often the replenishments should be done within the planning horizon. Contrary to this, a new solution approach to this problem is presented by Zachariadis et al[16]. In their approach, replenishment periods are pre-determined for the planning horizon for customers to be served and solutions from the instances are based on a local search with a tabu search algorithm as an improvement heuristic.

3.3 Solution Methods

The main methods recognized when studying or solving combinatorial optimization problems are exact and approximation methods. Exact methods are usually based on full enumeration and give optimal solutions but are limited to small problem instances and models; approximation methods do not guarantee an optimal solution but use good bounds on the solution. Lastly, heuristics unlike approximation methods do not give any bounds on the solution but in practice have been found to give quite good solutions. Metaheuristics have also been applied as they have the advantage of escaping local optima[12].

3.3.1 Exact Methods

Exact algorithms like Branch-and-bound and Branch-and-cut give optimal solution to optimization problems but are limited by the problem size. These methods use complete enumeration but not all solutions or branches are explored since they are cut off by either lower or upper bounds.

3.3.2 Heuristics

The VRP is characterized as a hard combinatorial problem which is usually solved using heuristics as exact methods are known to give wide deviations from the optimum due to the lack of good lower bounds and also fail on large instances[18]. Heuristics have been used mostly because they have proven successful in practice and trade simplicity for accuracy even though they give no bound on the solution quality. Cordeau et al.[12]; present an overview of classical heuristics which have been used for VRPs.

3.3.3 Metaheuristics

Metaheuristics is described as a heuristic which controls and guides another heuristic to find solutions better than those generated at a local optimum i.e. a heuristic within a heuristic. Another description given is a heuristic that escapes a local optimum by accepting worsening solutions and searching through most of the solution space. Two main classes are known but with many variations and names; Local search based and Population based metaheuristic.

Local Search based metaheuristics start with an initial solution and moves to another solution in its neighbourhood utilizing a neighbourhood operator and a criterion for accepting solutions. Among these include Tabu search, Simulated annealing and Deterministic annealing. The concept underlying tabu search is briefly described later in section 3.3.4.1 for the purpose of this project.

Population based metaheuristics combine a set of initial solutions to generate a subsequent set of new solutions and the population updated. Adaptive memory procedure by Rochat and Taillard[12] updates the population by replacing worst individuals with better ones. Genetic algorithms apply the concept of reproduction where alleles represent parent solutions which are combined to produce offspring.

A survey on the fleet composition and routing problem in the maritime sector is presented by Andersson et al.[15]. The authors present an overview of industrial cases which have been studied over the years from as early as 1988 to 2007 with the solution approaches adopted in each case.

3.3.3.1 Tabu search

Tabu search introduced by Fred Glover in 1986, is a metaheuristic which applies the principles of a local search to find optimal solutions to an optimization problem by cutting out parts of the search from the search space using some guidance. At every iteration (t), the tabu search moves from a current solution (s) to the best solution in its neighbourhood $N(s_t)$. The choice of neighbourhood is selected by a given neighbourhood operator, the neighbours in the search space are evaluated and checked for feasibility. The best feasible move in the neighbourhood is selected based on a criterion e.g. best improvement, first improvement.

As a metaheuristic, tabu search escapes local optima by accepting worsening moves. The word tabu was coined by Glover as certain attributes of a move are made tabu i.e. moves with those attributes are not allowed. This actually prevents solutions from being revisited and also solutions with the attribute from being visited. Such moves remain tabu for a certain duration referred to as the tabu tenure. It is likely that a good solution can be made tabu due an attribute. In order to allow such good solutions to be selected, an aspiration criterion may be included / implemented to allow such solutions to be visited if only it gives a best objective so far in the search and has not been visited previously. Other properties which could be added are diversification and intensification. Diversification ensures that more of the solution space is visited and intensification is used to search more within a promising part of the solution space[12].

Tabu search can therefore be considered as a good improvement heuristic for solving the VRP/IRP for NorStone in the project "Ny logistikk løsning for NorStone" which is being carried out by Møreforskning AS and Molde University College.

3.4 Contract Evaluation and Optimization

In relation to the costs of hiring vessels under the different contracting terms mentioned in section 2.9, the various contracts can also be optimized. As mentioned, these contracts are reviewed every couple of years during replacement of vessels, increasing capacity, changing market conditions etc. In contract optimization, the number of vessels to be hired under each given type of contract is determined based on the terms within the contract such that costs are optimized[15]. Combining contract optimization with the fleet size optimization is likely to yield more savings as compared to optimizing the fleet size only.

3.5 Shipping cost structure model

The primary objective is to reduce costs for a firm. A firm's costs will depend on the factors contributing to production and the price paid for their use. These determine the costs involved; the pricing of the product and thus, it is important for the firm to be able to identify and control them as much as possible.

In economic terms, costs are classified as Total, Fixed and Variable. **Total fixed costs** (TFC) are costs which remain the same irrespective of the output level, these are unavoidable costs or in other terms overhead costs. **Total variable costs** (TVC) are dependent on the output level and as such are subject to corresponding increases or decreases in production or output levels. The **Total costs** (TC) of any firm represent all costs at any output level and given as the sum of the **Total fixed costs** and **Total variable costs**.

$$TC = TFC + TVC$$

The costs involved in running a vessel can also be classified under the above mentioned elements but a more detailed breakdown of the cost accounting items is given by McConville [19] and Stopford [7]. These cost accounting elements include Capital costs, Operational costs, Voyage costs, Cargo handling, General overhead costs and Maintenance. A cash flow model of this model is presented in Figure 3.4.

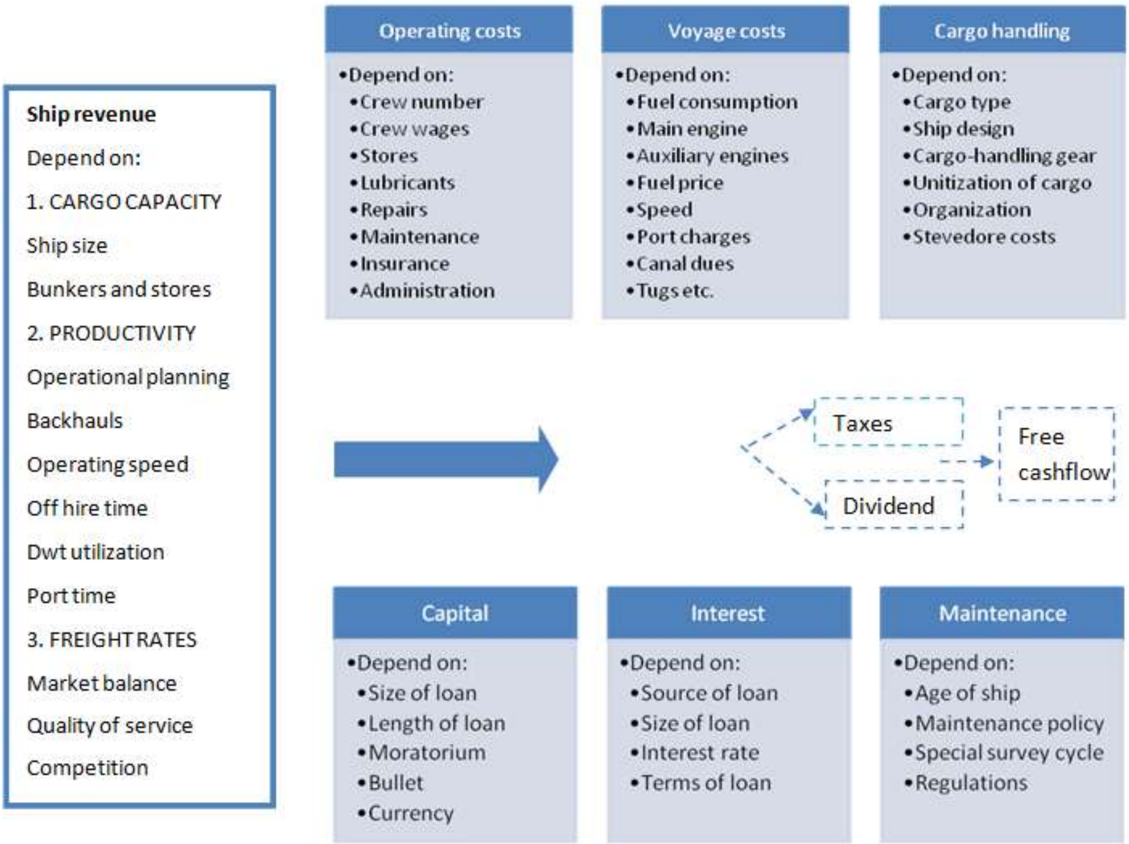

Figure 3.4: Shipping cash flow model, taken from [7]

3.5.1 Ship Revenue

Ship revenue basically is the money the firm receives from operating a ship or fleet of ships. From the model, this is a factor of the cargo capacity, productivity and freight rates.

Cargo capacity of any vessel depends on its size. Throughout literature, the economies of scale is an underlying factor suggesting that the unit cost is lower for larger vessels compared to smaller ones. This becomes more significant considering that the operating costs and voyage costs are fixed costs and do not increase with respect to an increased tonnage or vessel size. For example, the number of crew members required to man a vessel with a cargo capacity of 1300 tons is the same for a 3700 ton cargo capacity vessel at NorStone given the expertise of the crew members and other agreements.

As a result, vessel capacities have been increasing over the past decades with the limiting factor being engineering technology and design, the fixed costs of acquiring new vessels and the drawbacks of loss of flexibility and limitation on ports that can be visited. Cargo capacity is reduced by the amount of space dedicated to storage and bunkers. This could be anything from cabins for crew to fuel tanks etc. which prevent the full utilization. Generally, 95% is an acceptable utilization rate for the total deadweight tonnage for bulk vessels[7].

Productivity is a ratio of output given the input based on manufacturing terms but in the shipping industry, the productivity of a vessel is given as ton miles i.e. number of tons shipped multiplied by the number of nautical miles travelled[19]. Inefficient operational planning could potentially reduce the productivity of some vessels even though experience and some expertise are employed in manual operational planning. This is a result of the problem size, the planning horizon and the inability of the human being to view all or most dimensions of the problem and possible solutions.

Port times are related to the loading and discharging processes and the rates associated with these activities. Efficient loading and discharging equipment are required to reduce the time spent in ports in order to reduce port rates, and the time gained can be directed into other activities. The use of tugboats and barges as an example compared to the use of traditional bulk vessels offers great flexibility where tugs do not have to stay at ports for unloading but can be directed for other activities.

Port time also forms part of the operating speed with the addition of the time spent on voyages. Time spent on voyages is directly related to the travel speed of the vessel, an increased speed implies a short time and vice versa. It therefore makes it likely to suggest increasing the speed of vessels, however, there are regulations on speed limits and studies have indicated that increasing speed by 1% results in a 3% increase in fuel consumption[19]. Reducing the speed gives a lot of saving with respect to fuel price and its consumption, however the number of demands served at lower speed is reduced resulting in revenue loss.

In order to ensure good utilization of the total deadweight, orders have to be assigned to vessels with the lowest capacity available to serve the order and the possibility of serving multiple products or demands as described in Section 3.2.2.2. Backhauls offer the possibility of doing pick-ups on return trips from customer locations, but in this study all pick-ups would be at the production sites and hence there is no real savings from backhauls. Backhauls are therefore not considered in this study.

Competition in markets should never be overlooked, even in monopolistic markets deterrent games are used to keep out possible competitors. The choice of competitive advantage can be in the form of service quality leading to customer satisfaction. Competitive advantage can also be low or reduced production costs. It could also be a combination of various elements, and in a market such as the maritime which depends greatly on the oil industry as source of fuel oil, price fluctuations of fuel coupled with demand variability makes it difficult to maintain competitive advantage. Firms which fail in this aspect are likely to go bankrupt with possible collapse or a take-over.

3.5.2 Operating Cost

The cost of running a vessel is its operating cost. This consists of the number of crew members and their wages, insurance, maintenance in the form of unforeseen breakdowns (repairs), stores, lubricants and administration charges. These costs are considered to be fixed costs and do not depend on the level of output or productivity[19].

3.5.3 Voyage Cost

Voyage costs represent the variable costs of serving an order. Voyage costs are affected by fuel prices and its consumption by a particular vessel. Fuel consumption has been pointed out to be directly influenced by the sailing speed i.e. 1% increase in speed results in 3% increase in fuel consumption. Fuel consumption is also affected by the efficiency of the engine and age of the vessel. Distance between the production site and the destination port also makes the cost variable. Increasing the travel distance for a particular vessel definitely increases its fuel consumption and consequently the cost for the voyage.

3.5.4 Maintenance

Maintenance can be in the form of repairs needed when there is a breakdown and the cost associated with this is covered in the operating costs. Periodic maintenance, which is done every 2 – 4 years, is necessary for inspecting the whole vessel to ensure its capability to be used in coming years as well as for insurance purposes. The costs related to this can be very high for older vessel which would require more frequent maintenance checks compared to newer ones. Another cost contributing factor from older vessels is steel-wear due to corrosion; as such these parts have to be replaced in order to meet standards[7].

The cash flow or profit generated is obtained when all the fixed costs (operating and maintenance costs); variable voyage cost and other cost elements such as taxation, loans and interests (where applicable) are deducted from the revenue generated from operating a vessel or fleet of vessels.

3.6 Alternative for transportation cost reduction

From the literature presented in the previous sections, there are possibilities for reducing costs involved with the transportation of products from the production sites of NorStone AS to its various customers. The savings algorithm by Clarke and Wright[14] saves costs when multiple orders are served by a single vessel which is rarely put into practice at NorStone AS.

3.6.1 Tugboats and Barges

The use of tugboats and barges is another option of major interest and can be related to a pick up and drop system. In practice, tugboats move between production sites and customers, picking up barges with load to be delivered to customers or empty barges from customers to production sites. Consequently, waiting time is reduced and more work could be done within a period compared to bulk vessels and also travel time is reduced as tugboats have higher speed than traditional bulk vessels, both with and without load.

A small example is illustrated below and compared with traditional bulk vessels. This has been done assuming that the customer destinations are within 40 miles from the production site.

Solving this with the regular bulk vessel gives the following solution:

- Bulk vessel arrives at Plant A to pick up first order 3000 tons at time 0
- Loading (1000 tons/hour) takes 3 hours, vessel leaves at time 3
- Given speed of vessel 10 knots, it is assumed that it takes 2 hours to reach customer port, arriving at time 5
- Unloading (400 tons/hour) takes 7.5 hours, ready to leave at time 12.5
- Return trip to Plant A at 12 knots takes 1.48 hours for the same distance, arrives at time 13.98.

At the current time of 13.98, there is not enough time in Day 1 for the bulk vessel to deliver a second order. The second order of 2800 tons would require 7 hours for unloading to be completed. Adding the unloading time alone would put the time at 20.98 at which the customer port is closed.

Solving the same problem using a tugboat with barges gives the following solution:

- Tugboat arrives at Plant A with barge 1 to pick up first order 3000 tons at time 0
- Loading (1000 tons/hour) takes 3 hours, tugboat leaves with barge at time 3
- Given speed of tugboat with order 12 knots, it will take 1.48 hours to cover the same distance as the bulk vessel to reach customer port, arriving at time 4.48
- Unloading (400 tons/hour) takes 7.5 hours, barge ready to leave at time 11.98
- Tugboat ready to leave at time 4.48

With the time difference between when the barge would be ready to leave and when the tugboat is actually free i.e.7.5 hours, it is actually possible to pick up another order.

- Tugboats leaves to Plant B (17 knots) to pick up barge 2, deliver to Plant A(15 knots), given the short distances, activity takes 2.5 hours
- Loading of barge 2800 tons, takes 2.8 hours
- Deliver to customer 2, taking another 2 hours
- Unloading completed after 7 hours, barge 2 ready to leave at 18.78, tugboat ready to leave at time 11.78

The tugboat can now travel from customer 2 to customer 1 to pick up barge 1 and it arrives shortly after unloading or barge 1 is completed. The tugboat with barge 1 is ready to leave 12.50 considering the distance between the two customer locations. Similarly, there is enough time to load barge 1 at Plant A for a third order for another customer before picking up barge 2 and lastly picking up barge 1 from customer 3 first thing on Day 2.

A single tugboat with two barges as illustrated with the small example serves three orders in a single day (approximately 15-18 orders per week) compared to one order completed by the traditional bulk vessel (approximately 10-12 orders per week).

3.6.2 Increased vessel capacity

A bulk vessel with large loading capacity is another option as they give a reduced unit cost compared to smaller vessels. This could also be used together with the savings algorithm by combining several orders and serving them on a single route.

3.7 Chapter remarks

Due to the number of cost elements which have to be considered, some being long term and others short term and the inability to gather all needed data on these cost elements in sufficiently accurate terms, analysis of the fleet composition would be geared towards improving the deadweight utilization, productivity and operational planning which ultimately improves the amount of revenue generated.

CHAPTER FOUR
DATA FOR ANALYSIS

4.0 Primary data

Data to be used for analysis is from the demands from the period of April-June, 2008. From Figure 2.4 in Section 2.4, these three months indicate periods where demand was at its highest i.e. peak season. This period is characterised by inability of the already existing fleet to serve all demands within the time windows. As an alternative, the Spot market is used which has already been introduced as the most expensive of the vessel contract types. The use of fleet size with minimum or no Spot market vessels would therefore reduce the transportation cost. The use of demand data from the peak period will ensure optimal utilization of existing fleet and thus reduced dependence on the spot market

Analysis of customer demand distribution received within this period indicates the existence of three clusters (Figure 4.2) with a few others sparsely distributed within these clusters. For this reason, the data set to be used for our analysis would include the following:

- ✓ Cluster 1: Customers distributed around Jelsa, Tau, Årdal and Dirdal
- ✓ Cluster 2: Customers distributed around Askøy
- ✓ A mix of orders from both clusters
- ✓ Cluster 3: Customers distributed between Clusters 1 and 2 located around Dimmelsvik
- ✓ Selected week in the peak season with large number of received orders

Case	Time/Week	No. of Orders	No. of fractions	No. of vessels	Total demand (tons)
Case 1	Week 18	14	4	7	12306
Case 2	Week 24	39	4	9	50357
Case 3	Week 20	15	5	6	14268
Case 4	Week 20	18	5	8	21582

Table 4.01: Real world cases selected for analysis

4.1 Data cleaning/analysis

Data received was basically orders received from the period of April-June, 2008. These include orders to which have destinations outside Rogaland and Hordaland i.e. other regions in Norway, some European countries. Over-head costs have been added to give a better balance of the whole cost involved in the transportation. As this study is focused on the Rogaland and Hordaland region, orders outside these regions have been ignored together with the overhead costs. The remaining data to be used for analysis therefore does not capture the full utilization of the vessels as shown by Haug and Ormåsen[3].

4.2 Cost data

Transportation cost for product delivery is charged on the basis of the distance between the plant/origin and the destination the customer requests the product to be delivered. This assigned destination could be customers' location or other designated locations or project sites.

The rates charged are given as a radius as shown in Figure 4.1. Customers within the radius X from the plant are charged the same; the only difference here is the order quantity. This is also the case for customers within radius Y.

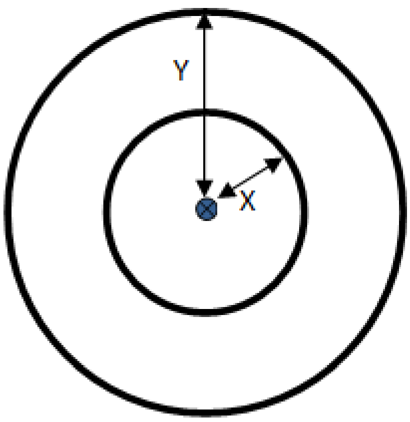

Figure 4.1: An illustration of pricing rates

Another factor which is incorporated into the pricing is the plant from which the order is served and the region in which the destination is located. Orders from particular plants to specific region attract different rates.

4.3 Distances

From the data set and cases selected for testing, a distance matrix was constructed. This matrix gives the estimated distances between each production site/plant and destinations or customer locations. Distances for the matrix were obtained using Dataloy Distance Table (DDT) which is an online tool for calculating of sailing routes and distances. Google Earth Mapping Tools was also used for locations not supported by DDT and such distance estimates may be affected in terms of accuracy based on the number of way points used in their estimation.

4.4 Customer Distribution

Analysis of the data after cleaning and plotting of customer locations and plant locations on the map in Figure 4.4.1 showed that customers are distributed into fairly distinct groups or clusters within a 50mile radius:

Cluster 1: Customers distributed around Jelsa, Tau, Årdal and Dirdal
This cluster is made up of four plants surrounded by the greatest percentage of customers. This represents approximately 60% of the total number of customers i.e. 29 which is served within the three months. These customers are located within 50 miles radius or less from the plants and also between each other.

Cluster 2: Customers distributed around Askøy
Approximately 30% of the customers i.e. 15 are located within Cluster 2 with Askøy as the only plant. The distance between the customers and the plant here is also within 50 miles radius.

The third group which is **Cluster 3** has a few number of customers and is located between Clusters 1 and 2 located. This group is made up of three customers located around Dimmelsvik and represents approximately 6% of the total number of customers.

The remaining 4% represents customers located at distances greater than 50miles and also found between Clusters 1 and 2. The long distances here can be attributed to the water networks which in Norway are referred to as the fjord. This creates rather long routes which have to be travelled which in linear measurements are quite short.

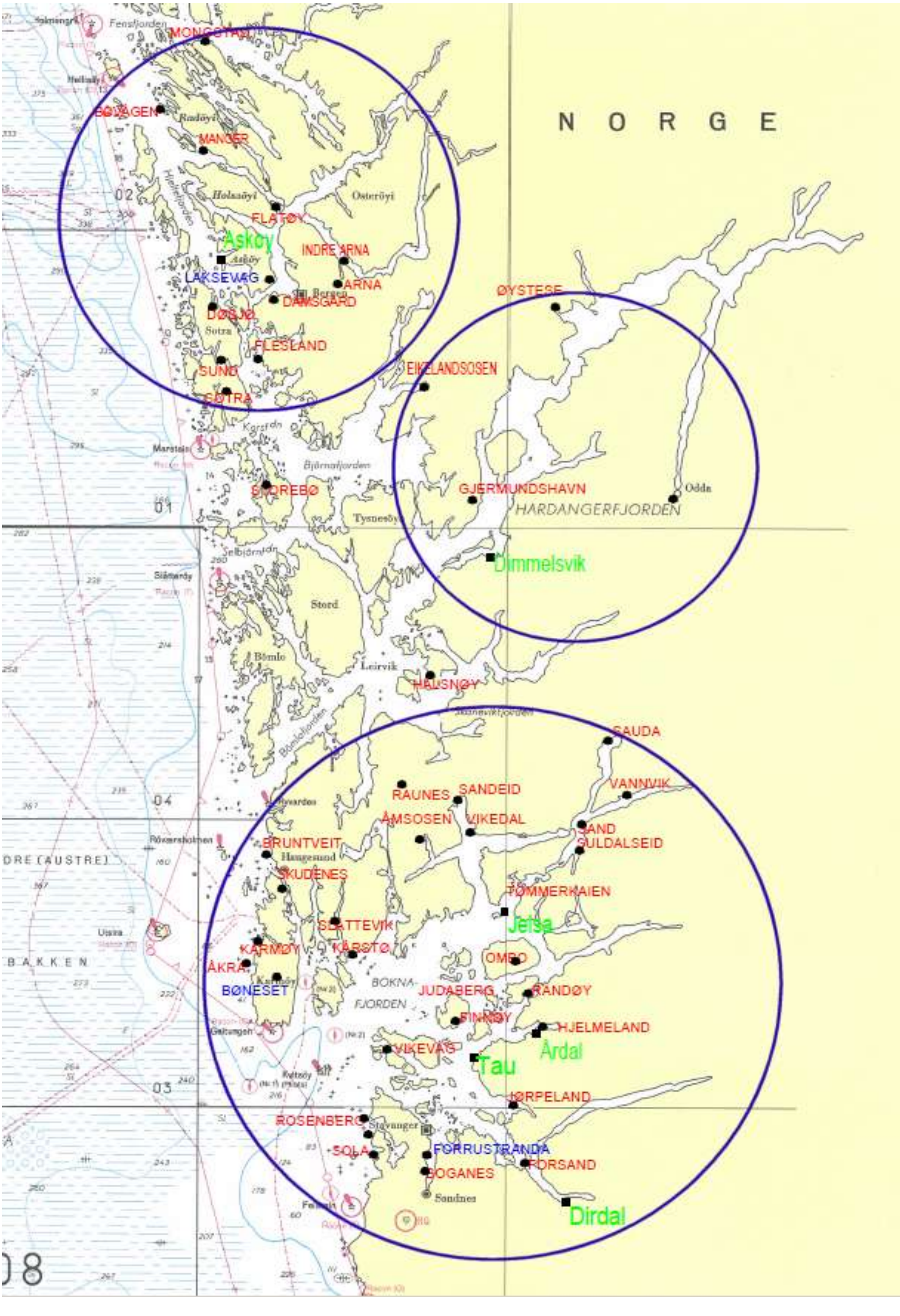

Figure 4.2: Illustration of customer distribution into clusters around plants

4.5 Product availability

Rocks and sand serve as the main raw materials used in the production of the various fractions. Products are almost all the same at each production site, differences arise from the quality of rock material used and available at the mine site of a particular plant. Some plants are also known to have products unique to them and variety of fraction produced also limited by the size of the plant and complexity. Consequently, orders can be served from almost all the plants reducing the amount of waiting time when other ports are busy.

4.5.1 Tau plant

DuraSplitt® which is a trademark product is a unique product which is only available at Tau together with fractions which fall within the four main product groups i.e. asphalt aggregates, concrete aggregates, offshore products and railway track ballasts. Analysis of the sail report indicates that 16 different fractions were produced or made available within the study period to serve various customer orders. Out of the total number of orders received throughout the period, 21% was served from the Tau production plant; 87% out of this was served within its cluster (Cluster 1) and the remaining 13% delivered to some customers within Cluster 2 and the Askøy production site. However, this 13% of products could have been served from Askøy since fractions were available at the site (see Appendix A).

4.5.2 Årdal plant

Årdal over the period recorded just seven fractions which included sand products. With this low number of fractions it could be expected that the number of order received will be low. On the contrary, it received 42% of the total order which is the largest proportion of the order distribution among the plants. 63% of these orders were served within it Cluster 1 with the remaining 37% being delivered outside. This 37% is greatly accounted for by one of the regular customers; a cement manufacturing company requiring particular quality of products on a regular basis.

4.5.3 Dirdal plant

Products from the Dirdal plant are used in the offshore industry for preparing sea beds and covering underwater pipelines and some for the construction industry in the local markets.

Eight fractions were produced for the local market and construction purposes. 6% of the orders were served from Dirdal, approximately 27% of this being delivered to customers outside its cluster. These orders outside the region were mostly delivered to a terminal owned by NorStone, which is considered as a customer.

4.5.4 Jelsa plant

Fractions available at this plant are not so different from those at the Tau plant. 10% of the orders were delivered from this plant. These were 50 individual orders; 10 of which were delivered outside its cluster to either a terminal (customer) and a few other customers.

4.5.5 Dimmelsvik plant

Dimmelsvik which located between Clusters 1 and 2 is surrounded by a few customer locations and is the smallest plant owned by NorStone. It received the smallest percentage of orders i.e. 3%. This was made up of 14 orders, two of which were delivered to customers outside the 50mile radius. However these customers were within the 50mile radius in linear terms but due to the fjord system, the distance for the route was more than 50miles.

4.5.6 Askøy plant

The production plant at Askøy has products which are similar to those found at Tau; the difference between these two is attributed to the quality of the raw material base. Fraction made available over the period at Askøy were 21 i.e. 5fractions more compared to Tau. However, it received 18% of the orders compared to the 21% received at Tau. Similarly, a few of the orders were delivered outside its cluster; approximately 3%.

Figure 4.3 illustrates the percentages of orders received at each of the plants and the proportion of those orders which were not delivered within the 50mile radius (orders outside) which determines the bound of each cluster. The illustration is shown in an order of the plant with the greatest percent of received orders to the least percentage of orders received.

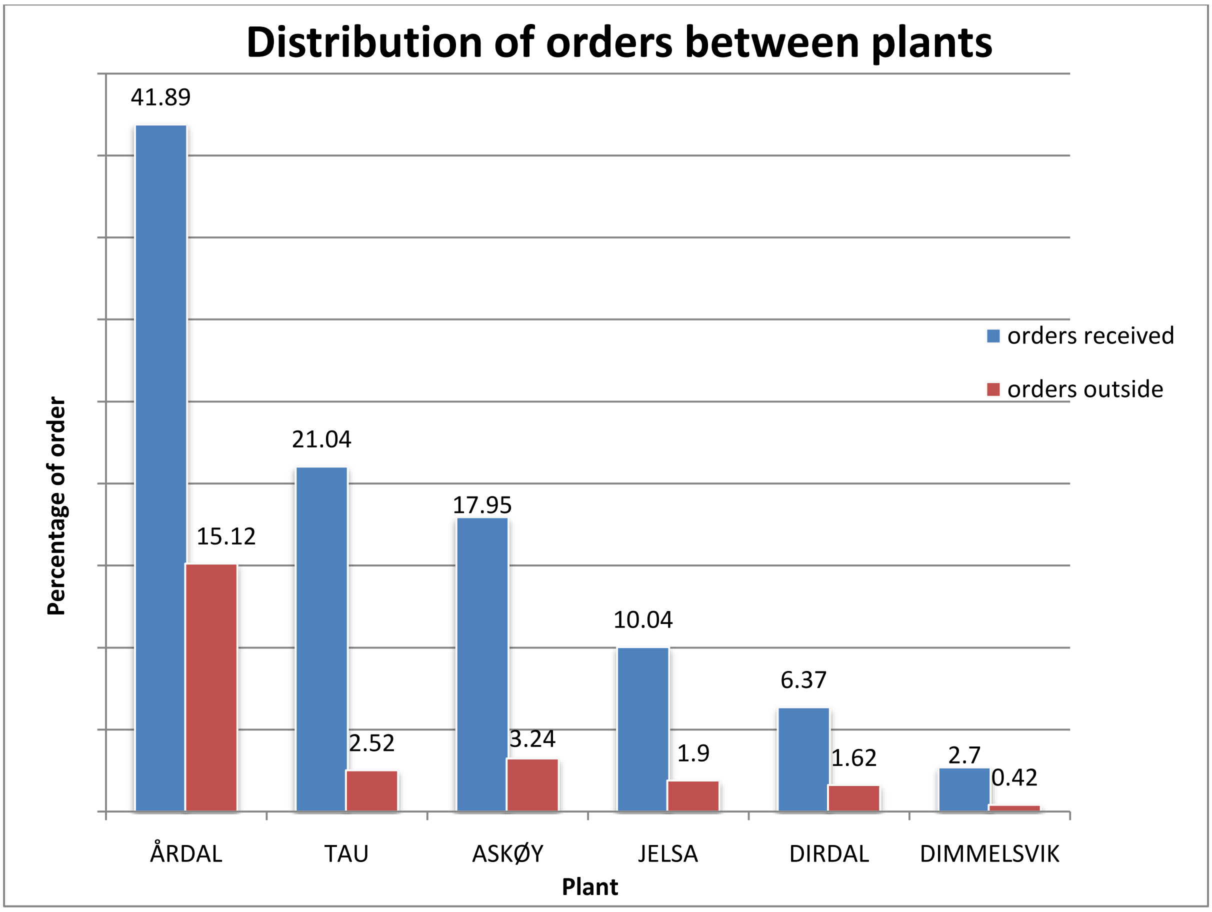

Figure 4.3: Graph showing the distribution of orders between plants

4.6 *Comparison of coverage*

From Figure 4.2 and product availability at each plant described in the previous sections, the following conclusions can be made for each of the clusters:

Cluster 1 with the plants Jelsa, Tau, Årdal and Dirdal: customers within this cluster can be sufficiently served when the product varieties at these plants are combined and in addition to the high production rates here. It can also be realised that these four plants are located within an area which has most of the customer located. This serves as a strategic positioning of the plants to serve a wider coverage and thus service greater portion of the customers.

Cluster 2 has customers served by a single production plant being Askøy. Relatively, there are fewer customers within this cluster compared to Cluster 1. The number of fractions produced at Askøy was the highest for any single plant; ensuring that most of the demands are covered. Some of the orders for this region were served from the plants located in Cluster

1 in order to boost inventory levels and also to serve demands of particular quality e.g. DuraSplitt® from Tau.

Cluster 3 which is also served by a single plant located at Dimmelsvik has the least number of customers, receiving only 14 orders in the whole 3 month period. Even though the number of fractions available here is small, the customers are covered quite well. A few orders were however served from Cluster 1 and 2 but these were delivered to the plant itself when inventory levels were low.

Analysis of the customer distribution, product availability, the comparison of coverage and the percentage of orders received and served within each cluster and outside indicates that close to 90% of the orders are delivered within the 50 mile radius. These are short distances covered in about 4 hours. The other 10% are distances which fall between 60 to 140 miles and completed in about 5 – 9 hours.

4.8 Demand Distribution

Table 4.02 shows the number of orders received at each plant in the whole peak season i.e. 3 months. From the number of orders received, an average number of orders per week have been determined. The number of weeks in the whole three months was taken to be 12.

The average number of orders per week is determined as

$$\frac{Number\ of\ orders}{12}$$

Plant	Number of Orders	Average orders Per week	Cluster	Estimated
TAU	108	9.00	34.17	40
ÅRDAL	217	18.08		
DIRDAL	33	2.75		
JELSA	52	4.33		
DIMMELSVIK	14	1.17	1.17	3
ASKØY	93	7.75	7.75	12
Total	517	43.08	43.08	55

Table 4.02: Demand distribution

Based on the location of each plant and the cluster to which is belongs, the average number of orders have been combined for each cluster.

Example: Cluster 1 is made up of Tau, Årdal, Dirdal and Jelsa; the average combined number of orders per week is therefore 34.17. From the real data, the number of orders received per week is between 30 and 45. The combined number of orders for Cluster 1 is within this range. However an estimated number of 40 orders is being used. In this way, the number of orders be used is close to the higher end to ensure robustness of the fleet size and composition.

The plant at Askøy received 93 orders with an average of 8 orders per week and the least number of orders received was received at the Dimmelsvik plant with an average of 1 order per week.

4.7 Other data

Other data used in the analysis included inventory holding capacities for various fractions available at each production site and their production rates. Since production sites are located within a few meters of the raw materials and shortages rarely occur, values for production rates are set so that stock-outs do not occur and no overflow of inventory occurs at the end of the planning horizon.

Actual capacities of vessels were obtained for those with such data available and for those which were not available; their maximum tonnage within the study period was used as capacity. Data on vessel speed were also obtained, port restrictions as well as loading rates at the plants and unloading rates at the customer points.

CHAPTER FIVE
INTRODUCTION TO SOLVER

5.0 Overview of solver

The solver used to explore the fleet design for maritime transportation in NorStone in this thesis is developed by our supervisor Associate Professor Johan Oppen. The solver which is being developed as part of the "Ny logistikk løsning for NorStone" project as used for this thesis is in its preliminary development stage. It uses a greedy approach to construct solutions; an improvement heuristic would later be implemented. Implementation of the improvement heuristic is expected to give some percentage increase in the solution quality and hence all solutions at this stage have the same possibility to be improved.

The following steps explain how the solver is used to construct solutions:

- ✓ First, a plant with the fraction required is located. From previous chapters, it can be recalled that NorStone has six plants along the western coast of Norway. Each plant has more similar product types, just a few of specific products are produced by one particular plant. With this in mind, an order may be delivered by any plant which produces the required products. In order to ensure that the order is served from a single plant, the plant with the earliest feasible day to deliver the order (here time window for the customers' port will be considered) is chosen. As fractions are available at different plants, it is possible to serve the order from any of them.

- ✓ The strategy is to assign orders to vessel, starting with the order with the earliest time window, i.e. first come first serve. Each order is assigned to the vessel that can serve the order earliest and also has the needed capacity. The preference of such assignment of vessels to orders ignores the ratio of the order quantity to the vessel capacity. This could possibly give solutions reflecting partial utilization of the vessel capacity.

- ✓ Finally, a plant and vessel is assigned for the delivery of the order

- ✓ The list of orders is updated and steps repeated for the next order

5.1 Solver validation

A small instance of the problem which can be solved by hand is tested on the solver using Case 1. The solution from the solver has been evaluated for correctness and the ability of the solver to produce feasible solutions by comparing it with the hand solved solution. Feasibility of the solutions is based on the following:

5.1.1 Planning

The general planning to serve orders is such that allocations in terms of vessels and plants are made for the orders as they are received i.e. first-come, first-serve. The construction of initial solutions is expected to follow this sequence of assignment. An implementation of the improvement heuristic would have allowed this sequence to be altered in the search for better solutions. The solution generated was checked and the planning was done on the basis of first-come first-serve.

5.1.2 Vessel assignment / capacity

Capacity constraint imposed by the vessels ensures that an order assigned to a vessel is feasible and the vessel has enough capacity to deliver the order. The smallest vessel with enough capacity is the preferred option among the list of available vessels. With regards to these, assignment of vessels to a particular order followed the pre-defined rules and there were no violations, and only a single vessel served any single order.

5.1.3 Plant allocation

It can be recollected that with the similarity in fractions available at the various plants, an order could possibly be served by more than one plant with the exception of particular ones. From the solution generated by the solver, all orders were served from a single plant.

5.1.4 Time windows / Port times

Time windows could imply two things; opening times at ports and latest day for which an order has to be served. With regards to the opening time at customer ports, unloading or arrival is not allowed when the port is closed. And lastly, orders have to be served by the latest promised day. Another feature at the customer port is that, the ports are closed on day 7 (Sunday) and as such orders cannot be delivered.

5.1.5 Inventory levels

At this stage, fractions produced at the various plants are expected to be always available even though there are maximum inventory levels. It has been therefore allowed to have overflow of inventories during the planning horizon. This can however be controlled by adjusting the weekly production rates.

5.2 Real solution

Case 1 consists of 14 orders, with a total tonnage of 11870.90. Table 5.01 below shows the real solution plan for orders received in Week 18 (Case 1).

Vessels	Capacity	Order quantity				
		Day 1	Day 2		Day 3	
Bulk vessel no 1	1000	798.00	800.00		301.10	500.60
Bulk vessel no 2	1000	853.10	350.00	500.00	850.00	
Bulk vessel no 3	2000	1,750.00				
Bulk vessel no 4	1000	650.00				
Bulk vessel no 5	1000	806.00				
Bulk vessel no 6	2000		1,102.10	1,710.00		
Bulk vessel no 7	1000		900.00			

Table 5.01: Real solution from data Case 1

Seven vessels were used in serving these orders. Out of these, bulk vessels 3 and 6 have a capacity of 2000 tons and the remaining five vessels have a capacity of 2000 tons each. From the manual plan, bulk vessels 1 and 2 serve four orders each; bulk vessel 6 serves two orders and the remaining vessels (3, 4, 5 and 7) each serve single orders. Day 3 was the last day to complete all orders.

5.3 *Solver solution*

Testing data Case 1 on the solver gave the results presented in Table 5.2. The solution indicates that the set of 14 orders which was served by seven vessels could also be served by two vessels. All orders were completed by the end of Day 4 within the required time window. The initial solution generated by the solver indicated that three vessels were not used in serving any order. Following the exploitation used in determining an optimal fleet size, these vessels were eliminated. Bulk vessels 2, 4 and 5 were eliminated and the instance solved again. This left vessel 2 and 7 being utilized for a few orders and these were also eliminated. Testing this instance again with the reduced number of vessels from seven to two gave the results shown in Table 5.02.

Vessel	Days	Order	Start time	Loading time	Departure (from plant)	Arrival (customer port)	Unloading duration	Finish time
Bulk vessel no. 1	1	1	1.5	0.9	2.4	6	2.25	8.25
		2	10.85	1.7	12.55	14.65	4.25	18.9
	2	3	0	0.8	0.8	6	2	8
		4	11.9	1.7	13.6			
	3	4				6	4.25	10.25
		5	14.45	1.1	15.55			
	4	5				6	2.75	8.75
Bulk vessel no. 6	1	6	1.36	0.7	2.06	6	1.75	7.75
		7	9.39	0.65	10.04	12.67	1.63	14.3
		8	15.21	0.8	16.01			
	2	8				6	2.02	8.02
		9	9.11	0.35	9.46	10.82	0.88	11.7
		10	12.6	0.5	13.1	13.92	1.25	15.17
		11	15.99	1	16.99			
	3	11				6	2.5	8.5
		12	8.77	0.7	9.47	11.38	1.75	13.13
		13	15.04	0.5	15.54			
	4	13				6	1.25	7.25
		14	9.89	0.9	10.79	11.7	2.25	13.95

Table 5.02: Solution from solver using data Case 1

From Table 5.02, we can see that 2 bulk vessels were able to serve all the orders by the end of day 4 which is within the time window of the last order received. There is a time fulfilment of 1 to 2 days within which an order has to be served. From this, an order received on day 3 will be served on day 3 as the earliest day and day 5 as the latest day.

All order started and were served on the same day except order 4, 8, 11 and 13 which started in the middle of the day and were completed the next day. These have been highlighted as seen in Table 5.02.

Taking order 8 as an example, it starts at time 15.21 on day 1; the vessel is loaded and ready to leave at time 16.01 (4 pm). At this time, there is just 6hours remaining for the customer port to close which implies that the travel time and unloading time should be at most 6hours in total. This is actually not enough time to have the unloading completed. The vessel is allowed to wait at the customer port and unloads at time 6 (6 am) on day 2 when the port opens. This feature applies in practice in the operation of port activities.

5.3 Comparison of solutions

From the solution given by the real planning and the solver generated solution, the utilization of the vessels have been calculated and shown in Table 5.03. The utilization has been given in terms of the number of orders served by each vessel and also by the percentage of the total demand carried by each vessel.

Vessels	Utilization	
	Number of orders served	% tonnage of total demand
Bulk vessel no 1	4	21.94
Bulk vessel no 2	4	21.53
Bulk vessel no 3	1	13.81
Bulk vessel no 4	1	5.28
Bulk vessel no 5	1	6.55
Bulk vessel no 6	2	22.75
Bulk vessel no 7	1	8.13
Total	14	100

Table 5.03(a): Utilization of vessels from real solution

Vessels	Utilization	
	Number of orders served	% tonnage of total demand
Bulk vessel no 1	9	49.62
Bulk vessel no 6	5	50.38
Total	14	100

Table 5.03(b): Utilization of vessels from solver generated solution

The utilization of vessels under the real plan has a maximum of 22.75% with two orders being served. This in actual sense may be considered as biased as bulk vessel 6 has a capacity which is twice that of bulk vessel 1. Bulk vessel 1 serves 4 orders serving 21.94% of the orders.

The reduced fleet size in the solver generated solution gave a share of approximately 50% each to both bulk vessels used. Five orders were served by bulk vessel 6 and 9 orders by bulk vessel 1.

The poor utilization of the vessels in the real plan is partly due to their use outside the Rogaland and Hordaland region. The vessels were put to use based on their availability within the period. The solution from the solver represents how vessels could be used to serve orders only within the region, and thus having a small fleet to serve orders.

CHAPTER SIX

DETERMINING THE FLEET SIZE

6.0 Research Objectives

The objectives of this research include:

- ✓ An analysis to determine an optimal fleet design for the transportation and distribution of the various sand and stone products to the customers of NorStone.
- ✓ Possibilities of using alternative vessels e.g. larger vessels which give a reduced unit cost compared to smaller vessels.
- ✓ The use of tugboats and barges which give more flexibility and time saving which can be directed into serving more orders.

The different contracts would also be taken into consideration, capacities of the vessels and efficiencies when these objectives are being analyzed.

6.1 Research Questions

Some questions which could be addressed include:

- How many barges can one tugboat handle efficiently?
- How many extra orders can a vessel with more efficient discharging equipment serve in a given time horizon?
- How much waiting time would disappear if all ports were open 24/7?
- How many tugboats and barges are needed to replace a given number of traditional bulk vessels?

6.2 Research Tasks

The research tasks addressed in this study covers the geographical distance from the production site to the customer and the weight of the product.

- ✓ Solving the fleet size and mix problem using problem instances
- ✓ Comparison of solutions when alternative vessels in the market are used

Comparing solutions or plans can answer questions which have been listed in Section 6.1.

The possible use of alternative vessels would be as follows:

- Tugboats and barges
- Bulk vessels with more efficient discharging equipment

6.3 Exploring the fleet size

In the search for a minimum fleet size, it is important to have an idea as to how the fleet size could be, given a particular instance and conditions of the problem. The fleet size for any problem instance is affected by a number of factors. These include the volume of demand and distribution of customers, and the business strategy being adopted[20].

In theory and practice, a high volume of demand would require a large fleet size and vice versa. The distribution of customer locations determines the tour duration. Having a widely dispersed customer locations would also require and large fleet size compared to a less dispersed distribution in order to serve them within a given planning horizon. Analysis of data for this study has indicated that customers are quite dispersed within the region. However, they are located in clusters which are in close proximity to the plants. The distances here are quite short and a large percentage of orders are served within each cluster. Comparing the percentage of orders received in each cluster, it is expected that Cluster 1 would have a larger fleet size compared to Cluster 2. Cluster 3 would have the smallest fleet size.

NorStone AS is known to be a leader in their market, and their success has been based on high quality of products together with a high level of customer service. The order fulfillment is within one to two days after an order is received. Operating with a large fleet gives more flexibility and an increased order fulfillment rate but this is associated with a high cost. Operating with a smaller fleet gives a lower cost but with reduced flexibility. A balance between these has to be achieved when searching for the optimal fleet.

It has to be pointed out that in maritime transportation industry where there are huge costs associated with investing in a vessel, it would not always be possible to change the fleet size. It is therefore important to find a fleet size which is capable of satisfying the varying demand in most periods of the year. This serves as the basis for choosing demand from the peak season as it is characterized by high volumes of demand. The number of orders received each week ranges from 30 to 45. A fleet size capable of satisfying orders in this period would also be capable of serving orders in the off-peak season.

The order quantities are as low as a few hundred tons to as high as five thousand tons. The current vessels have different capacities and therefore fleet composition is heterogeneous. Another distinguishing feature in solving instances is the starting point for each vessel. Changing the starting point of a vessel can give a different solution in terms of cost and number of orders served due to the change in distance. In practice, all vessels start at the plant. If the fleet size is larger than the number of plants, then some of them have to start from a customer point. This is because each port has only one berth and accommodates a single vessel at any time.

The fleet composition being determined in this study does not consider cost associated with operation but rather focuses on increasing productivity of the fleet. Increasing productivity of the fleet results in an increase in revenue gained from their operation. The fleet design is also expected to give flexibility and maintain the high customer service rate or improve it if possible.

6.4 Fleet sizing principle

The principle underlying the exploitation of the sizing problem is to remove vessels which carry high costs. In this thesis, vessels which are used less frequently are eliminated. Currently, the fleet size is very large as vessels also operate both within the region and outside. Consequently some vessels are used more than others partly due to their availability. Solving Case 1 as a test instance outlines this situation. Solving the same case with the solver leaves some vessels not being used as orders are better served with other vessels while some vessels are used to serve several demands. The stepwise elimination of less frequently used vessels and subsequent testing ends with in a minimum fleet size which is capable of serving all orders. Orders are served within their respective time windows and at an early time in the planning horizon. At this point, elimination of any other vessel from the fleet will leave some orders not being served.

6.5 Solving instances with traditional bulk vessels

Traditional bulk vessels currently in operation are quite old and their capabilities in terms of travel speed and efficiency is low compared to modern vessels. The travel speed for the traditional bulk vessel is 12 knots when there is no cargo onboard and 10 knots when with cargo. In addition, the bulk vessels have to wait at the customer port for unloading to be completed before they would be available to serve any other order.

6.5.1 Minimum fleet size for Cluster 1

Problem Case 2, which has been selected from week 24, is solved with traditional bulk vessels. The real solution from the data set had nine bulk vessels used in serving the 39 orders received in the week.

Run 1

In determining the minimum fleet size, an initial run was done based on the nine vessels. Table 6.01(a) shows the distribution of orders between the vessels as they are assigned to serve these orders.

Bulk vessels	1	2	3	4	5	6	7	8	9
Orders served	2003	1700	750	1650	950	1096	587	1100	1009
	800	805	756	1650	646	1013	502	1650	591
	2100	2000	800	1656			570	2005	1500
	2107	1240	800					2500	805
	2140							2105	800
								800	1805
								2500	1254
								1120	1500

Table 6.01(a): Initial solution for Case 2 using 9 traditional bulk vessels

The results from the initial solution show that orders are distributed unevenly among the vessels. Most orders were completed by bulk vessels 8 and 9. Bulk vessels 8 and 9 would therefore be expected to have a higher utilization compared to the others.

The utilization of the vessels have been estimated and presented in Table 6.01(b).

$$Utilization = \frac{Total\ tonnage}{Total\ weekly\ demand} \times 100$$

Vessel	1	2	3	4	5	6	7	8	9	Total
Number of orders	5	4	4	3	2	2	3	8	8	39
Total tonnage	9150	5745	3106	4956	1596	2109	1659	13780	9264	51365
Percentage of demand	17.81	11.18	6.05	9.65	3.11	4.11	3.23	26.83	18.04	100.00

Table 6.01(b): Utilization of bulk vessels in the initial solution (9)

As was expected, bulk vessels 8 and 9 carried a larger percentage of the total demand with utilization of 26.83% and 18.04% respectively. Bulk vessels 5 and 7 had the least utilization and therefore selected to be removed. Even though bulk vessel 7 served one order more than bulk vessel 6, vessel 6 had a higher utilization. This is because bulk vessel 6 has a larger capacity and therefore serving only two orders gave a total tonnage greater than the total tonnage of vessel 7 with three orders. Maintaining bulk vessel 6 in the subsequent run would also be able to serve orders which were previously served by vessel 7.

Run 2

Run 2 of Case 2 is done with a reduced number of vessels. The number of vessels here is 7. Orders completed by each vessel is summarized and presented in Table 6.02(a). The results from Run 2 show an improvement in the distribution of orders among the current number of vessels.

Bulk vessels	1	2	3	4	6	8	9
Orders served	2003	1700	750	1100	587	1650	1009
	950	805	756	1650	502	2005	1650
	2500	1500	800	2105	570	1096	591
	2000	1013	646	1656		2100	800
	2107	1240	800			800	805
	2140					2500	800
						1120	1805
							1254
							1500

Table 6.02(a): Solution from Run 2 with reduced number of bulk vessels

Similar to Run 1, the utilization of the vessels from Run 2 has been estimated and presented in Table 6.02(b). The number of orders served by each vessel has increased compared to the previous run. Again, the vessel with the least utilization has been selected to be removed. Bulk vessel 6 is thus eliminated from the current fleet

Vessel	1	2	3	4	6	8	9	Total
Number of orders	6	5	5	4	3	7	9	39
Total tonnage	11700	6258	3752	6511	1659	11271	10214	51365
Percentage of demand	22.78	12.18	7.30	12.68	3.23	21.94	19.89	100.00

Table 6.02(b): Utilization of bulk vessels in Run 2 with reduced number of bulk vessels(7)

Run 3

Bulk vessel 6 was eliminated and the problem solved with a current fleet size of 6. More improvements has been realised in the current solution when compared to the initial solution where 9 vessels were being operated.

Bulk vessels	1	2	3	4	8	9
Orders served	2003	750	587	1650	1100	1009
	805	1700	756	1096	1650	591
	2100	1650	800	2105	2005	950
	646	502	805	1656	1500	800
	2000	1013	800		2500	570
	2107	1240			800	800
	2140				2500	1805
					1120	1254
						1500

Table 6.03(a): Solution from Run 3 with 6 bulk vessels

Table 6.03(b) shows the distribution of orders between the six vessels and the number of orders served by each. Similarly, the utilization which is the percentage of the total demand carried by each bulk vessels has been calculated. Bulk vessel 3 with the least utilization of

7.30% has been selected to be eliminated. The number of vessels therefore reduces from six to five in the next run.

Vessel	1	2	3	4	8	9	Total
Number of orders	7	6	5	4	8	9	39
Total tonnage	11801	6855	3748	6507	13175	9279	51365
Percentage of demand	22.97	13.35	7.30	12.67	25.65	18.06	100

Table 6.03(b): Utilization of bulk vessels in Run 3 with reduced number of bulk vessels(6)

Run 4

In Run 4, the number of vessels has been reduced from six in the previous solution to five. In solving each subsequent run, vessels are relocated to start at the plants. In this way, the solution quality improves further compared to a starting point at a customer port. As the solution quality improves with the reduced number of vessels, more orders are assigned to each vessel in the planning horizon.

Table 6.04(a) below is the results from Run 4 showing the orders served by the current fleet.

Bulk vessels	1	2	4	8	9
Orders served	2003	1100	587	1650	1009
	805	1650	750	2005	1700
	2100	1650	756	1096	591
	2105	502	800	1500	950
	2107	1013	805	2500	800
	2140	1656	570	2000	646
		1120	800	800	800
				2500	1240
				1254	1805
					1500

Table 6.04(a): Solution from Run 4 with 5 bulk vessels

The steps so far adopted in reducing the fleet size are repeated. The utilization rates are calculated and bulk vessel 4 is found to have the least utilization.

Vessel	1	2	4	8	9	Total
Number of orders	6	7	7	9	10	39
Total tonnage	11260	8691	5068	15305	11041	51365
Percentage of demand	21.92	16.92	9.87	29.80	21.50	100.00

Table 6.04(b): Utilization of bulk vessels in Run 4 with reduced number of bulk vessels(5)

Comparing the number of orders completed shows that bulk vessel 4 served seven orders with a utilization of 9.87%. Bulk vessel 1 served six orders with a utilization of 21.92% which is higher than bulk vessel 4. This observation is attributed to the different capacities of these two vessels. Bulk vessel 1 has a higher capacity and hence serving a lower number of orders, gives it a total tonnage higher than the total tonnage of bulk vessel 4.

Run 5

Run 5 is gives a solution to problem Case 2 when operating a current fleet size of four bulk vessels. All vessels start at a plant since the current number of vessels is equal to the number of plants.

Bulk vessels	1	2	8	9
Orders served	1100	587	1650	1009
	1650	750	2003	1700
	1096	756	2005	591
	950	805	800	1650
	502	800	2100	1500
	646	805	2500	1013
	800	570	2105	2000
	800	800	2107	1656
	1805		2500	1240
	1500			1254
				1120

Table 6.05: Solution from Run 5 with 4 bulk vessels

The solution from Run 5 had all orders completed except one. The fleet size in Run 5 is therefore not able to serve all orders within the planning horizon. The solution to Case 2 would be to use a fleet size of five bulk vessels as in Run 4. However, a careful analysis of the results from Run 5 showed that there is enough time to serve the remaining order. The number of orders served by vessel 2 in comparison with the other vessels indicates that is possible for it to serve an additional order. This was not possible because the demand quantity of the order which was not served was higher than the capacity of vessel 2. Instead of using a fleet size of 5 in Run 4, bulk vessel 2 is replaced with a vessel with enough capacity to serve the remaining order. It is thus expected that this new vessel would be able to serve the orders originally served by bulk vessel 2 and the remaining order.

Final solution

The final solution to Case 2 using bulk vessels was obtained by replacing bulk vessel 2 in Run 5 with a vessel with larger capacity. In doing this, all 39 orders were served in week 24 and the last order was completed on day 6.

Table 6.06 illustrates the activities of the bulk vessels from the solution to Case 2. The last order is completed on day 6 and bulk vessel 3 completes its last order on day 5 as seen in Table 6.06(b). It is therefore possible for bulk vessel 3 to serve one additional order which would be completed on day 6. This additional order would give a total number of orders being served to be 40.

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No 1	1	1	0.909	0.587	1.496	6.000	1.468	7.468
		2	10.104	0.750	10.854	13.490	1.875	15.365
	2	3	0.000	0.756	0.756	6.000	1.890	7.890
		4	8.799	1.650	10.449	13.995	4.125	18.120
		5	21.392	0.502	21.894			
	3	5				6.000	1.255	7.255
		6	8.891	0.646	9.537	11.901	1.615	13.516
		7	15.880	0.570	16.450			
	4	7				6.000	1.425	7.425
		8	9.061	0.800	9.861	11.680	2.000	13.680
		9	15.498	1.240	16.738			
	5	9				6.000	3.100	9.100
	6	10	11.009	1.805	12.814	15.451	4.513	19.963

Table 6.06(a): A set of solution for fleet size of data Case 2 (Bulk vessel No. 1)

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No.3	1	11	0.900	1.100	2.000	6.000	2.750	8.750
		12	10.350	2.003	12.353	12.753	5.008	17.761
	2	13	0.000	1.096	1.096	6.000	2.740	8.740
		14	11.640	0.950	12.590	15.490	2.375	17.865
		15	22.265	0.800	23.065			
	3	15				6.000	2.000	8.000
		16	10.100	2.500	12.600	12.700	6.250	18.950
		17	19.550	2.000	21.550			
	4	17				6.000	5.000	11.000
		18	12.200	0.800	13.000	14.900	2.000	16.900
		19	18.700	2.500	21.200			
	5	19				6.000	6.250	12.250

Table 6.06(b): A set of solution for fleet size of data Case 2 (Bulk vessel No. 3)

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No.8	1	20	1.091	1.650	2.741	6.000	4.125	10.125
		21	11.580	1.650	13.230	14.321	4.125	18.446
		22	19.536	2.005	21.541			
	2	22				6.000	5.013	11.013
		23	13.013	0.800	13.813	15.540	2.000	17.540
		24	18.903	2.100	21.003			
	3	24				6.000	5.250	11.250
		25	13.523	2.105	15.628			
	4	25				6.000	5.263	11.263
		26	13.081	0.800	13.881	14.790	2.000	16.790
		27	18.608	2.107	20.715			
	5	27				6.000	5.268	11.268
		28	11.813	2.140	13.953	14.498	5.350	19.848
	6	29	0.000	1.500	1.500	8.000	3.750	11.750

Table 6.06(c): A set of solution for fleet size of data Case 2 (Bulk vessel No. 8)

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No.9	1	30	0.455	1.009	1.464	6.000	2.523	8.523
		31	10.432	1.700	12.132	13.495	4.250	17.745
	2	32	0.000	0.591	0.591	6.000	1.478	7.478
		33	9.114	0.805	9.919	11.555	2.013	13.568
		34	17.386	1.500	18.886			
	3	34				6.000	3.750	9.750
		35	10.205	0.805	11.010	14.828	2.013	16.840
		36	20.658	1.013	21.671			
	4	36				6.000	2.533	8.533
		37	13.260	1.656	14.916			
	5	37				6.000	4.140	10.140
		38	12.413	1.254	13.667	15.303	3.135	18.438
		39	21.165	1.120	22.285			
	6	39				8.000	2.800	10.800

Table 6.06(d): A set of solution for fleet size of data Case 2 (Bulk vessel No. 9)

*Order numbers from the table distinguish separate orders but do not reflect the actual order number from the problem case

The minimum fleet size to Case 2 using traditional bulk vessels from the solution is four. This is a heterogeneous fleet with capacities 2000, 2000, 2500 and 2500.

6.5.2 Minimum fleet size for Cluster 2

Problem Case 3 from week 20 has been selected to determine a fleet design for customers in Cluster 2. Cluster 2 has a single plant serving the surrounding customers. Case 2 is made up of 15 orders and the real solution had orders being completed with six bulk vessels.

Run 1

In solving Case 2 with the bulk vessels, the solution which was determined indicated that the number of vessels needed to complete 39 orders was four. Therefore in solving Case 2 with 15 orders, the starting number of vessels chosen was three.

Table 6.07 shows the distribution of orders between the vessels and their utilization.

Bulk vessel	1	2	4
Orders served	800	800	1750
	850	860	1650
	800	196	600
	1500	1250	
		660	
		1652	
		900	

Table 6.07(a): Initial solution for Case 3 using 3 traditional bulk vessels

Vessel	1	2	4	Total
Number of Orders	4	7	3	14
Total tonnage	3950	6318	4000	14268
Percentage of demand	27.68	44.28	28.03	100.00

Table 6.07(b): Utilization of bulk vessels in the initial solution (9)

From the utilization rates, vessel 1 has been selected to be eliminated in the subsequent run.

Run 2

Solving Case 3 with two bulk vessels gives an improvement is the distribution of orders between the vessels. The result for the distribution of orders is presented in Table 6.08(a) and their utilization shown in Table 6.08(b).

Bulk vessel	2	4
Orders served	800	800
	860	1750
	1650	850
	800	196
	1250	600
	660	
	1500	
	1652	
	900	

Table 6.08(a): Solution from Run 2 with 2 bulk vessels

Vessel	2	4	Total
Number of Orders	9	5	14
Total tonnage	10072	4196	14268
Percentage of demand	70.59	29.41	100.00

Table 6.08(b): Utilization of bulk vessels in Run 2 with reduced number of bulk vessels

The result from Run 2 gives an optimal fleet size as any further decrease in the number would have some orders not being served. The fleet composition is homogeneous with a capacity 2000 tons.

The last orders are completed on days 3 and 6 for each bulk vessel. It is thus possible for the current fleet size to serve some additional orders. Table 6.09 shows the serving of orders by bulk vessels at different times of the day within the week

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No.2	1	1	0.909	0.8	1.709	6.255	2	8.255
		2	12.8	0.86	13.66	14.66	2.15	16.81
		3	17.81	1.65	19.46			
	2	3				6	4.125	10.125
		4	13.943	0.8	14.743			
	3	4				6	2	8
		5	11.818	1.25	13.068	15.341	3.125	18.466
	4	6	0	0.66	0.66	6	1.65	7.65
		7	8.559	1.5	10.059	11.423	3.75	15.173
		8	16.536	1.652	18.188			
	5	8				6	4.13	10.13
		9	12.312	0.9	13.212			
	6					6	4.25	10.25

Table 6.09(a): A set of solution for fleet size for Cluster 2 (Bulk vessel No. 2)

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No.4	1	1	2.909	0.8	3.709	6.891	2	8.891
		2	12.073	1.75	13.823	15.914	4.375	20.289
		3	22.28	0.95	23.23			
	2	3				6	2.125	8.125
		4	8.307	0.196	8.503	10.685	0.49	11.175
	3	5	12.456	0.6	13.056	18.456	1.5	19.956

Table 6.09(b): A set of solution for fleet size for Cluster 2 (Bulk vessel No. 4)
*Order numbers from the table distinguish separate orders but do not reflect the actual order number from the problem case

6.5.3 Minimum fleet size for Cluster 3

Cluster 3 has a single plant located at Dimmelsvik, with about 4 customers located around it. The data analysis showed that the average number of order received per week is one. An estimated number of orders served from this plant is given to be three in order to cater for unexpected demands.

A fleet size for this cluster can therefore be determined without necessarily using the solver. Based on previous knowledge gained from determining the fleet size for Cluster 1 and 2, the number of bulk vessels required for Cluster 3 would be one. One bulk vessels is capable of serving more than three orders in a week. Choosing a capacity for this single vessel is based on the order quantities received. Based on these order quantities, the preferred capacity to use in this case is 3500 tons.

6.5.4 Combining Clusters 2 and 3

The fleet composition which was determined for Cluster 2 had two bulk vessels. Nine orders were served by one vessel and five by the other vessel (Table 6.04(a)). It is also possible for this fleet size to serve additional orders within the planning horizon. The fleet composition also determined for Cluster 3 had one bulk vessel serving an estimated number of three orders per week. The number of orders served is below the average number of orders served by any single vessel per week.

In order to put the bulk vessel in Cluster 3 to more work, it was quite reasonable to combine Clusters 2 and 3 given their close proximity. The total number of orders would be 18; the number of plants is two; approximately 80% of the distances are within 60 miles from the plant at Askøy and the remaining 20% are within 70 – 110 miles since they would be located in Cluster 3.

Combining the fleet from the two clusters gives a total of three bulk vessels with capacities 3500, 2000, and 2000 tons. In solving the problem with combined clusters, the initial run is based on four bulk vessels.

Table 6.10 shows the distribution of orders and the utilization which is the percentage of the total demand served by each vessel.

Run 1

Bulk vessel	1	2	3	4
Orders served	800	860	1750	800
	660	850	1250	1650
	905	800	3500	600
	900	1500	2507	196
		402		
		1652		

Table 6.10(a): Initial solution for combined clusters using 4 traditional bulk vessels

Vessel	1	2	3	4	Total
Number of Orders	4	6	4	4	18
Total tonnage	3265	6064	9007	3246	21582
Percentage of demand	15.13	28.10	41.73	15.04	100.00

Table 6.10(b): Utilization of bulk vessels in the initial solution

From the utilization of each vessel, vessel 4 was selected for elimination. Run 2 is done with three bulk vessels.

Run 2

Solution tables from Run 2

Bulk vessel	1	2	3
Orders served	800	1750	800
	850	196	860
	800	1250	1650
	1500	660	3500
	905	402	2507
	900	1652	600

Table 6.11(a): Solution from Run 2 with 3 bulk vessels

Vessel	1	2	3	Total
Number of Orders	6	6	6	18
Total tonnage	5755	5910	9917	21582
Percentage of demand	26.67	27.38	45.95	100.00

Table 6.11(b): Utilization of bulk vessels in Run 2 with 3 bulk vessels

Run 3

In Run 3, bulk vessel 1 from the previous run has been eliminated and the solution is based on two bulk vessels. The solution obtained showed that three orders were not served when vessel 1 is eliminated. This is due to the long distances which the bulk vessels have to cover between the two clusters.

The fleet composition is the same as directly combining the individual clusters. However, with the combination of the clusters, the bulk vessel from Cluster 3 has more orders to serve. The capacities for this heterogeneous fleet would be 2000, 2000 and 3500 tons.

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No. 1	1	1	0.9	0.8	1.7	6.7	2	8.7
		2	13.7	0.85	14.55	14.75	2.125	16.875
		3	17.075	0.8	17.875			
	2	3				6	2	8
	4	4	0	1.5	1.5	6	3.75	9.75
	5	5	11.25	0.905	12.155			
	6	5				6	2.263	8.263
		6	18.0625	0.9	18.9625	8	2.25	10.25

Table 6.12(a): A set of solution for fleet size when combining Clusters 2 and 3

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No. 2	1	7	7.545	1.75	9.295	11.386	4.375	15.761
	2	8	0.125	0.196	0.321	6.048	0.49	6.538
		9	7.447	1.25	8.697	10.97	3.125	14.095
	4	10	0	0.66	0.66	6	1.65	7.65
		11	8.559	0.402	8.961			
	5	11				6	1.005	7.005
		12	19.459	1.652	21.111			
	6	12				8	4.13	12.13

Table 6.12(b): A set of solution for fleet size when combining Clusters 2 and 3

Vessel	Day	Order*	Starting time	Loading duration	Departure from plant	Arrival time (customer port)	Unloading duration	Finish time
Bulk vessel No. 4	1	13	3.181	0.8	3.981	7.163	2	9.163
		14	12.345	0.86	13.205	14.205	2.15	16.355
		15	17.355	1.65	19.005			
	2	15				6	4.125	10.125
	4	16	0	3.5	3.5	9.318	8.75	18.068
		17	21.613	2.507				
	5	17			0.12	8.484	6.267	14.751
		18	22.933	0.6	23.533			
	6					8	1.5	9.5

Table 6.12(c): A set of solution for fleet size when combining Clusters 2 and 3

Table 6.12 shows the operation of bulk vessels when the two clusters are combined. Orders which are completed on a second day after being started on the previous are a result of the long distances which have to be covered in order to serve the customer. These orders could have as well been served from the cluster to which they belong in a much shorter time. No orders were served on day 3 for all the vessels. Additional orders can therefore be served apart from the 18 orders being used in this instance.

6.6 Solving instances with Tugboats and barges

Problem Case 2 with 39 orders which has been previously solved with traditional bulk vessels is again being solved using tugboats and barges. From this, an assessment can be made on the fleet size and the completion day for the last order.

Tugboats are highly manoeuvrable vessels by pulling barges or moving ships. The idea of using tugboats and barges is to save the waiting time from unloading to improve the utilization. As mentioned before, bulk vessels have to wait until all products are unloaded, before they can leave the customer port to production site to pick up another order.

At an unloading rate of 400 tons per hour, it will take approximately 5 hours to unload an order quantity of 2000 tons. Within these five hours, the tugboat can leave from the customer port right away after dropping the barge since it does not need to wait for the unloading activity. In practice, the speed of tugboats is higher than bulk vessels. The speed is 12 miles per hour if the tugboat is pulling a loaded barge; 15 miles per hour if pulling an empty barge and 17 miles per hour when travelling without a barge. Increasing the order quantity gives the tugboat more time which can be used in carrying out other activities.

From the small example in Section 3.6.1, a tugboat can handle up to two barges sufficiently. Exploiting the fleet size using tugboats and barges from this concept can be approached with a tugboat / barge ratio of 2:1. Hence, three tugboats would work with six barges.

6.6.1 Minimum fleet size for Cluster 1

In this case, there are 39 orders in week 24. Based on the tugboat / barge ratio, the problem is initially solved with three tugboats and six barges. And the capacities chosen for the barges were 2000 and 2500 based on the order quantities. Three barges each for the capacities chosen.

Run 1

Table 6.13(a) shows the operation of the barges as they are used in serving orders. Day 1 is seen to be utilised more with each barge serve two orders. Not many orders are served in the remaining days by each barge as the orders are spread over all the barges. The last order in this initial solution is completed on day 6.

Barges / Day	Barge no.1	Barge no.2	Barge no.3	Barge no.4	Barge no.5	Barge no.6
Day 1	587 1650 805	750 1650	2003 756	1100 1700 1096	1650 2005	1009 591
Day 2	800	502	2100	2000	800	950
Day 3	1013	646	2105		1500 2500	805
Day 4		1240	2107	800	570 800	800
Day 5			112	1656 1254	2500 2140	1805
Day 6						1500

Table 6.13(a): Initial solution for Case 2 using tugboats / barges

Based on the orders served by each barge, their utilization as a percentage of the total demand in Week 24 have been estimated and presented in Table 6.12(b). the number of orders served has also been shown.

$$Utilization = \frac{Total\ tonnage}{Total\ weekly\ demand} \times 100$$

Barge	1	2	3	4	5	6	Total
Number of orders	5	5	6	7	9	7	39
Total tonnage	4855	4788	9183	9606	14465	7460	50357
Percentage of demand	9.64	9.51	18.24	19.08	28.72	14.81	100.00

Table 6.13(b): Utilization of barges in the initial solution

From the utilization rates, barges with the least utilization were selected and taken out. These are barges 1 and 2. The problem case is then solved again with this new reduced number of barges. The subsequent solution is then based on three tugboats and four barges.

Run 2

Run 2 is the subsequent solution to problem Case 2 with the reduced number of barges. The solution from this is presented in Table 6.14(a). The table shows the number of orders completed daily by each barge. The last order is completed on day 5 compared to day 6 in Run 1.

Barges / Day	Barge no.3		Barge no.4			Barge no.5		Barge no.6		
Day 1	587	2003	1100	1700	591	1650	2005	1009	750	1650
Day 2	2100		756	1500		805	800	1650	950	
Day 3	2500	646	1013			800	2105	520	805	
Day 4	800	2500	570	1656		800	2107	2000	800	
Day 5	112		1500			2140	1254	1240	1805	

Table 6.14(a): Solution from Run 2 with reduced number of barges

The utilization rate from Run 2 has its lowest to be 20.62%, compared to 9.51% in the initial run. The number of orders served by the barges is fairly distributed in this solution.

Barge	3	4	5	6	Total
Number of orders	9	9	10	11	39
Total tonnage	12344	10386	14466	13179	50375
Percentage of demand	24.50	20.62	28.72	26.16	100.00

Table 6.14(b): Utilization of barges from Run 2

Since the tugboats and barges work in a ratio of 1:2, the current number from Run 2 does not follow this pattern. The number of tugboats is therefore reduced from three to two. In this way, there would be two tugboats working with four barges which is 2*(1:2).

Run 3

Results obtained from Run 3 when problem Case 2 is solved with two barges and four tugboats indicated that not all customer orders were served. From the solution, 10 orders were not served in the week. This is because the current fleet size is too small to complete all the orders within the week.

Run 4

The problem was solved again with an increased number of barges which also deviates from the tugboat / barge ratio. Run 4 was done using two tugboats and five barges. The solution from this was an improvement as compared to Run 3. Even though all the orders were not served, only six orders were not completed in the week. There is not much flexibility in this fleet. The time gained by the tugboats after leaving a barge at a customer port is not enough to allow alternation between the increased number of barges.

From the various runs done, a fleet design for problem Case 2 would be made up of three tugboats and four barges. Based on the order quantities in Case 2, the capacities of the barges were 2000 tons; 2000 tons; 2500 tons and 2500 tons.

The operation of the tugboats as they alternate between barges in serving orders has be shown in Table 6.14. The results presented in the tables are solutions obtained from Run 2. Orders are started and completed on the same day. Some orders are started on a day and completed on the next day and these have been shown with the highlights.

Vessel	Days	Order *	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No. 1	1	1	1.81569	1.88235	1.03334	2.91569	6	6
		2	8.5225	9.7225	0.75	10.4725	12.8892	12.8892
		3	17.9772	24				
	2	3			0.591	0.591	6	6
		4	6.94118	7.67451	1.096	8.77051	12.1872	12.1872
		5	14.9272	18.3938	2.1	20.4938		
	3	5					6	6
		6	8.375	10.3083	0.502	10.8103	12.3103	12.3103
		7	13.2157	13.549	1.013	14.562		
	4	7					6	6
		8	8.5325	11.2658	0.57	11.8358	12.3358	12.3358
		9	12.9829	14.2496	0.8	15.0496	15.8829	15.8829
		10	17.8829	19.1496	2.5	21.6496		
	5	10					6	6
		11	12.25	13.9833	0.112	14.0953	15.4287	15.4287
		12	16.9581	18.2247	1.5	19.7247		
	6	12					8	8

Table 6.15(a): A set of solution for fleet size of data Case 2 (Tugboat no. 1)

Since the plants are open 24 hours each day, the starting time is 0.

On Day 1, tugboat no. 1 picks up the empty at 1.81569 and goes to production site, arriving at 1.88235. After loading order, the tugboat will depart from production site at 2.91569 to deliver the order at the customer port. Unlike the traditional bulk vessel, the tugboat leaves the barge with its load at the port and ready to leave at then which will go to pick up other empty barge no. 2 and leave at time 6. Unloading of the load would be completed after four hours. Within these four hours, the tugboat leaves to pick up another barge to serve a second order.

Tugboat 1 is able to complete a second order in day 1 and start a third. This third order is completed on day 2.

Tables 6.15(b) and 6.15(c) also show the operation of tugboats 2 and 3 respectively.

Vessel	Days	Order*	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No. 2	1	13	1.52157	1.58824	1.58333	3.17157	6	6
		14	6.84118	6.87451	0.587	7.46151	8.29484	8.29484
		15	9.1772	10.7772	1.7	12.4772	13.7272	13.7272
		16	14.6095	15.6762	2.005	17.6812		
	2	16					6	6
		17	10.125	10.925	1.65	12.575	15.825	15.825
		18	18.0039	20.1372	0.8	20.9372		
	3	18					6	6
		19	6.88235	7.54902	1.5	9.04902	9.46569	9.46569
		20	11.25	12.9833	2.5	15.4833	15.7333	15.7333
		21	16.2627	19.0627	0.805	19.8677		
	4	21					6	6
		22	6.52941	6.72941	0.646	7.37541	9.54208	9.54208
		23	11.2625	12.7292	0.8	13.5292	15.1958	15.1958
		24	17.1958	18.5292	2.107	20.6362		
	5	24					6	6
		25	6.23529	7.03529	1.656	8.69129	10.2746	10.2746
		26	11.2675	11.6675	2.14	13.8075	14.3075	14.3075
		27	19.6575	19.9242	1.254	21.1782		
	6	27					8	8

Table 6.15(b): A set of solution for fleet size of data Case 2 (Tugboat no. 2)

Vessel	Days	Order*	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No.3	1	28	1.52941	1.92941	1.009	2.93841	6	6
		29	9.76234	10.429	2.003	12.432	12.7653	12.7653
		30	14.7642	15.4308	1.65	17.0808		
	2	30					6	6
		31	7.52941	8.72941	0.756	9.48541	11.9021	11.9021
		32	13.0197	13.6864	0.805	14.4914	15.9914	15.9914
		33	19.95	22.35	0.95	23.3		
	3	33					6	6
		34	8	9.26667	0.80003	10.0667	11.9	11.9
		35	13.9	15.3667	2.105	17.4717		
	4	35					6	6
		36	8.0125	10.8125	2.0	12.8125	13.8125	13.8125
		37	18.8125	19.6125	0.8	20.4125		
	5	37					6	6
		38	8	9.26667	1.24003	10.5067	11.84	11.84
		39	14.94	16.34	1.805	18.145		
	6						8	8

Table 6.15(c): A set of solution for fleet size of data Case 2 (Tugboat no. 3)
*Order numbers from the table distinguish separate orders but do not reflect the actual order number from the problem case

Further testing and exploitation using the fleet composition from Run 2 also indicated that it is possible to serve four additional orders. The total number of orders therefore becomes 43 which would all be completed on Day 6. Depending on the order quantities, approximately 45 orders can be served in each week with this current fleet.

6.6.2 Minimum fleet size for Cluster 2

Solving Case 2 using tugboats and barges in Section 6.6.1 gave a final solution whose fleet composition consisted of three tugboats working with four barges. This fleet composition served 39 orders in a week with the possibility of serving some additional orders.

Run 1

Using the solution from Case 2 as a reference point, Case 3 which has 14 orders is solved initially with two tugboats and three barges.

Table 6.16 shows the number of orders served by each boat and the percentage of the total demand that was served.

Barges / Orders completed	1	2	3
Order 1	1750	800	800
Order 2	800	860	850
Order 3		1650	196
Order 4		1500	1250
Order 5		600	660
Order 6			1652
Order 7			900

Table 6.16(a): Initial solution for Case 3 using tugboats / barges

Barges	1	2	3	Total
Number of orders	2	5	7	14
Total tonnage	2550	5410	6308	14268
Percentage of demand	17.87	37.92	44.21	100

Table 6.16(b): Utilization of barges in the initial solution

Following the steps adopted in exploring the fleet size problem, barge 1 with the least tonnage (17.87 %) of the total demand is selected and eliminated. Barge 1 from Table 6.16(a) serves only two orders.

Run 2

In run 2, the number of barges has been reduced from three to two and the number of tugboats from Run 1 is maintained.

Barges / Orders completed	5	6
Order 1	800	800
Order 2	1750	860
Order 3	1650	850
Order 4	1250	196
Order 5	1500	800
Order 6	600	660
Order 7		1652
Order 8		900

Table 6.17(a): Solution from Run 2 with reduced number of barges

Barges	5	6	Total
Number of orders	6	8	14
Total tonnage	7550	6718	14268
Percentage of demand	52.92	47.08	100

Table 6.17(b): Utilization of barges from Run 2

The fleet composition in Run 2 is such that the percentage of demand served by each of the barges is almost even. Reducing the number of barges any further would leave orders not being served. The number of tugboats is currently two and is reduced.

Run 3

Solving Case 3 with 1 tugboat and 2 barges leaves a single order not being served.
Maintaining the fleet composition from Run 2 would actually be able to serve more than 14 orders. The amount of productivity which could be gained is not achieved as the number of orders received is low and the fleet size being quite large. Alternatively, the fleet composition from Run 3 can be maintained and the single order not served at the end of the week, is served at the beginning of the upcoming week.

6.6.3 Minimum fleet size for Cluster 3

Cluster 3 is made up of a single plant at Dimmelsvik, with about 4 customers. Data analysis showed that the average number of order received per week is one. From the solution to Cluster 2, one tugboat with 2 barges can serve 13 orders per week based on the distances. Using the same fleet composition for Cluster 3 to serve 3 orders per week is a huge loss. Also, reducing this fleet size to one tugboat a one barge gives the same solution as a traditional bulk vessel with the added loss of the intended flexibility which should have been gained from the tugboats/barges.

6.6.4 Combining Clusters 2 and 3

Two possible solutions were obtained at for Cluster 2. The first solution has a fleet size which is capable of serving a lot more orders than the demand and the second solution serves all orders except one. Cluster 3 also gives a similar solution; the first solution can serve additional orders and the second solution operates as bulk vessels. In both clusters, the solutions obtained seem to have drawbacks. Combining these clusters and finding a fleet composition is expected balance these drawbacks i.e. the large fleet composition from one cluster could balance the needs in the other.

As in the case of the bulk vessels, combining these two clusters would result in a mixture of short and very long distances. The total number of order is 18 and two production sites (Askøy and Dimmelsvik).

Run 1

The initial fleet composition used in solving this problem is made up of three tugboats and four barges. The solution obtained is presented in Table 6.18. Barge 1 is selected to be eliminated in the next run; the fleet size is reduced from 4 barges to 3 barges.

Barges	1	2	3	4
Order 1	800	800	1750	860
Order 2	850	402	1250	1650
Order 3	1652	3500	1500	660
Order 4		2507	600	905
Order 5			800	196
Order 6			900	

Table 6.18(a): Initial solution for combined clusters using tugboats/barges

Barges	1	2	3	4	Total
Number of orders	3	4	6	5	18
Total tonnage	3302	7209	6800	4271	21582
Percentage of demand	15.30	33.40	31.51	19.79	100

Table 6.18(b): Utilization of barges in the initial solution

Run 2

The number of orders in each barge has increased. The percentage of total demand has been calculated for each barge and the fleet size for this case determined.

Barges	2	3	4
Order 1	800	1750	800
Order 2	860	1250	850
Order 3	402	1500	1650
Order 4	3500	1652	660
Order 5	2507	600	905
Order 6		800	196
Order 7		900	

Table 6.19(a): Solution from Run 2 with reduced number of barges

Barges	4	5	6	Total
Number of orders	5	7	6	18
Total tonnage	8069	8452	5061	21582
Percentage of demand	37.39	39.16	23.45	100

Table 6.19(b): Utilization of barges from Run 2

The current fleet composition is optimal as any further reduction in the number of tugboats or barges gives a solution in which the total number of orders is not completed. The current fleet consists of three tugboats and three barges. The operation of the tugboats within the week has been presented in the subsequent tables.

Vessel	Days	Order*	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No.1	1	1	1	0.933333	0.79999	1.73333	6	6
		2	8	11.3333	0.86	12.1933	13.11	13.11
		3	15.26					
	4	3		0	0.402	0.402	11.8187	11.8187
		4	12.8237	21.957				
	5	4			3.5	1.457	6.79033	6.79033
		5	14.7333	17.5333	0.9	18.4333		
		5					8	8

Table 6.20(a): A set of solution fleet size of data Case 4 (Tugboat no. 1)

Vessels	Days	Order*	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No.2	1	6	1	5.8	1.75	7.55	9.46667	9.46667
		7	13.8417					
	2	7		0	1.25	1.25	6	6
		8	9.125					
	4	8		0	1.5	1.5	6	6
		9	9.75	10.75	1.652	12.402	14.402	14.402
		10	18.532					
	5	10		0	0.6	0.6	6	6
		11	7.5	8.43333	0.8	9.23333	12.7333	12.7333
		12	15.2627	17.5961	0.196	17.7921		
	6	12					8	8

Table 6.20(b): A set of solution fleet size of data Case 4 (Tugboat no. 2)

Vessels	Days	Order*	Pick-up barge time	Start time	Loading duration	Departure from plant	Arrival (customer port)	Departure (tugboat)
Tugboat No.3	1	13	1	4.33333	0.8	5.13333	8.05	8.05
		14	10.05	12.3833	0.85	13.2333	13.4	13.4
		15	15.525	15.6583	1.65	17.3083		
	2	15					6	6
		16	10.125					
	4	16		0	0.66	0.66	6	6
		17	7.65	8.31667	0.905	9.22167		
	5	17					6	6
		18	15.5403	18.1403	2.507	20.6473		
	6	18					8	8

Table 6.20(c): A set of solution fleet size of data Case 4 (Tugboat no. 3)

The results from Table 6.20 show that all tugboats had no orders to deliver on day 3. In addition, Tugboat 1 had no deliveries on day 2. Another observation made from the results indicates that most orders are started and completed on the next day. This is attributed to the long distances which tugboats have to cover when the clusters are combined.

6.7 Comparison of solutions

A summary of the fleet composition is presented in Table 6.21. In general, the fleet compositions from bulk vessels indicate that the number of bulk vessels corresponds to the number of barges to be used in the alternative vessel type. An analogy which could be used here is that the tugboats represent the engine part of the bulk vessel. Where there are a number of bulk vessels to serve a certain number of orders, the same number of barges is required but the same amount of orders can be served with a lower number of tugboats/engine.

More orders are served daily by tugboats/barges which imply an increase in productivity. An increase in the productivity potentially leads to an increase in the revenue.

Traditional bulk vessels	Tugboats ad barges
Cluster 1	
Fleet composition: 4 bulk vessels Capacities: 2500,2500, 2000, 2000 All orders served No additional orders possible	Fleet composition: 3 tugboats 4 barges Capacities: 2500,2500, 2000, 2000 All orders served Additional orders possible
Cluster 2	
Fleet composition: 2 bulk vessels Capacities: 2000, 2000 All orders served Additional orders possible	Fleet composition (a): 1 tugboat 2 barges One order not served
	Fleet composition (b): 2 tugboat 2 barges All orders served Additional orders possible Capacities: 2000, 2000
Cluster 3	
Fleet composition: 1 bulk vessel Capacity: 3500 All orders served Additional orders possible	Fleet composition: 1 tugboat 1 barge All orders served Additional orders possible Capacity: 3500
Combining Cluster 2 and 3	
Fleet composition: 3 bulk vessel All orders served Additional orders possible Capacities: 3500, 2000, 2000	Fleet composition: 3 tugboat 3 barge All orders served Additional orders possible Capacities: 3500, 2000, 2000

Table 6.21: Summary of results for various problem instances

Solving the same problem instances with tugboats/barges gave solutions different from the traditional bulk vessel. This is due to the flexibility in operating tugboats and barges. A lot of time is gained by eliminating the time spent for unloading. This time is invested into serving more orders. Consequently, more orders are served by tugboats and barges daily (Figure 6.1) and a smaller fleet is also used. Orders are also completed early in the planning horizon and also with a high order fulfilment rate.

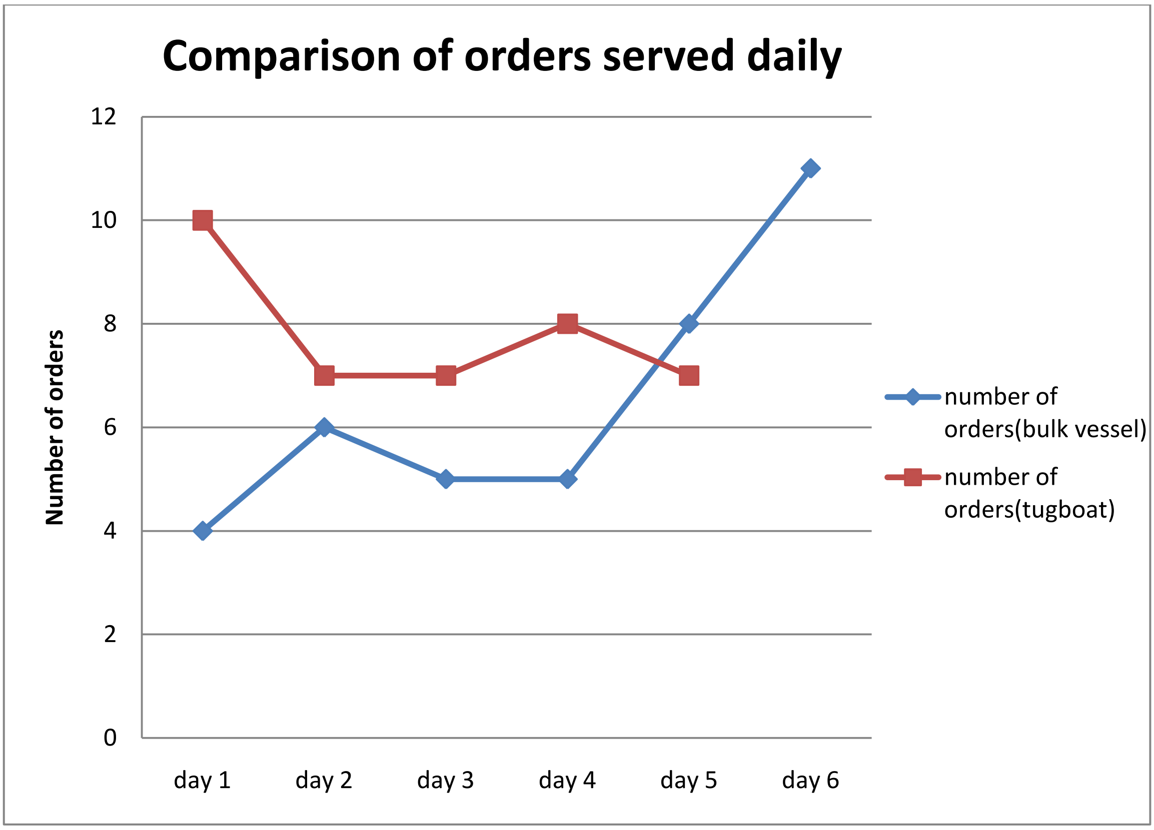

Figure 6.1: Graph showing the comparison of the number of orders served daily

From this graph, we can see that 3 tugboats and 4 barges can serve more orders daily which is good for planning the activity in a week24. Comparing day 1 to the other days, it is possible for the tugboat/barges to serve more orders. The total number of orders served is 39 and completed on day 6 by the traditional bulk vessel. The same number of orders is completed on day 5 by tugboats and barges. In this way, the bulk vessels continue to work through day 5 and 6 to complete all orders as seen from the graph.

The use of tugboats/barges has a greater utilization compared to the traditional bulk vessels. Tugboats are almost always moving around either starting an order; picking up an empty barge or delivering an order.

Even though costs were not analysed, it has been mentioned that the crew number used in operating bulk vessels is higher than tugboats/barges. The use of bulk vessels would therefore have a higher cost associated with crew members as compared to tugboats/barges.

The use of tugboats/barges is greatly seen for Cluster 1 where there are a large number of customers in relatively short distances. Tugboats/barges from the different test cases are seen to be more efficient when dealing with short distances coupled with high order quantities. The low unloading rate provides more time for the tugboats to have their high flexibility in moving between different orders.

6.8 Effect of adding long distances

Increasing the distances with low order quantities gives the opposite result of increased flexibility. The tugboats are more constrained with time and the solutions derived from such instances are similar or approach those obtained from using traditional bulk vessels. This observation is made when Cluster 2 and 3 are combined. The fleet composition when using both vessel types is quite similar. Unlike instances with short distances where most order are completed on the same day, most orders in this case where completed on a second day after they are started. The fleet composition does not seem to improve and the expected balance is not gained when these clusters are combined.

6.9 Extending port hours

In the instances tested so far, customer ports are opened from 06:00 to 16:00 during the workdays, and 08:00 to 14:00 on Saturday. Plants on the other hand are open 24/7. In this instance, an analysis is made on how much the waiting time can be reduced when all ports are open 24 hours during the whole week (7 days) and the fleet size and composition.

If all customer ports are open 24 hours each day for the entire days in a week, the fleet size of each case with bulk vessels will be as follows:

In Case 2, 2 bulk vessels were used to serve the orders, but one order could not be served. Therefore, using 3 bulk vessels can serve all the orders in a week and additional orders can also be served.

Similarly, the fleet size reduces in Case 3 and 4 with the possibility of serving additional orders.

The results from tugboats/barges follow a similar pattern. In previous solutions, some orders are not completed on the same day since they arrive late when customer ports are closed. By extending the opening hours, such events have been eliminated. The fleet composition has also reduced and orders are completed early in each week.

The fleet composition has been compared and summarised in Table 6.22.

Cluster	Port hours 10/6	Port hours 24 /7
Cluster 1	4 bulk vessels	3 bulk vessels
Cluster 2	2 bulk vessels	1 bulk vessel
Cluster 3	3 bulk vessels	2 bulk vessels

Table 6.22(a): Fleet size for extended port hours with bulk vessels

Cluster	Port hours 10/6	Port hours 24 /7
Cluster 1	3 tugboats and 4 barges	2 tugboats and 2 barges
Cluster 2	2 tugboats and 2 barges	1 tugboat and 1 barge
Cluster 3	3 tugboats and 3 barges	2 tugboats and 2 barges

Table 6.22(b): Fleet size for extended port hours tugboats and barges

Extending port hours by customers can be regarded as an asset specific investment which is a result of the relation that exists between the customer and the supplier. This may represent a major cost investment by the customer. The major advantage to such investment would be realized by the supplier which in this case is NorStone. The customer gains by receiving orders a lot early compared to previous instances. Alternatively, customer ports can be opened for extended hours upon request by the supplier to ensure completion of orders on the same day.

CHAPTER SEVEN
CONCLUSION AND RECOMMENDATION

7.0 Conclusion

The conclusions are based on the results of the findings presented in the previous chapter, thus the conclusions will be used to develop recommendations for the next stages of the main project.

Based on the results obtained in the previous chapter, the following comparison is made between traditional bulk vessels and tugboat/barges:

Speed: In practice, the speed of tugboats is higher than bulk vessels. Tugboats as a result of the design operate on three different levels i.e. tugboat alone, tugboats with an empty barge and lastly tugboats with a loaded barge. All three levels have different speeds with the fastest being a tugboat with no barge and the slowest being a tugboat with a loaded barge. On the other hand, traditional bulk vessels have two speed levels i.e. an empty bulk vessel and a loaded bulk vessel. In all cases, tugboat/barges have higher speeds. The lowest speed is at 12 miles per hour loaded barge which is equivalent to a bulk vessel when it is travelling with no load. With respect to speed, tugboats save a lot on time and tour duration.

Waiting time: A lot of time is spent at ports for the purpose of loading or unloading. Most of the time spent at the port is used for unloading as the rate is low. For example, an order 2000 tons would require approximately 5 hours for unloading. Traditional bulk vessels in this time have to stay at the customer port for the unloading to be done. Contrary to this, the tugboats which pull the loaded barge can leave the barge at the customer port for this unloading to take place. The five hours gained by the tugboat can then be directed into serving another order or picking up an empty barge from some other customer port. The waiting time for unloading is eliminated altogether. The utilization of this time for other activities is greatly realised when the tour length is relatively short i.e. about 50 miles. Extending the distance makes it difficult to make a full utilization of the time gained.

Flexibility: Tugboats/barges compared to traditional bulk vessels can be seen to be more flexible in the sense that the can operate with or without the storage space which is the barge. The bulk vessels on the other hand are always constrained since the storage space/available capacity is always tied to the engine. Even though there are a lot of contract agreements involved in chartering a vessel, it would be relatively easier to manage a fleet composed of tugboats and barges. It would be easy to change an existing fleet size by adding or taking out a barge compared to the replacement of an entire bulk vessel. Fleet size is more flexible with tugboats and barges than with bulk vessels.

Productivity: By combining the speed, flexibility and the elimination of waiting time, tugboats and barges give a high level of productivity than traditional bulk vessels. This productivity is related to the number of orders served daily and weekly. It will take a larger fleet size of traditional bulk vessels to complete the same number of orders.

Costs: Costs associated with operating the different vessel types were not analyzed in this study. Costs such as general maintenance, tax, insurance and crew associated costs which also fall under the operating costs can be highlighted. Theoretically and in practice, general maintenance and costs associated with tax tend to increase with the age of a vessel. The existing fleet of bulk vessels are more than 30 years with some being considered for replacement. From the gains realised, replacing the bulk vessels with tugboats and barges would no doubt be a good start. The number of crew required for tugboats/barges is also less and thus leads to reduced costs.

7.1 Recommendation

All the cases analysed and results obtained are based on the sailing report for the peak season (April, May, and June) in 2008. The fleet size determined so far is only valid for instances with similar demand or order patterns. The fleet size and composition may change under different instances. However, the number of orders used for each instances was higher than the estimated to give some robustness to the solution.

Based on the solutions and analysis, the following findings have been realised:

1. Waiting time at ports can be eliminated to a large extent by using tugboats/barges. The advantages gained when using this vessel type include increased flexibility, increase in the level of productivity, reduction in the amount of idle time and a reduced number of crew.

2. The application of tugboats/barges as an alternative is of major significance in Cluster 1. This is a result of the relatively short distances between all the ports in the cluster and the high number of customers and orders received.

3. Traditional bulk vessels are a better option in instances where the distances are long as was seen in Cluster 3. In such instance, flexibility from the tugboats/barges is lost and their operation becomes similar to the bulk vessels.

4. A fleet composition for the region would consist of a mix of traditional bulk vessels and tugboats/barges. The bulk vessels are applicable in areas with long distances and less demand while tugboats/barges can serve areas with relatively short distances with high demand.

Based on the instances tested, the fleet composition for the various clusters is as follows:

Cluster 1: 3 tugboats and 4 barges
Capacities: 2500, 2500, 2000, 2000

Cluster 2: 1 tugboat and 2 barges
Capacities: 2000, 2000

Cluster 3: 1 bulk vessel
Capacity: 3500

The fleet composition for the first two clusters would have a very high utilization rate as the number of orders received from those groups is high. Cluster 3 would have some idle time since there are just a few orders per week. This idle time can be used for serving orders between terminals or clusters. Such orders are of require high quantity of product and the have an associated long distance. The bulk vessel from Cluster 3 has the needed capacity, idle time and is a preferred option for long distance.

In this way, demand originating from any location in the region would be sufficient covered by this fleet design.

CHAPTER EIGHT

8.0 Further Studies

The solver used in this study is still being developed and we believe that the solution obtained so far can be improved when the solver is completed. Further studies would there be required to analyse the costs associated when the vessel types are used for the transportation of products. Another area which has to be studied is the type of contract to be used. The choice of contract would be to put most vessels under Time charter and the remaining under Contract of affreightment. The Spot market should be avoided if possible or only a few vessels taken from the spot market.

Due to time constrain on this study, some areas which were left out such as the use of vessels with increased capacity and the inventory routing problem can also be analysed in later studies.

Appendix

Appendix A: product ranges/fraction available at production sites

ASKOY	TAU	JELSA	ARDAL	DIRDAL	DIMMELSVIK
2-5	2-5	2-5	8-16	0-32	8-16
5-8	5-8	8-11	0-2	0-22	0-8
8-11	8-11	8-16	0-4	16-32	0-32
8-16	8-16	11-16	0-8	5"	16-22
11-16	11-16	0-16	16-22	20-120	16-32
16-32	0-11	0-32	SAND	50-120	SAND
0-16	0-16	0-5	VOLLYBALLSAND	KONSTRUKSJON	
0-32	0-2	20-120			
32-63	0-22	5-16			
0-5	0-32	5-11			
32-64	0-8	5-8			
0-11	16-32	3-64			
16-64	32-63				
0-125	AB 16				
5-16	AGB 16				
20-120	GRØFTEPUKK				
0-2					
0-8					
16-22					
0-4					
GRØFTEPUKK					

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