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Capacity issues in transport of animals for slaughtering in Gilde

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Preface

First I like to say thanks to my supervisors, Professor Arne Løkketangen and Mr. Johan Oppen. Without their constructive instructoins, it would not be possible for me to finish this thesis. I also feel sorry for having occupied their holiday time.

From my perspective, this thesis is not only to explore the the livestock collection issues for Gilde Norsk Kjøtt, but also a process during which I have deepened my understanding and insight of these problems.

Abstract

This master thesis focuses on the capacity issues of two slaughterhouses of the biggest meat corporation in Norway, Gilde Norsk Kjøtt.

With the livestock collection route planning system developed by Oppen and Løkketangen (2008), 5 sets of data provided by Gilde have been tested in order to explore the right fleet for the two slaughterhouses.

First, I have compared the differences between current manual planning method and the solver based planning system, including the possible improvement of the total transportation costs if the new planning system is adopted.

The main part of this thesis is to search for the right fleet size and mix for the two slaughterhouses. Through data testing, the minimum fleet size for each slaughterhouse has been found. In addition, whether is profitable to use trailer and small capacity vehicle has also been explored.

At last, some attention is paid to the feasibility analysis of setting up holding pens for the slaughterhouse at Oppdal.

In this thesis, real instances of live animal collection problem with up to 32 vehicles and more than 200 farms have been examined. Maybe this is the first time to analyse such large size real livestock collection problems with the tool developed by Oppen and Løkketangen.

Contents

1. Introduction

Efficient transportation is becoming more and more important to society. Economic growth, increasing consumption, and globalization tend to increase the need for transportation. For most manufacturing companies, transportation (inbound and outbound) activities have consumed a large fraction of logistic costs. Strong competition between businesses induces higher demands on efficiency, customer service, timeliness, reactivity and cost reduction in the transportation function. It is therefore very important to improve the transportation management and operations in order to maintain competitive advantage. This is the reason why Gilde Norsk Kjøtt has been seeking to improve its transportation operations for years. This is also the reason why topics involving transportation appeal to me.

Gilde Norsk Kjøtt is the biggest meat corporation in Norway. The corporation is making carcasses, cut meat and processed meat for sale to retailers, convenience and fast food shops, kiosks, petrol station chains, hotels, restaurants, catering and other meat industry. Its main products include carcasses (whole and in parts), cuts, steaks and fillets, burgers, minced meat, sausages, sliced meat, salted and cured meat, ready-to-eat meals (also fish-products), pizza, canned food, hides, wool and by-products for further processing and so forth. In 2005, volumes of types of meat processed by Gilde Norsk Kjøtt are showed in the Table 1 (more information can be found at http://www.gilde.no/).

Table 1: Volumes of types of meat processed by Gilde in 2005

	Tonnes	Carcasses
Pork	80,600	1,069,530
Beef	63,500	232,960
Veal	1,600	14,220
Mutton and lamb	17,600	859,580
Others	400	14,230
Total	163,800	2,190,600

From Table 1, it is obvious that the company has to perform considerable transportation activities so as to maintain its production. How can the company transport live animals to slaughterhouses both effectively and efficiently? That is a critical issue Gilde has to deal with.

Currently, Gilde Norsk Kjøtt has about 20 slaughterhouses in different counties around Norway. The company collects live animals from farms almost every working day. They hire a number of vehicles to collect animals at farms and bring them in to provide a steady flow of animals to the slaughterhouses. There is a lairage with a limited capacity at each slaughterhouse which can temporarily or overnight store a certain number of animals for later use. The inventory level of the lairage must be kept within a predefined interval all the time. Several farms where animals are available for collection are assigned to each vehicle according to some rules. A set of vehicles performing different routes must satisfy the demand of production of the slaughterhouse and the lairage capacity at the slaughterhouse each day. There are several factors which affect transport operations of the company.

Firstly, due to the increasing competition in the business, the need for cost effective transportation increases substantially. Secondly, there are relevant regulations taking care of animal welfare which restrict transportation activities. Some of these are national, some are imposed by the EU. For instance, the most prominent part of the regulations is that no animal may spend more than eight hours on a vehicle. There are also regulations on how much space must be provided to each animal. The good thing is there is a connection between financial gains and animal welfare. The better an animal is treated before being slaughtered, the more valuable the meat will be. In practice, the company has to organize its transportation with cost effective orientation while taking care of animal welfare.

The task of this master thesis is to explore the capacity issues in transport of animals for slaughtering for two slaughterhouses of Gilde Norsk Kjøtt, located at Ålesund and

Oppdal respectively. The company now thinks that they may have too many vehicles since some drivers complained there were often not enough load. Based on a solver (livestock collection route planning system) developed by Oppen and Løkketangen (2008), several sets of data have been tested so as to find out the appropriate vehicle fleet for the two slaughterhouses. In addition, some effort has been put into the feasibility analysis of setting up some holding pens for the slaughterhouse at Oppdal in order to find out whether the measure can improve cost efficiency in transporting ovine to the slaughterhouse.

The rest of this paper is organized as follows: first a detailed problem description is presented in section 2, then literature review in section 3. Section 4 introduces what data will be tested. Section 5 describes solver validation and the capacity exploration composes section 6. Section 7 explores how much transportation cost can be reduced if some pens are set up to hold sheep (or goat) temporarily so that the animals may be collected directly from the pens for the slaughterhouse in big batches. Finally, conclusion is summarized in section 8, which is followed by references.

All testing have been run on PCs with Intel® Core™2 CPU 2.13GHz and 2GB of RAM at computer lab of Molde University College. Microsoft Visual Studio 2005 has been used as the environment of the solver.

2. Problem descriptions

2.1 The Livestock Collection Problem

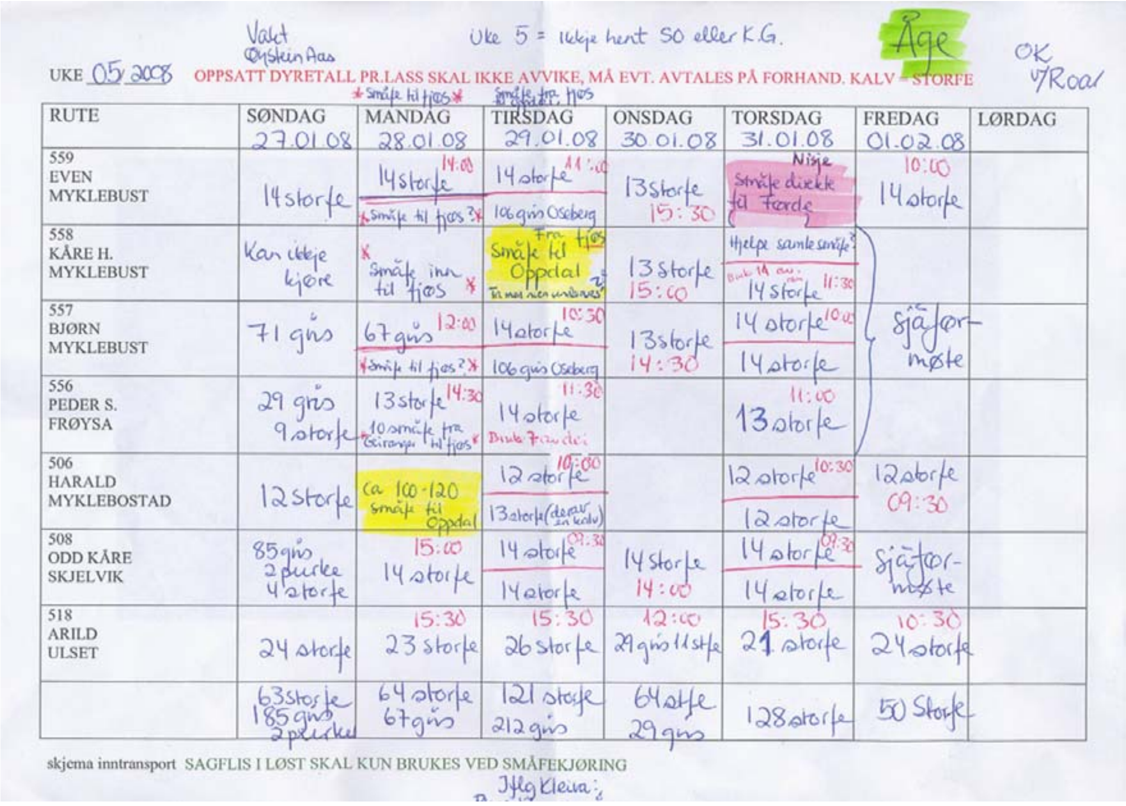
The problem dealing with transportation of livestock from farms to slaughterhouses is denoted as the Livestock Collection Problem (LCP). The LCP includes two parts, the planning of routes for the fleet and tackling an inventory problem related to production. A detailed description is presented in the following part.

2.1.1 Practical procedures

In practice, the farms register by telephone or website to inform Gilde that a certain number of animals are available for collection. There are two kinds of registration, ordinary and long term. The animals registered in ordinary form will normally be collected the week after registration. The long term registration allows the slaughterhouse to collect the animals registered within a period of 3 or 5 weeks. Thus, slaughterhouses have more flexibility in arranging collection from the long term registration.

Taking both market demand and registered animals into consideration, the slaughterhouse then makes its production plan. After that collection assignments are made for the fleet so that the animals registered during the previous time period can be collected and supply for the production can be obtained. Usually the planning horizon is one week. Since no animals are allowed at lairage on weekends, the collection is normally performed from Sunday through Friday. Currently Gilde hires several transport companies to collect the animals. Gilde has divided the area from which they collect animals for slaughtering, into small districts. A driver or a transport company normally collects all animals from the assigned district. That means that Gilde partitions all farms to a number of clusters and the driver or the transport company decides the best order to serve farmers in each route. The planning is mainly performed manually (Oppen and Løkketangen 2006). Table 2, obtained from the slaughterhouse at Ålesund, demonstrates how the tasks of each vehicle during a certain week were assigned in practice. The table was made by the transportation planner at the slaughterhouse and stated the number of animals each truck should collect every day and the required delivery time.

Table 2: Weekly plan of collecting animals for each truck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UKE 05 2008 OPPSATT DYRETALL PR.LASS SKAL IKKE AVVIKE, MÅ EVT. AVTALES PÅ FORHAND. KALV - STORFE

RUTE	SØNDAG 27.01.08	MANDAG 28.01.08	TIRSDAG 29.01.08	ONSDAG 30.01.08	TORSDAG 31.01.08	FREDAG 01.02.08	LØRDAG
559 EVEN MYKLEBUST	14 storfe	14 storfe 14:00 / *småfe til fjøs?*	14 storfe 11:00 / 106 gris Oseberg	13 storfe 15:30	Nisje småfe direkte til Førde	10:00 14 storfe	
558 KÅRE H. MYKLEBUST	Kan ikkje kjøre	* småfe inn til fjøs *	Småfe til Oppdal fra fjøs	13 storfe 15:00	Hjelpe samle småfe? / 14 storfe 11:30		
557 BJØRN MYKLEBUST	71 gris	67 gris 12:00 / *småfe til fjøs?*	14 storfe 10:30 / 106 gris Oseberg	13 storfe 14:30	14 storfe 10:00 / 14 storfe	Sjåførmøte	
556 PEDER S. FRØYSA	29 gris 9 storfe	13 storfe 14:30 / 10 småfe fra Geiranger til fjøs	14 storfe 11:30		11:00 13 storfe		
506 HARALD MYKLEBOSTAD	12 storfe	ca 100-120 småfe til Oppdal	12 storfe 10:00 / 13 storfe (derav 1 kalv)		12 storfe 10:30 / 12 storfe	12 storfe 09:30	
508 ODD KÅRE SKJELVIK	85 gris 2 purke 4 storfe	15:00 14 storfe	14 storfe 09:30 / 14 storfe	14 storfe 14:00	14 storfe 09:30 / 14 storfe	Sjåførmøte	
518 ARILD ULSET	24 storfe	15:30 23 storfe	15:30 26 storfe	12:00 29 gris 11 stfe	15:30 21 storfe	10:30 24 storfe	
	63 storfe 185 gris 2 purke	64 storfe 67 gris	121 storfe 212 gris	64 stfe 29 gris	128 storfe	50 storfe	

skjema inntransport SAGFLIS I LØST SKAL KUN BRUKES VED SMÅFEKJØRING

Iflg Kleiva:

From this table, we can see there are 8 trucks (one driver has two trucks) collecting animal for the slaughterhouse. Since the lairage can only hold a limited amount of animals overnight and slaughtering may start at 7am, some animals have to be delivered in the morning, such as 9:30 am, so that there will be enough animals available for production.

2.1.2 Animal type and categories

Gilde usually slaughters several types of animals. The livestock is divided into types and categories. The types are by and large the different animal species. Each type can be divided into categories by age, size and gender. For some categories, there is a need for further splitting. The basic types and categories are depicted in Table 3.

Table 3: Animal types and categories

Types	Categories	Further splitting
Bovine	Calf Veal calf Young bull Bull Heifer Cow	With horns and without horns
Ovine	Lamb Sheep Ram Kid Goat	With wool and without wool
Pig	Slaughter hog Sow Boar	

In practice, slaughterhouses also process some other animal types, such as reindeer and horses. However, since the volume of those animals slaughtered is quite small, those animal types are excluded in our discussion.

Due to animal welfare, the different types and categories of animals have to be kept in separate sections or compartments when they are loaded into the same vehicle. This restriction leads to a mixed loading problem, which adds complexity to the transportation planning while decreasing the utilization of vehicle capacity.

2.1.3 The vehicle fleet

The vehicle fleet is normally heterogeneous with varying capacity. For the purpose of the transportation of livestock, the vehicles are physically divided into several sections (usually three). Most sections may be split into two or three tiers (A tier in a section is called a compartment). These tiers usually are movable, and can be adjusted if necessary. For vehicles whose sections are split into tiers, bovine can only have pigs or ovine on top of it owing to its height. Pigs and ovine may be stacked in two or three tiers owing to their small sizes. A typical vehicle can load about 15 cows (or bulls), or 90 slaughter hogs, or 150 lambs. In practice, the vehicle capacity can vary due to different vehicle type or animal categories. Even animals of the same category can be different in size. All these factors induce the variety of a vehicle's capacity. Figure 1 show how the different types of animals can be loaded into sections and compartments of a truck (Oppen et al. 2007).

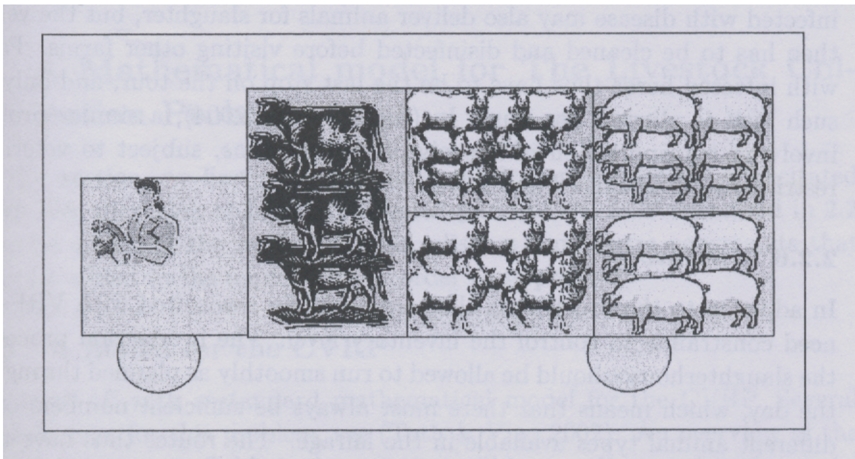

Figure 1: Example of mixed load

An important fact is that the vehicles have to be loaded from the front and backward, each section is loaded from the top and downwards. There is at most one nonempty compartment accessible in the vehicle at any time since it is not possible to load animals into a compartment by passing through another compartment that is already used.

Some of the vehicles have trailers. Owing to animal welfare, trailers are not allowed to be left behind and be collected later if they are loaded with animals. In general, the trailers can increase the vehicle capacity, reduce the total travel distance and unit transportation cost per animal, and quite often reduces the total transportation cost. If most farms can be visited by vehicles with trailers, to add trailers to vehicles can be an option to reduce the transportation cost and meet the demand of the peak season.

Some vehicles have time to be used for several routes per day, since some farms are close to the slaughterhouse. Usually a vehicle can perform 2, 3 or 4 routes per day, even more during the lamb season in the autumn. The first tour each day starts from the driver's home while the following routes start from the slaughterhouse because the vehicles have to bring animals back there. The location of driver's home will thus affect the routing of vehicles and the transportation costs.

These adjustable compartments also increase the complexity of the problem. For example, since the sections of most vehicles are split into movable tiers, the vehicle capacity can be dynamic and may be adjusted to the animal categories. In practice, the driver can perform this adjustment during tours by lifting and lowering the floors in the sections.

2.1.4 Visiting and loading order

In practice, different animal health statuses also impose restrictions on visiting order. Farms with breeding herds must be visited by an empty and clean vehicle, which means a farm with breeding herds has to be the first visit of the route. For farms with disease herds, the farm has to be the last stop on the tour in order to minimize the possible spread of infection.

In addition, the fact that the upper tier of a vehicle has to be loaded before the lower tier also affects visiting order. For example, if a driver wants to load some sheep into the upper tier in order to maximize the utility of his truck, he has to visit farms with sheep first. Otherwise, it is not possible to use the upper layer if cows are loaded into the lower tier first.

2.1.5 Time windows

In the Livestock Collection Problem, there are some practical requirements which create time windows. For instance, some farmers are not always at home, they are only ready to deliver animals at a certain time. In addition, the working time at the slaughterhouse is also a time window. No vehicles can arrive later than its closing time. In practice, it seems these time windows are not really hard ones, which can be overcome by communication or some other measures. For example, when a truck is going to arrive late evening, the driver can call the slaughterhouse to make an appointment in advance.

2.1.6 Route length and duration

A general animal welfare rule says that no animals are allowed to stay on the vehicle for more than eight hours. This fact restricts the total duration of a tour. As long as some animals are loaded into a vehicle, it has to go back to the slaughterhouse within 8 hours even though the vehicle is underloaded. For the LCP, there is normally no limitation on route length and duration derived from the working time of drivers or travel length of vehicles.

2.1.7 Travel time, loading time and unloading time

Since there is a restriction on tour duration, it is necessary to calculate the travel times and loading times of routes. In the real world, both travel times on roads and loading times at farms are uncertain. Travel time can be affected by weather, road quality and road conditions. In addition, the existence of ferries also brings uncertainty to travel time. The load on a vehicle is believed to have impact on travel time as well. The speed is higher when a vehicle is empty. Another factor may be the type of animals on board. When bovine is loaded, the driver may slow down a bit in order to keep the vehicle stable. There are several factors which affect loading time, such as the number and type of animals, the physical conditions at farms, availability of special loading facilities, the condition of the vehicle and so on.

At the end of each tour, the vehicles have to be unloaded and cleaned before starting a new route. The unloading time may be affected by the number and category of animals on board as well as the capacity of unloading ramps. The cleaning time may be influenced by cleaning capacity at the slaughterhouse.

Even though the times are uncertain, it seems that no huge deviation happens. Anyway, it is essential to figure out an acceptable way to estimate these times based on load, road quality and speed limit in order to trace the total duration of tours.

2.1.8 Inventory

When the animals arrive at the slaughterhouse, they are unloaded into a lairage and kept until the time of slaughter. The lair serves as a temporary warehouse between the farm and the slaughterhouse. The capacity of the lair is limited and differs for different animal types. In general, there is room for more ovine than bovine, not only because of the size but also because the bovine requires stalls instead of pens. The live animals can be kept in the lairage for one night, but not more than that. Inventory must be large enough to ensure a stable production during the morning of the following day. To meet the need of Monday morning, some livestock collection is done on Sunday. No animals are allowed to be kept over the weekend. In addition, the number of animals in the lairage can not exceed its capacity at any time.

2.1.9 Production plan

Each slaughterhouse usually processes one or more animal types. When more than one type is processed, they have a separate production line for each animal type. Every production line has its capacity measured in animals slaughtered per hour. Several production lines can operate at the same time. Using information from farms about animals registered for collection in a certain time period and the capacity of each production line, taking market demand into account, the slaughterhouse can generate a production plan for the time period. The plan indicates the number of different animal types to be slaughtered each day and the time and the rate at which the production line will operate. It is very important to keep a steady supply of animals for the production line, otherwise a large monetary loss may occur. Considering the demand from production and the limited capacity of lairage, we are confronted with a set of inventory constraints.

For the two slaughterhouses which are analyzed in this master thesis, the one at Ålesund processes bovines and pigs while the other one at Oppdal slaughters ovine.

2.1.10 Measurement of transportation cost

Usually transportation cost is measured in geographical distance. The transportation cost of a vehicle often depends on the total distance travelled. In some situations, total travel time can also be used as a measurement of transportation cost. Less travel time, lower cost. Generally speaking, it is easier to obtain accurate data of distance than travel time. Sometimes fixed costs derived from capital costs of purchasing vehicles or costs of the maintaining company-owned fleet have to be considered while measuring transportation costs.

In general, trucks with bigger capacity will generate higher cost per kilometre than smaller ones, but they usually have lower unit cost per animal due to the higher capacity. So are vehicles with trailers. A vehicle with trailer will cost more to travel the same distance but more animals can be collected compared with a single truck.

In addition, for the LCP, a bigger fleet of vehicles (many vehicles) may generate lower total travel distance compared with a smaller one (fewer vehicles). However, it requires a high fixed cost to support a big fleet.

2.1.11 Problem size

The size of a livestock collection problem is measured in number of customers and number of vehicles. Different slaughterhouses may have various situations. The length of the planning period also plays an important role in the problem size.

From previous papers (Oppen and Løkketangen 2006, Gribkovskaia et al. 2006), the number of customers visited per day is between 40 and 200. The number of farms visited per route is usually from 2 to 6. The number of routes per day is between 8 and 40. Thus, in general for large slaughterhouses, it can be seen that the problem instances for a week may have up to 1000 farms and about 200 routes.

2.1.12 Problem domain

Since the Livestock Collection Problem deals with allocations of transportation tasks to a fleet of vehicles with simultaneous routing for each vehicle, it can be regarded as an extension of the Capacitated Vehicle routing Problem (CVRP) (Oppen and Løkketangen 2008). The CVRP is a computational hard optimization problem with high industrial relevance. In the basic version of the CVRP, each customer has a certain demand. The vehicles are identical and based at a single depot, there are only vehicle capacity constraints. Between each pair of customers or between a customer and the depot, there is a certain travel cost. The objective is to minimize the total cost to service all customers once (Toth and Vigo 2002).

2.2 Another measure for transportation cost reduction

For the slaughterhouse at Oppdal, the amount of sheep (or goats) at most farms available for collection is often quite small. It might be profitable to set up some pens for the purpose of accumulating livestock so that the slaughterhouse can collect those live animals in big batches with fewer stops. How to choose the amount of holding pens and select their positions is a location problem. The objective of this location problem is to minimize the sum of the fixed setup cost of holding pens and variable transportation cost of collecting the live animals.

3. Literature review

3.1 Vehicle Routing Problem

The vehicle routing problem (VRP) tackles the allocation of transportation tasks to a fleet of vehicles, and the simultaneous routing of each vehicle. The VRP was first described by Dantzig and Ramser (1959), and is a computationally hard optimization problem with high industrial relevance.

The classical or capacitated VRP (CVRP) 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 where the vehicles depart from and return to. The other vertices are the customers which have a certain demand to be delivered (or picked up). The travel cost between customer i and j is defined by $c_{ij}>0$ and d_i is the demand for customer i. The vehicles are identical. Each vehicle has a capacity of Q. The objective is to design a least cost set of routes, all starting and ending at the depot. The customers are visited exactly once. The total demand of all customers on a route must be within the vehicle capacity Q (Oppen et al. 2007).

In order to mirror real transportation problem, many CVRP variants exist in different cases by adding diverse constraints, such as CVRP with time windows, CVRP with route duration constraints, CVRP with heterogeneous fleet, CVRP with mixed load, CVRP with delivery and pickup and so forth. Compared with common extensions to the CVRP, LCP is kind of unique because of its inventory constraints.

3.2 The fleet size and mix vehicle routing problem

The fleet size and mix vehicle routing problem is an important variant of VRP in which a fleet of vehicles have different capacities and costs. It is also known as the mixed fleet VRP or as the heterogeneous fleet VRP. The objective of the fleet size and mix vehicle routing problem is to optimize the fleet size and the mix of vehicles in the fleet. When designing routes for each vehicle, the fleet composition, how many each type of vehicles are in the fleet, should be decided simultaneously as well. The problem was first considered in a structured way in Golden et al. (1984). In practice, a fleet of vehicles is rarely homogeneous. The reasons for this phenomenon include two aspects, namely supply factor and demand factor. For example, a company may purchase its vehicles at different time and from various suppliers, which bring the heterogeneous vehicles. As for demand factor, customers often have various amount of demands, some of them are small, suitable for vehicles with low capacity while some others are huge enough for large trucks. Thus, is more efficient to serve them with vehicles having different capacities. Hoff et al. (2008) gives an overview of the literature on this field.

3.3 Solution methods for VRP and LCP

In general, it is acknowledged that there are three main types of methods to solve optimization problems like VRP, namely exact algorithms, approximation algorithms and heuristic algorithms. Exact algorithms are methods which are able to give the optimal solution to an optimization problem. Approximation algorithms can not guarantee to find the optimal solution, but there is a bound on the solution quality. Heuristic algorithms do not even necessarily have a bound on how bad the result is. However, in practice, exact methods can usually be used to solve small problem instances and relatively simple models. For most large problem instances, heuristic algorithms have been proved very successful. Especially, it has been noticed that many researchers apply tabu search, one so-called metaheuristic, to successfully solve different variants of VRP (Oppen et al. 2007).

3.4 Tabu search

Tabu search is a local search based metaheuristic. It was introduced by Fred Glover in 1986. Tabu search performs a local search by moving from current solution to its best neighbour generated by a certain neighbourhood generation method at each step. In order to escape from the local optimum, Tabu search allows moves which may cause the objective to get worse. To prevent from cycling between the same solutions, attributes of the solutions which the local search recently moved to are declared tabu for a number of iterations. The best neighbours are only selected if its similar attributes are non-tabu. The tabu neighbours with new best objective values can be accepted, which is called aspiration. Tabu search algorithms also use long term memories to control their search progresses, namely diversification and intensification technique, so as to explore the most promising solution space. Tabu search has been successfully used on numerous optimization problems, especially vehicle routing problems (Cordeau et al. 2002).

3.5 Previous works on LCP

LCP can be related to a project. The project “Transportation of living animals – reduced transportation costs, good animal welfare and first-class meat quality” is a co-operation between Norwegian Meat Research Centre, Gilde Norsk Kjøtt, Fatland and Molde University College. Norwegian Meat Research Centre is a centre for competence and emergency control in the Norwegian meat industry. Gilde Norsk Kjøtt and Fatland are Norwegian meat companies. The project was launched in 2003 and has lasted for 5 years. The main goal of the project is to develop a decision support system to reduce transportation costs and secure good animal welfare and meat quality (Oppen and Løkketangen 2006). Much work related to the LCP has been done in this project.

There are several student groups at Molde University College who did their master thesis related to the Livestock Collection Problem. In 2004, Gullberg and Hovden formulated a model and used AMPL and CPLEX solver for data testing. They were able to achieve optimal solution for a data set with one slaughterhouse, seven farms, two days and two trucks with possibility for driving three tours each day. Kjell Aarskog and Eivind Østvold also wrote their master thesis in 2005 titled “Transportation of livestock to slaughterhouses”. They chose to use ILOG (ILOG 2008) Dispatcher and a constraint modelling and local search approach to solve a LCP model without inventory constraints (Aarskog and Østvold 2005).

The other relevant papers are mainly written by researchers at Molde University College. Among those papers, two models are chosen to make a comparison. Due to different purposes, the two models have different focuses. The main features of the two models are summarized in Table 4.

Table 4: Two ways of modelling the LCP

Attribute	**Model 1**	**Model 2**
Objective function	Minimize total travel time	Minimize total travel distances
Planning horizon	Several days	A week
Loading assumption	Single animal category in each vehicle	Different animal categories in each vehicle
Heterogeneous fleet	Different capacity of each vehicle	Different capacity of each vehicle
Start point of first route	Slaughterhouse	Driver's home
Tour duration	Less than a certain time	Less than 8 hours
Health status	Not considered	Considered
Travel and loading time	Travel and loading time	Travel and loading time Plus a fixed time per farm
Unloading and cleaning	Not considered	Considered
Multiple use of vehicles	Considered	Considered
Inventory constraints	Considered	Considered
Multiple periods during each day	Split a day to several periods	Not considered
Time windows	The end of working day	The end of working day
Loading sequence	Not considered	Considering each compartment of a vehicle
Solution method	CPLEX	Tabu search
Problem size	4373 variables	8824320 variables

The model 1 is presented in Gribkovskaia et al. (2006) while the model 2 is introduced in Oppen et al. (2007). Previously, CPLEX was used to solve the model 1 for seven farms for a two days planning horizon, where each day is split into four production intervals, for two vehicles with maximum three routes per vehicle per day, and it was found that adding the eighth farm made the problem too hard for CPLEX to find an optimal solution in reasonable time (Gribkovskaia et al. 2006). As for the model 2, Oppen and Løkketangen (2008) present a Tabu search based solution method, which can solve real world test instances with 8 vehicles and 184 farms in reasonable time.

3.6 Location theory

Location theory was first formally introduced in 1909 by Alfred Weber, who considered the problem of locating a single warehouse to minimize the total travel distance between the warehouse and a set of spatially distributed customers. Since then, considerable research has been carried out in the field of location theory. A number of different classes of problems have been identified and solved, and location methodologies have been extended to a variety of practical applications (Brandeau and Chiu 1989). A definition presented by Brandeau and Chiu (1989) is as follows: A location problem is a spatial resource allocation problem. In the general location paradigm, one or more service facilities serve a spatially distributed set of demands. The objective is to locate facilities to optimize an explicit or implicit spatially dependent objective.

A characterization of model forms and objectives provided by ReVelle et al (1970) divides location problems into private sector problems and public sector problems. The private sector problems seek the sites for plants or warehouses. The objective of the location decision is the minimization of cost or maximization of profit to the private owners. In contrast, public sector problems seek facility sites that optimize the population’s access to those facilities. The objective and constraints of these problems are not easily quantifiable. Public facilities can include post offices, schools, parks, fire stations, hospitals and so on. The ways that different location problems might be treated vary to a large extent.

One of commonly used models for private sector location problems is the p-median model. This model takes as input the demands at each customer, the distances between each customer and each candidate facility site, the number of facilities to be located. The key decisions are where to locate the p facilities and which facility should serve each customer so that the total serving cost can be minimized. When the amount of facilities is not predetermined, the extension of p-median model can be used to seek the right number of facilities as well by minimizing the sum of the facility location costs and the transportation costs (ReVelle et al. 2008).

Solution techniques for location problems include exact and heuristic solution approaches. Most multi-facilities location problems have been shown to be NP-hard, which usually have to be solved with heuristic solution methods (Brandeau and Chiu 1989).

4. Data for testing

4.1 Primary data

Since currently the planning horizon for live animal collection is a week, the data of a week from a slaughterhouse is regarded as a case. Five data cases related to the two slaughterhouses have been acquired from Gilde.

Table 5: Data cases

Data case	Time	Slaughterhouse
Case 1	Week 01 2008	Ålesund
Case 2	Week 35 2007	Ålesund
Case 3	Week 41 2007	Ålesund
Case 4	Week 35 2007	Oppdal
Case 5	Week 41 2007	Oppdal

Each set of data mainly includes the production plan of the slaughterhouse during the week, orders which were collected in practice during the week, lairage capacity, the address and coordinates of every farm, each driver's home and the slaughterhouse, the number of vehicles and load records of some routes.

For the slaughterhouse at Ålesund, its production is relatively stable. Both week 35 and week 41 are within the common season. In addition, for the slaughterhouse at Oppdal, it mainly functions during the lamb season. Week 35 is the start of lamb season while week 41 highlights the peak level.

For data case 1, the real routes of each vehicle performed in practice during the week are provided. Therefore data case 1 has been used to test the solver's validity and find the possible improvement if the routes for practical animal collection are designed by the solver.

4.2 Other data

From the coordinates of addresses of farms, drivers' homes and slaughterhouses, the travel distances between each pair of farms, farm and driver's home, and farm and slaughterhouse, are calculated basing on the real road network. The capacity of each vehicle is standardized by considering both real data and the reasonable simplification. Table 6 demonstrates the capacity of different types of vehicles.

Table 6: Vehicle capacity

	Type	Capacity for each type of animal		
		bovine	slaughter hog	Sheep
compartment	1	6	19	28
	2	5	17	25
	3	5	16	23
	4	4	15	22
	5	4	14	21
Section	1	one tier for a section		
	2	both tiers only for sheep or pig		
	3	two tiers, sheep or pig can be loaded above bovine		

A section may have 1 or 2 compartments. Only one compartment within a section can be loaded with bovine due to its height. The capacity for other categories of animals can be different according to their size.

5. Solver validation

5.1. Brief introduction of the solver

The solver used to explore the capacity issues of the two slaughterhouses in this thesis is developed by Johan Oppen and Arne Løkketangen. The Livestock Collection Problem (LCP) model is formulated by adding inventory constraints and some other LCP constraints to a VRP model. Then a tabu search algorithm is designed to solve the model. The solver can produce a set of vehicle routes for the objective of minimizing the total transportation costs of all vehicles (fixed cost is not included). More descriptions about the solver can be found in Oppen and Løkketangen (2008).

5.2 Running time and the deviation of solutions

Since it has been designed and tested for years, the solver is used as a black box processor. I only test how the solution quality changes along with the running time in this thesis.

With each random seed, which is applied to control tabu tenure, the solver will generate a unique series of solutions. Among those solutions, the one with the lowest cost is taken as the solution of a certain run in this thesis. The solutions of different runs (with different random seeds) differ from each other due to randomness. It is important to know how much the solutions deviate and how the running time affect the deviation of solutions.

For the above purpose, each scenario (a combination of an instance and a running time) has been run ten times with ten different random seeds so as to generate ten solutions. Among the ten solutions, the best one (with lowest cost) and the worst one (with highest cost) are recorded. The best solution of the ten runs is appointed to represent the result of each scenario. 16 scenarios (four instances and four running durations) have been tested. The following figures depict the results.

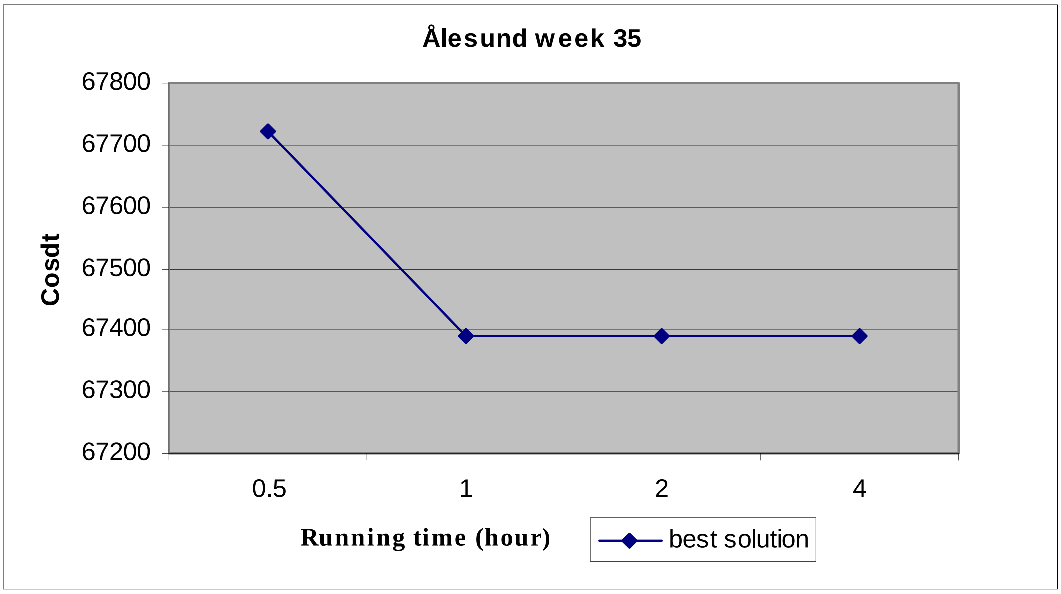

Figure 2-a: Solution quality from different running durations

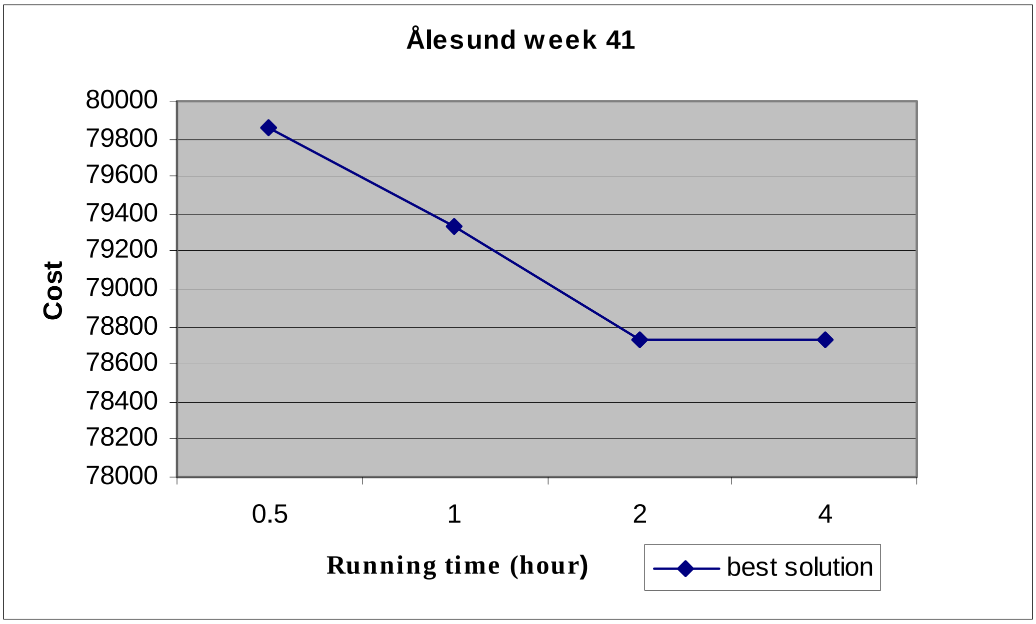

Figure 2-b: Solution quality from different running durations

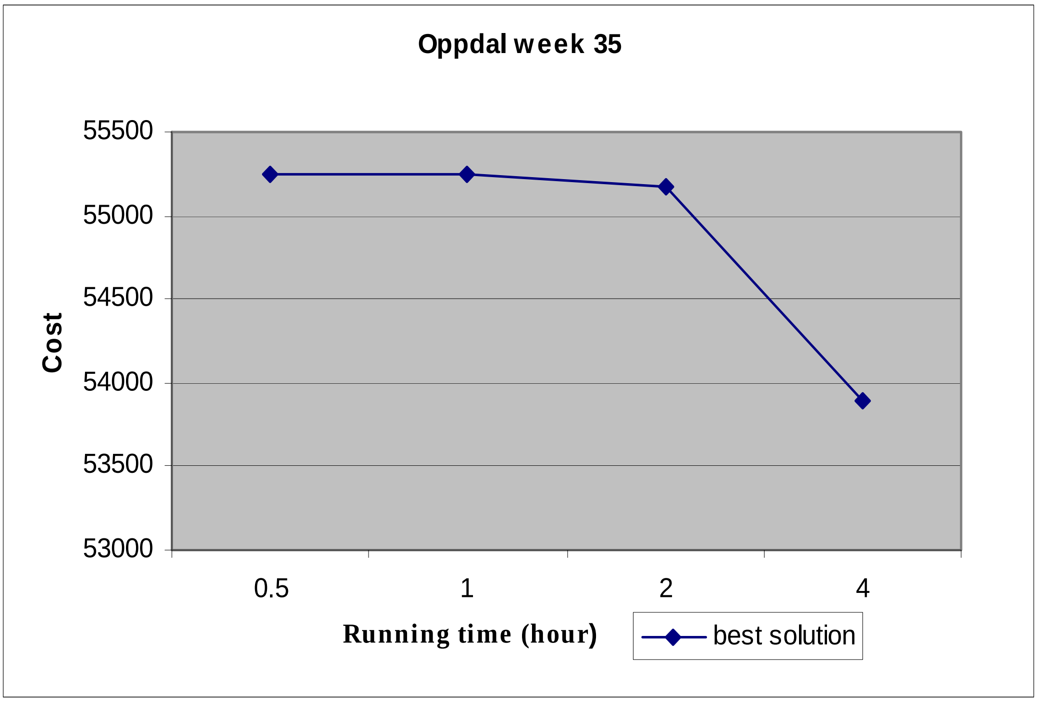

Figure 2-c: Solution quality from different running durations

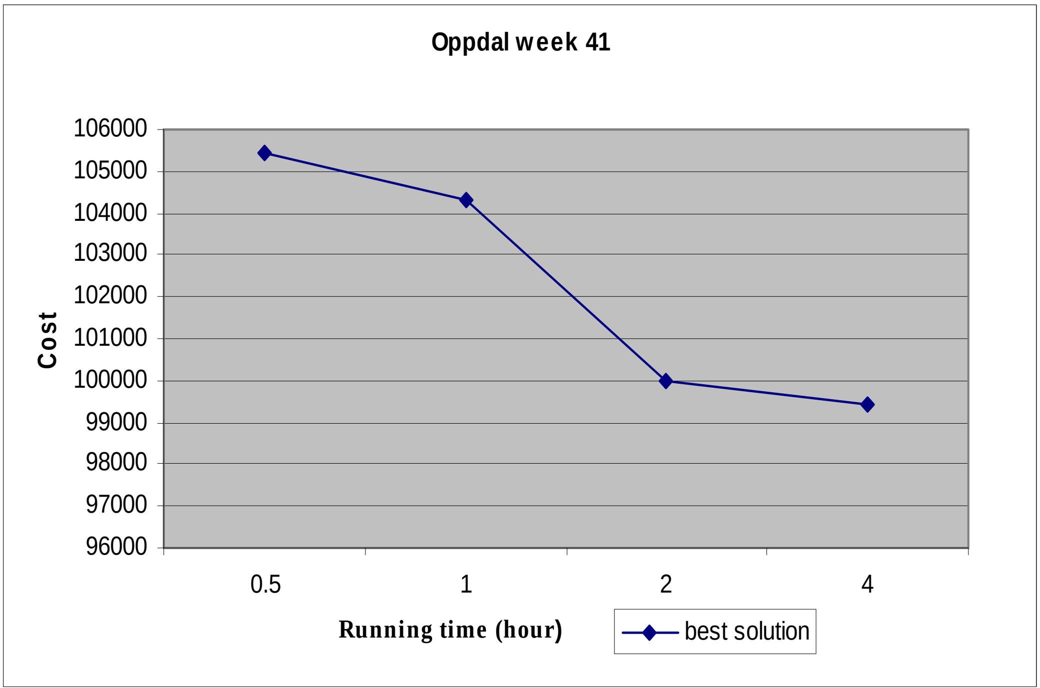

Figure 2-d: solution quality from different running durations

From Figure 2, it is clear that solution quality increases (the value of the best solution decreases) as running time is prolonged. But after running time reaches a certain level, to extend running time will not be able to improve solution quality.

For each scenario, we use the value of [(worst solution-best solution)/best solution] to indicate the deviation of different solutions. For each data case, the deviation of solutions also fluctuates along with running time (showed in Figure 3). The testing results illustrate the difference of solutions for most scenarios are less than 5%.

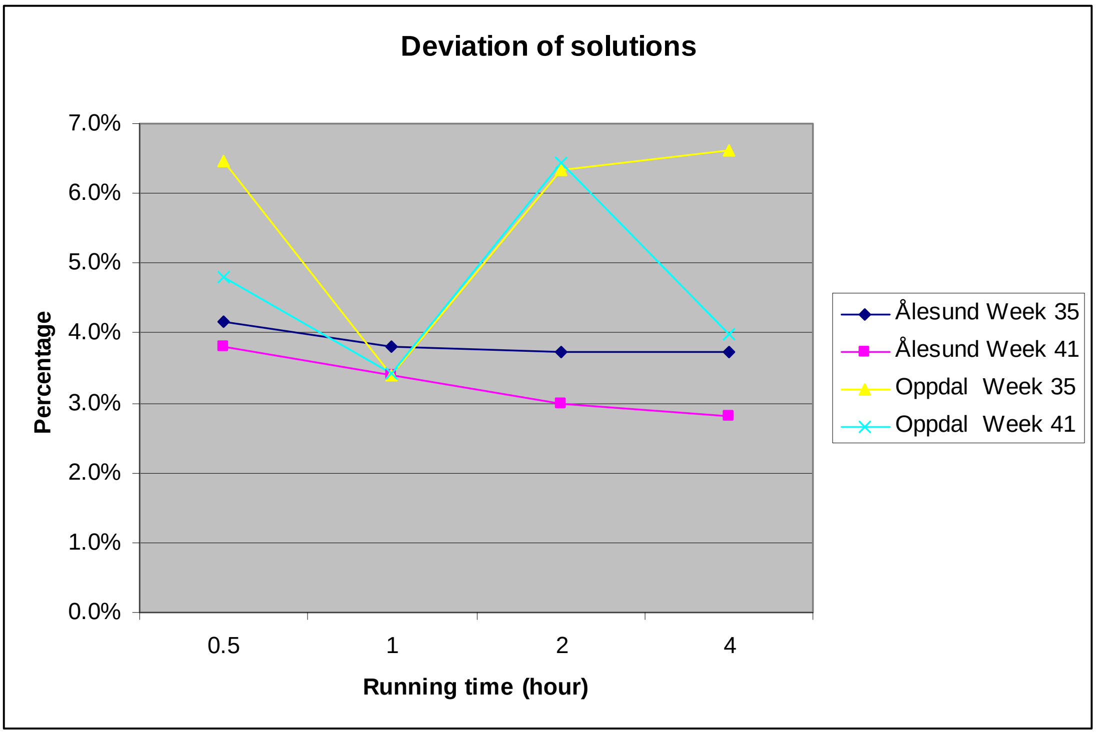

Figure 3: Deviation of solutions for the four instances.

Since the solution quality is good enough and available time for data testing is limited, the following testing scenarios are mainly performed with a running time of 1 hour.

5.3 Validating solutions of the solver

Due to the fact all the routes have to satisfy all the constraints of the Livestock Collection Problem, it is necessary to verify whether solution routes violate any constraints. In such a way, we can estimate how good the model works and how significant our research results could be. Table 7 shows a set of routes generated by the solver according to the data of week 01 2008 at the slaughterhouse located in Ålesund (data case 1).

Table 7: A set of solution routes of data case 1

vehicle	date	number of Tours	start time	first load time	Finish Time	tour duration	Animal load Bovine	Animal load pig	number of orders collected
Truck No. 1	Sunday	1	6:00	6:58	12:04	5:06	8	33	6
	Monday	1	6:00	6:15	11:11	4:56	8	39	4
	Tuesday	1	6:00	7:49	14:44	6:55	8	20	5
	Wednesday	1	6:00	6:34	12:42	6:08	11		5
Truck No. 2	Sunday	1	6:00	6:35	10:21	3:46	14		4
	Monday	1	6:00	6:37	12:38	6:01	9	28	7
	Tuesday	1	6:00	6:21	10:41	4:20	13		4
	Wednesday	1	6:00	6:32	9:40	3:08	13		3
	Wednesday	1	10:03	11:32	15:05	3:33	13		5
Truck No. 3	Sunday	1	6:00	6:27	14:16	7:49	18	35	4
	Monday	1	6:00	6:37	12:58	6:21	18	12	5
	Monday	1	13:21	13:50	18:10	4:20	3	120	5
	Tuesday	1	6:00	7:13	14:57	7:44	22	8	4
Truck No. 4									
Truck No. 5	Tuesday	1	6:00	6:18	9:47	3:29	4	55	5
	Wednesday	1	6:00	6:02	8:58	2:56	11		5
Truck No. 6	Tuesday	1	6:00	7:05	11:10	4:05	7	45	5
	Wednesday	1	6:00	6:21	9:11	2:50	13		3
Truck No. 7	Tuesday	1	6:00	6:27	8:24	1:57		92	2
Truck No. 8	Sunday	1	6:00	6:24	8:33	2:09	1	56	2
	Monday	1	6:00	6:29	10:00	3:31	14	10	4
	Monday	1	10:23	11:44	14:38	2:54	14		4
	Wednesday	1	6:00	6:26	9:17	2:51	12		4
Sum		22					234	553	95

(Days without routes are omitted)

Due to the existence of a holiday, in the week production only lasted for 3 days, from Monday to Wednesday. Therefore, the livestock collection was performed from Sunday through Wednesday. The above table contains 22 routes for 8 vehicles which should collect 95 orders available during that period. Do the set of routes satisfy all the constraints? The relevant verification is fulfilled from the practical perspective as follows.

5.3.1 Vehicle capacity constraints

It has been checked that the load of each solution route does not exceed the capacity of the vehicle which performs the tour. The sequence for loading is also feasible.

5.3.2 Animal types and categories

In practice, it is common to load the same type but different categories of animals into a compartment. Thus, the solution routes also follow the principle. Among the 22 routes, no different types of animals have to be loaded into the same compartment.

5.3.3 Visiting and loading order

There are no diseased or breeding herds in this case, so it is not necessary to worry about the constraints.

5.3.4 Time windows

The time window applied in this solver is the closing time of the slaughterhouse. No vehicles are allowed to arrive at the slaughterhouse after closing time (10pm). No route violates this restriction.

5.3.5 Route duration

Since no animals are allowed to stay on a vehicle more than 8 hours, all trucks have to arrive at slaughterhouse within 8 hours after the first animal is loaded. The figures in Table 7 shows the durations of all solution routes are less than 8 hours.

It should be pointed out that the accuracy of tour duration depends on the simulation of travel time, loading time and unloading time. In particular, vehicle travel time plays the most significant role. Since route duration is one of the most important constraints, the accuracy of modeling travel time is extremely vital.

5.3.6 Inventory

The solution routes have to be able to maintain the inventory level of the lairage at slaughterhouse all the time. In the solver, inventory constraint is checked day by day. Theoretically, it is possible that many trucks deliver animals collected in the late afternoon thus no enough supply for production in the morning. In the practical route plan depicted in Table 2, it is noticeable that some vehicles are required to deliver a certain number of animals in the morning in order to keep up the inventory level. It should make sense to find out whether solution routes can maintain adequate supply for production all the time within a day. The real routes completed during the week in practice are illustrated in Table 8. The information can help compare the inventory level.

Table 8: Real routes of week 01

vehicle	date	number of Tours	start time	first load time	finish time	tour duration	animal load		number of orders Collected
							bovine	Pig	
Truck No.1	Sunday	1	17	18:30	21:15	2:45		39	1
	Monday	1	12	13:45	22:05	8:20	12		5
	Tuesday	1	9	11:00	14:00	3:00	12		4
	Wednesday	1	6	6:35	11:10	4:35	13		3
Truck No.2	Sunday	1	8:30	9:45	13:25	3:40	14		2
	Monday	1	5:40	6:15	12:50	6:35	14	28	10
	Wednesday	1	5	5:50	9:50	4:00	14		4
Truck No.3	Tuesday	1	6:15	7:45	14:00	6:15	23		5
Truck No.4	Tuesday	1	5:30	6:00	10:30	4:30		55	2
	Wednesday	1	6:30	7:00	11:30	4:30	12		5
Truck No.5	Sunday	1	10:00	10:50	12:40	1:50		92	2
	Monday	1	6:00	7:50	12:35	4:45	7	45	5
	Tuesday	1	6:00	7:35	10:00	2:25	4	12	3
Truck No.6	Sunday	1	8:45	10:15	14:30	4:15	15		5
	Monday	1	9:00	10:15	11:00	0:45		67	1
	Monday	1	11:10	11:35	13:00	1:25	3	53	4
	Tuesday	1	6:00	8:40	10:00	1:20	9		4
Truck No.7	Sunday	1	8:00	9:10	14:30	5:20	15		7
	Monday	1	6:00	6:11	9:30	3:19	3	55	4
	Wednesday	1	5:30	7:30	10:00	2:30	14		3
Truck No.8	Sunday	1	8:30	8:46	13:36	4:50		74	3
	Monday	1	5:00	6:38	9:33	2:55	10	33	2
	Monday	1	10:30	11:25	17:05	5:40	13		4
	Tuesday	1	13:00	14:45	18:25	3:40	14		4
	Wednesday	1	6:45	7:30	10:30	3:00	13		3
Sum		25					234	553	95

(Days without routes are omitted)

According to the real routes and solution routes, the inventory level of each day can be calculated for each situation. A comparison is made so as to check how inventory constraints are met (Inventory lines are highlighted in blue).

Table 9: Inventory of bovine

		Sunday	Monday	Tuesday	Wednesday
Real routes	animals collected	44	62	62	66
	animals slaughtered	0	65	42	127
	inventory level	44	41	61	0
	number of early delivery	0	13	13	28
	latest time of early delivery		9:33	10:00	10:00
solution routes	animals collected	41	66	54	73
	animals slaughtered	0	65	42	127
	inventory level	41	42	54	0
	number of early delivery	0	14	20	49
	latest time of early delivery		10:00	10:41	9:40

Table 10: Inventory of pig

		Sunday	Monday	Tuesday	Wednesday
Real Routes	animals collected	205	281	67	0
	animals slaughtered	0	238	315	0
	inventory level	205	248	0	0
	number of early delivery	0	88	67	0
	latest time of early delivery		9:30	10:30	
Solution Routes	animals collected	124	209	220	0
	animals slaughtered	0	238	315	0
	inventory level	124	95	0	0
	number of early delivery		49	147	0
	latest time of early delivery		11:11	9:47	

From the above tables, it seems the inventory and early deliveries for bovine are almost the same. The collection of pigs of solution routes is later compared with real routes. No significant signs indicate the supply for production within a day may have problem.

5.3.7 Comments on real routes

The real routes of week 01 have been input to the solver for evaluation. The solver complains that there is one route violating the 8-hour tour duration constraint and 5 routes violating the vehicle capacity constraints. The duration of the tour of truck No.1 on Monday is 8 hours 20 minutes and does violate the 8-hour rule. The loads of 5 tours seem to exceed vehicle capacity according to the calculation with standard animal size. However, it is understandable how these exceptions could happen. First, it is common for a vehicle to be slowed down for various reasons and arrive late. Secondly, in practice, even animals of the same category vary in size. It is possible for a driver to load more small animals into his truck than animals of standard size.

5.4 Possible cost reduction

By evaluating the real routes and solution routes with the same travel cost standard, the possible transportation cost reduction has been compared. Table 11 presents the costs of real routes and solution routes.

Table 11: Cost of real routes and solution routes

	tour amount	Distance	Cost
real routes	25	4388.82	49240.75
solution routes	22	3443.50	39010.37

Number of routes decreases from 25 to 22.

Distance reduction of solution routes compared with real routes:

(4388.82-3443.50)/ 4388.82= 22%

Cost reduction of solution routes compared with real routes:

(49240.75-39010.37)/ 49240.75=21%

Since vehicle no. 3 and 4 have trailer and maybe not all farms can be accessed by trucks with trailer, another test (the routes of the two trucks with trailer are fixed, only seek better routes for the remaining 6 trucks) has been done. In such a way, we hope to find out how much improvement can be gained only through better routing (not allow more visits for trucks with trailer, thus eliminate the impact of using trailer). The results are depicted in table 12.

Table 12: Cost of solution routes without impact of trailer

	tour amount	Distance	Cost
real routes	25	4388.82	49240.75
solution routes (2)	24	3828.18	43634.29

Number of routes decreases from 25 to 24.

Distance reduction of solution routes compared with real routes:

(4388.82-3828.18)/ 4388.82= 13%

Cost reduction of solution routes compared with real routes:

(49240.75-43634.29)/ 49240.75=11%

The above results indicate the potential cost reduction of adopting better route planning methods is fairly significant.

5.5 Comparison of route feature

From the solver, solutions in Scalable Vector Graphics (SVG 2008) format can be generated to illustrate the distribution of orders and vehicle routes as a graph. Some of these files are presented in the following sections for the purpose of analyzing route features and the nature of demand.

Feature 1: In today’s practice, each vehicle can only collect animals within a predefined district. The fact exerts an important impact on the feature of real routes. Figure 4 compares some real routes and solution routes.

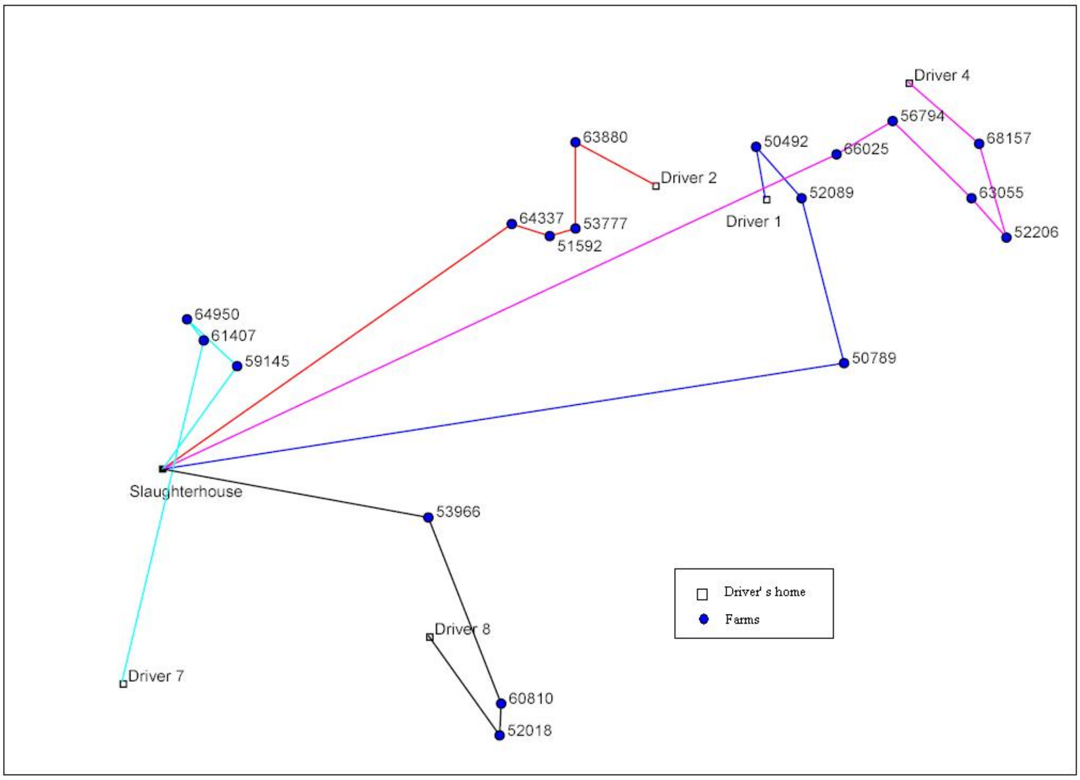

Figure4-a: Real routes

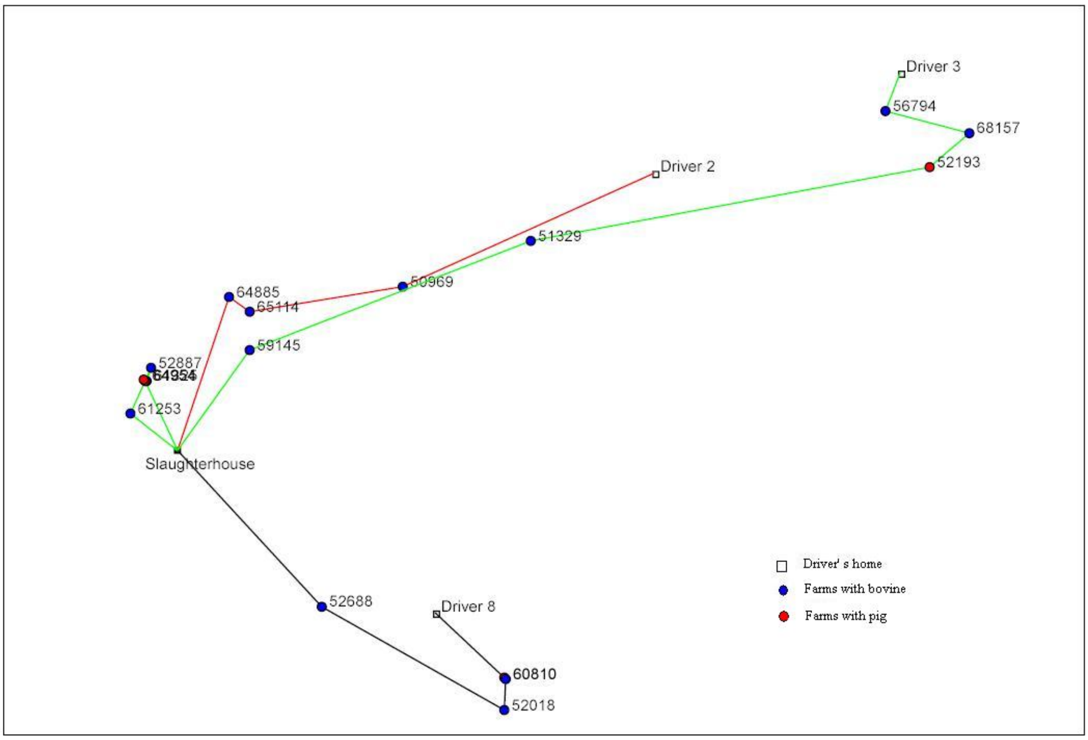

Figure 4-b: Solution routes

All the nodes of a real route locate within a certain area—the predefined district of the vehicle while solution routes may have nodes dispersed along the routes to slaughterhouse (since the model abolishes the limitation of a predefined district for each vehicle and allows a truck to pick up load from any farm).

Feature 2: In today's practice, a vehicle has to go back to its predefined area to pick up load in order to perform a second or third tour. On the contrary, among solution routes, any vehicle can perform a second or third tour by visiting farms near the slaughterhouse. Thus, more vehicles have the opportunity of performing their second or third tour. This fact will enable the orders near the slaughterhouse to be collected more efficiently.

Feature 3: More solution routes have mixed load. For data case 1, there are 6 routes with mixed types of animal among the total 25 real routes. Comparatively, 12 of 22 solution routes collect both types of animals on the same tour. The reason for this fact is the vehicles can select appropriate load within a broader scope in order to maximize the utilization of its capacity.

Feature 4: Solution routes have fewer tours than real routes. For data case 1, solution routes only need 22 tours while real routes have 25 tours. The feature should be the outcome of the better planning ability of the solver and the fact that all vehicles can select proper orders within the whole area.

Feature 5: The average number of orders collected on a tour increases. Since solution routes can serve the same demand with a smaller amount of routes, each vehicle will collect more orders on a tour.

6. Fleet capacity exploration of the two slaughterhouses

6.1 Purpose of research

Currently there are 8 vehicles collecting live animals for the slaughterhouse located in Ålesund while 16 trucks perform the task for another slaughterhouse at Oppdal. Those trucks also collect live animals for other slaughterhouses of Gilde. In this thesis, we try to find out how many vehicles will be enough for each slaughterhouse when the trucks can be fully used by one slaughterhouse. We also perform some testing to verify whether it is beneficial to use a mixed fleet.

6.2 Task analysis

Before starting to search for the required fleet size, it is critical to uncover the essence of the problem. Firstly, it should be pointed out that fleet size should be explored from several aspects, namely, the capacity of each vehicle in the fleet, the number of vehicles and locations of vehicles. The capacity of a vehicle refers to how many animals the vehicle can load. Number of vehicles states how many each type of trucks the fleet has. The fleet may be homogeneous or heterogeneous. Locations of vehicles are related to where the fleet departs for livestock collection. In current reality, each vehicle starts its first tour from the driver’s home. To serve a certain number of customers with a certain demand, all the three aspects will affect the output (total travel distances and costs).

In general, vehicles with smaller capacity have to travel more distances than larger ones because they have to travel from the slaughterhouse (or driver’s home) and customers more times than large trucks in order to collect the same amount of animals.

In addition, to collect a certain amount of animals, a big fleet with more trucks located in different places may consume less time and lower cost than a smaller amount of trucks. The reasons for this are as follows. Firstly, more trucks can perform more tours at the same time, so they can collect the animals faster. Secondly, vehicles start their first tour from the driver's home. The distance between the homes of different drivers and a certain customer may be different. A vehicle located near the customer can often serve the demand at lower transportation cost compared with a vehicle far from the customer. Therefore, a large fleet may serve a certain demand more efficiently.

Fleet size is usually determined by demand and a company's business strategy. Like fleet size, demand can also be scrutinized in two aspects: the volume of demand and the distribution of demand. The higher the volume of demand is, the larger the fleet size should be. The more dispersed the demand distributes, the larger the fleet may be. The same volume of demand with different distribution may require different size of fleet to serve. Apart from the demand, a company's business strategy exerts impact on fleet size as well. For example, some companies prefer to maintain a large fleet so as to keep flexibility and high service level. On the other hand, a small fleet is adopted by some companies so as to reduce cost.

For the two slaughterhouses, it is noticeable that both the volume of demand (the amount of animals collected) and the distribution of demand (where the animals are) vary to different extent along with time. Thus, the required fleet size for each week could be diverse. However, it is not possible for a company to change its fleet size all the time. In general, a company should select the fleet size which can satisfy its demand during most of business time. Next, the number of vehicles which can satisfy the requirement of the two weeks will be sought through data testing. Hopefully, our research results could help the company select a proper fleet size.

6.3 Minimum fleet size while using standard trucks

In practice, most of the trucks which collect live animals for the two slaughterhouses have similar capacities. This type of truck is appointed as our standard vehicles. It should be meaningful to find out at least how many standard trucks each slaughterhouse requires in order to maintain its production. Therefore, the minimum fleet size while using standard trucks has been searched as the first step.

According to the loads of real routes, the capacity of the standard trucks (all standard vehicles are the same size) for each slaughterhouse is set as follows:

Table 13: Capacity of standard vehicles

Slaughterhouse	Capacity
Ålesund	14 bovines or 98 slaughter hogs
Oppdal	158 sheep

6.3.1 Principles for searching fleet size

Since currently there are more vehicles than required, minimum fleet size can be obtained through gradually getting rid of trucks which induce high cost. Now that all the trucks have the same capacity, the only attribute which distinguishes each vehicle is the place where its first tour starts, namely, the drive’s home. The geographic distance between driver’s home and farms induces the difference in transportation cost while serving a certain number of farms with different trucks. The solver will minimize the utilization of vehicles which induce high cost. Thus, for a set of solution routes, some vehicles are utilized more than the others. One indicator of vehicle utilization is the travel distance. The reason why a vehicle travels a shorter distance is either it performs fewer routes or it is located near slaughterhouse. Table 14 presents a set of routes of Ålesund week 41.

Table 14: A set of routes of Ålesund week 41

vehicle	Date	tour	distance	cost	load		number of orders delivered	total tours	Total Distance
					type0	Type1			
Truck No.1	Sunday	1	122.71	1227.12	14		1	9	1822.25
	Monday	1	220.65	2206.46	16		3		
	Tuesday	1	171.92	1719.21	14		2		
	Tuesday	1	130.80	1308.00	13		2		
	Wednesday	1	223.21	2232.14	17		5		
	Wednesday	1	219.68	2196.83	13		2		
	Thursday	1	158.95	1589.49	14		3		
	Thursday	1	275.19	2751.90	14		7		
	Friday	1	299.13	2991.30	14		1		
Truck No.2	Sunday	1	127.38	1273.76	14		2	9	1144.82
	Monday	1	165.70	1657.03	12		2		
	Tuesday	1	133.05	1330.53	14		4		
	Wednesday	1	140.74	1407.37	14		4		
	Wednesday	1	143.13	1431.31	11		2		
	Thursday	1	152.95	1529.46	11		5		
	Thursday	1	121.83	1218.34	14		5		
	Thursday	1	37.43	374.31	14		1		
	Friday	1	122.60	1226.04	13		2		
Truck No.3	Sunday	1	221.63	2216.27		94	3	6	1563.93
	Monday	1	250.44	2504.39	14	15	6		
	Tuesday	1	236.18	2361.75	14		4		
	Wednesday	1	218.92	2189.21	14		4		
	Thursday	1	276.67	2766.72	14		3		
	Friday	1	360.10	3600.99	14		5		
Truck No.4	Sunday	1	297.73	2977.26	15		7	7	1232.92
	Monday	1	177.88	1778.78	14		4		
	Tuesday	1	186.72	1867.18	14		2		
	Wednesday	1	217.56	2175.62	15		4		
	Thursday	1	153.60	1536.00	13		3		
	Thursday	1	48.02	480.17	8		2		
	Friday	1	151.42	1514.20	15		2		
Truck No.5	Sunday	1	80.39	803.90	4	16	4	4	404.11
	Monday	1	101.15	1011.48	2	20	2		
	Tuesday	1	66.80	668.00	10		3		
	Wednesday	1	155.77	1557.74	13		4		
Truck No.6	Tuesday	1	125.63	1256.31	11		1	3	462.77
	Friday	1	132.93	1329.29	11		3		
	Friday	1	204.21	2042.14	14		5		
Truck No.7	Monday	1	69.49	694.92		50	2	3	379.16
	Tuesday	1	165.74	1657.40	14		4		
	Thursday	1	143.92	1439.23	14		2		
Truck No.8	Sunday	1	129.96	1299.59	15		4	7	976.48
	Monday	1	86.87	868.72	7	32	4		
	Tuesday	1	168.60	1686.01	13		5		
	Wednesday	1	216.21	2162.09	14		4		
	Thursday	1	60.54	605.43	5		2		
	Thursday	1	234.27	2342.70	14		3		
	Friday	1	80.03	800.30	12		3		
Total		48	7986.44	79864.40	583	227	157	48	7986.44

According to the table, truck no. 5, 6, 7, and 8 have shorter travel distances compared with the other trucks. Though truck no. 8 has 7 tours (same with truck no. 4), its distance is shorter since it is located near the slaughterhouse. For truck no 5, 6 and 7, they travel less because they are assigned fewer routes.

When a vehicle is assigned few routes or even no routes by solver, it must be more costly to use the vehicle compared with others. Thus it is reasonable to get rid of this truck.

For vehicles located near the slaughterhouse, they can only efficiently serve the farms near slaughterhouse. Trucks located far away from the slaughterhouse can also serve those farms efficiently by visiting them on the way to the slaughterhouse or performing their second or third tours around the slaughterhouse. On the other hand, it is more costly for vehicles located near the slaughterhouse to serve farms far away from the slaughterhouse. Therefore, to abolish the trucks close to the slaughterhouse is more economical than getting rid of vehicles located far from the slaughterhouse.

From above, our strategy of searching minimum fleet size will be to abolish the vehicles with short distances.

Due to the fact that both volume and distribution of demand vary all the time, the proper fleet size should be able to meet the requirements of different time periods. Thus, it is sensible to consider the demand of week 35 and week 41 simultaneously when trying to decide the fleet size for each slaughterhouse.

6.3.2 Minimum fleet size for the slaughterhouse at Ålesund

Step 1: run the solver 10 times for data case 2 and 3 with 8 vehicles. 10 different solutions can be found. In each solution, the total travel distance of a vehicle during the whole week (from Sunday to Friday) is summed by the solver. That figure could indicate the utilization of a truck. The longer the distance is, the more important the vehicle should be. In order to reduce the impact of randomness, 10 solutions are used together to evaluate the utilization of each vehicle. The results are presented in Table 15 and Table 16 (The red cells highlight the vehicles with the shortest distances).

Table 15: Total travel distance for each vehicle while having 8 trucks on week 35

run	1	2	3	4	5	6	7	8	9	10	sum	rank
tour number	41	40	40	40	41	41	41	41	40	42		
total distance	6789.84	6988.17	6991.19	6995.26	6880.09	6929.03	6944.60	6772.01	6739.08	6931.73		
Truck No. 1	1216.71	1369.66	1246.84	1251.17	1073.38	1041.20	1164.23	1222.14	1431.49	1614.63	12631.45	6
Truck No. 2	1030.98	1256.12	1242.80	1187.45	1086.09	1248.27	1027.38	1273.39	821.69	1016.00	11190.17	5
Truck No. 3	1373.19	1155.51	1257.63	1401.00	1289.30	1251.11	1343.13	1379.99	1215.95	1087.73	12754.54	8
Truck No. 4	1029.85	1335.98	1041.92	1203.08	1355.72	1414.25	1484.88	1119.48	1318.39	1394.54	12698.09	7
Truck No. 5	592.43	339.74	799.96	551.28	746.63	688.79	582.85	1112.97	815.97	622.86	6853.47	3
Truck No. 6	468.83	577.31	559.15	311.51	399.90	270.32	174.42	74.88	387.29	486.16	3709.75	2
Truck No. 7	242.08	197.16	125.85	216.97	199.35	153.65	449.57	68.74	106.44	188.45	1948.25	1
Truck No. 8	835.77	756.70	717.04	872.81	729.73	861.43	718.14	520.41	641.85	521.37	7175.25	4
Total	6789.84	6988.17	6991.20	6995.26	6880.10	6929.02	6944.59	6771.99	6739.07	6931.73		
Average	848.73	873.52	873.90	874.41	860.01	866.13	868.07	846.50	842.38	866.47		

Table 16: Total travel distance for each vehicle while having 8 trucks on week 41

run	1	2	3	4	5	6	7	8	9	10	sum	rank
tour number	46	47	46	46	46	46	47	48	46	45		
total distance	8203.75	8150.44	8087.01	8037.25	8093.02	8152.93	8145.81	7986.44	8050.9	8073.92		
Truck No. 1	1591.80	1713.48	1630.17	1703.98	1277.89	1838.97	1416.52	1859.68	1305.15	1449.73	15787.37	8
Truck No. 2	1398.99	1399.19	1618.26	1308.82	1152.31	788.76	1588.48	1107.38	1159.42	1536.14	13057.75	5
Truck No. 3	1655.06	1611.72	1324.68	1354.74	1588.56	1221.08	1507.89	1563.93	1375.66	1309.40	14512.72	6
Truck No. 4	1415.25	1548.85	1414.42	1512.33	1536.15	1683.37	1676.57	1232.92	1596.80	1636.41	15253.07	7
Truck No. 5	475.88	327.00	323.72	469.08	676.80	1158.09	280.42	404.11	451.82	470.22	5037.13	3
Truck No. 6	573.97	557.26	560.41	490.34	416.45	484.59	434.05	462.77	300.33	148.47	4428.65	2
Truck No. 7	200.17	213.42	170.61	489.49	406.86	241.87	501.79	379.16	705.92	772.12	4081.40	1
Truck No. 8	892.61	779.53	1044.75	708.47	1038.01	736.20	740.09	976.48	1155.82	751.43	8823.39	4
Total	8203.74	8150.45	8087.02	8037.24	8093.02	8152.93	8145.81	7986.44	8050.91	8073.92		
average	1025.47	1018.81	1010.88	1004.66	1011.63	1019.12	1018.23	998.304	1006.36	1009.24		

Among 10 sets of solution routes, some vehicles always have shorter total travel distances than others. Therefore, it is reasonable to stop using them. The results from the two weeks signal that vehicle No.6 and No. 7 have the lowest utilization. The reason for the phenomenon is because there are 3 trucks, namely No. 5, No.6 and No.7 located at the same place. There are not enough orders for them to collect. Figure 5 shows the starting locations of each vehicle for the slaughterhouse at Ålesund.

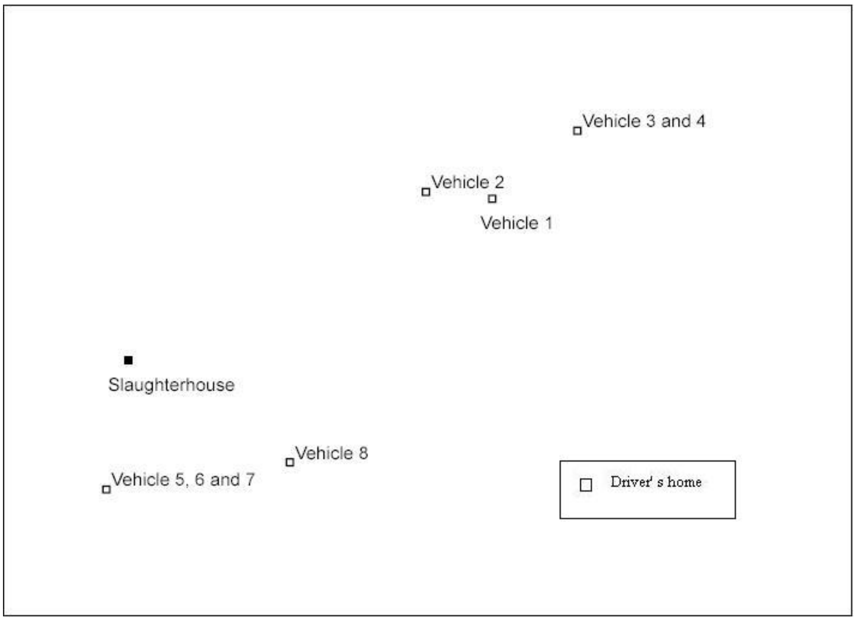

Figure 5: Vehicle locations for Ålesund

Thus, the conclusion of step 1 is to get rid of vehicle No.6 and No. 7**.**

Step 2: run the solver 10 times for data case 2 and 3 with 6 vehicles. Do the same procedures with step 1. The comparison of travel distances is listed as follows:

Table 17: Results of step 2

Vehicle	Week 35		week 41	
	total distance	rank	total distance	rank
Truck No. 1	14818.74	6	17660.89	6
Truck No. 2	11988.78	4	16187.54	4
Truck No. 3	13147.56	5	16661.99	5
Truck No. 4	11820.97	3	14391.31	3
Truck No. 5	9639.27	2	7151.85	1
Truck No. 8	9420.45	1	10260.80	2

The outcome of step 2 indicates it is time to get rid of vehicle No.5 and No.8.

Step 3: Repeat the same procedures with previous steps with 4 vehicles. The new finding is depicted in Table 18.

Table 18: Results of step 3

Vehicle	Week35		week 41	
	total distance	rank	total distance	rank
Truck No. 1	24067.58	4	22349.97	3
Truck No. 2	21277.57	3	20770.66	1
Truck No. 3	17464.48	2	20822.92	2
Truck No. 4	15989.78	1	22766.50	4

According to the above table, vehicle No.3 should be got rid of next if possible.

Step 4: Repeat the same procedures with 3 trucks.

With 3 trucks, there is no feasible solution for week 41. Thus, the minimum fleet size for slaughterhouse at Ålesund is 4 trucks.

In addition, it is still feasible to use 3 trucks to collect all the orders on week 35. It becomes infeasible when the number of trucks decreases to 2.

Step 5: Comparison with other possible vehicle combination

By getting rid of vehicles with shortest total travel distances, we reach the fleet composition of vehicle No.1, No.2, No.3, No.4. How about other combinations? Basing only on the vehicle locations, we combine vehicle No.1, No.3, No. 5 and No.8 as a new fleet and make a comparison with the first composition. Run the solver with the two fleet compositions; find the best solution among 10 runs for both week35 and week 41. The relevant results are demonstrated in Table 19.

Table 19: The total distance of the best solution for each week

vehicle composition	total distance		sum of
	week35	week41	two weeks
No.1, 2, 3, 4	7682.62	8554.23	16236.85
No.1, 3, 5, 8	7853.85	9229.90	17083.75
difference	2.2%	7.9%	5.2%

The above results show the fleet composition 2 will induce longer travel distance than the first composition. But the difference is not too big.

6.3.3 Minimum fleet size for the slaughterhouse at Oppdal

For the slaughterhouse at Oppdal, both volume of demand and distribution of demand vary tremendously over time. The volumes of demands at week 35 and week 41 are demonstrated in Table 20.

Table 20: Volumes of demand at Oppdal

	number of orders	number of ovine
week 35	89	1810
week 41	235	8443

The distributions of demand in week 35 and week 41 are demonstrated in Figure 6 and Figure 7.

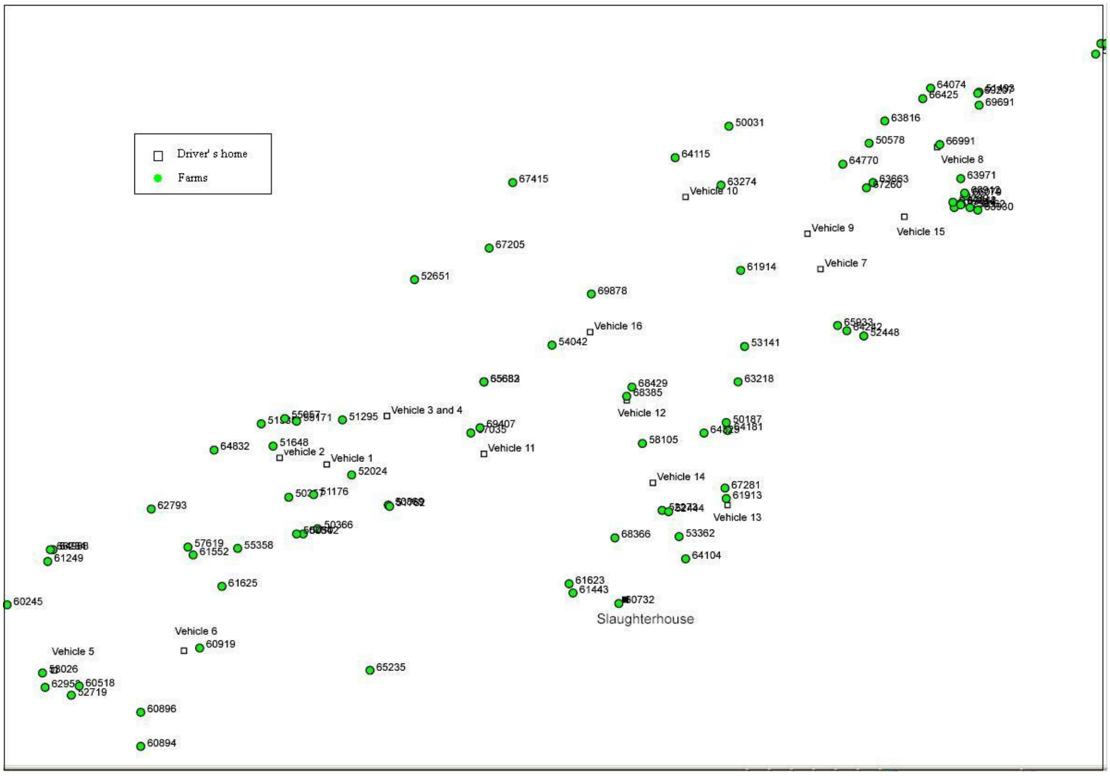

Figure 6: distribution of orders in week 35

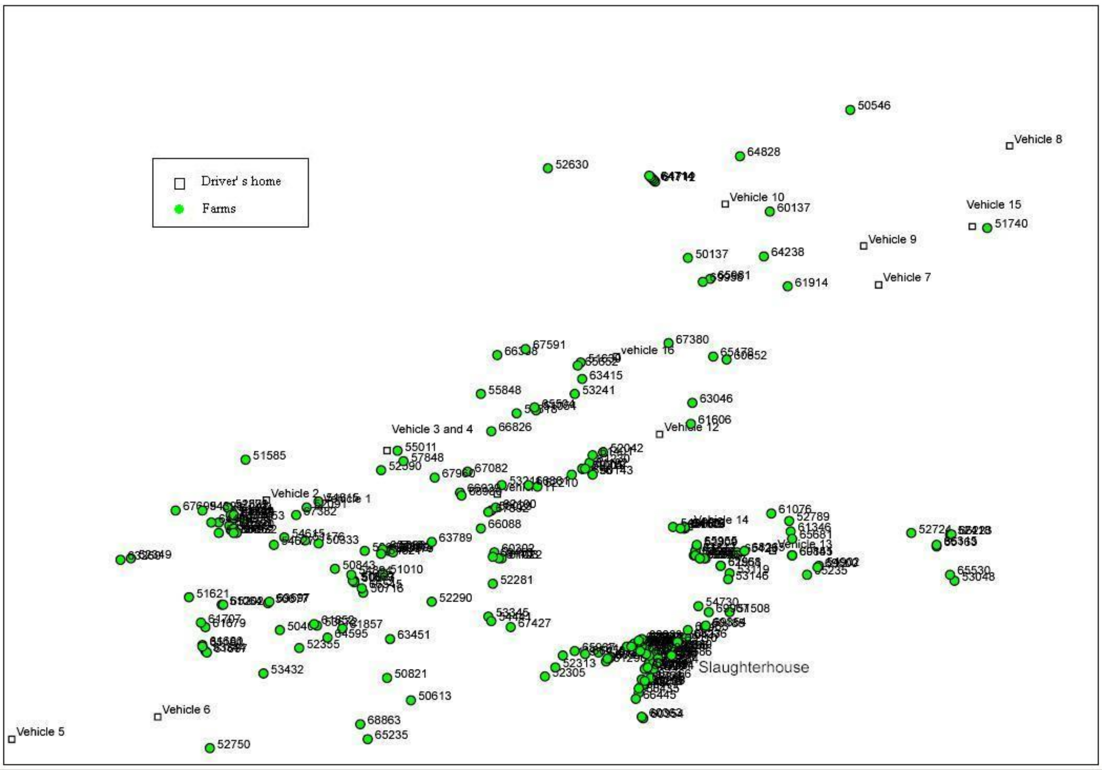

Figure 7: distribution of orders in week 41

The figures state demand of week35 is relatively dispersed while available orders on week 41 are concentrated near the slaughterhouse. The differences of demand will affect the utilization of each truck. In general, a vehicle has to travel longer distance to collect enough loads when the orders distribute dispersed. Just like what have been done for the slaughterhouse at Ålesund, several steps are performed.

Step 1: run the solver 10 times for data case 4 and 5 with 16 vehicles. The results are presented in Table 21 and Table 22.

Table 21: Total travel distance for each vehicle when fleet size is 16 on week 35

run	1	2	3	4	5	6	7	8	9	10	sum	Rank
tour number	18	17	19	18	19	18	19	18	18	18		
total distance	5543.60	5503.72	5684.28	5712.80	5583.69	5747.84	5511.39	5744.01	5717.09	5542.50		
Truck No. 1	324.00	227.38	0.00	0.00	480.28	0.00	422.68	0.00	259.54	0.00	1713.88	5
Truck No. 2	771.04	374.94	605.98	596.30	389.35	397.28	653.26	396.73	387.83	640.12	5212.82	12
Truck No. 3	305.93	305.82	634.91	634.89	296.40	616.55	339.23	616.28	622.73	185.29	4558.02	11
Truck No. 4	0.00	340.97	249.53	397.01	0.00	266.11	266.11	264.03	0.00	607.08	2390.84	6
Truck No. 5	685.82	700.71	700.71	700.71	685.82	685.82	685.82	685.82	685.82	701.94	6919.02	16
Truck No. 6	359.23	731.89	697.22	359.23	707.55	689.04	689.05	685.60	689.68	694.03	6302.52	14
Truck No. 7	684.80	806.30	677.54	677.54	673.33	821.95	297.32	755.26	677.54	677.54	6749.11	15
Truck No. 8	246.22	553.53	293.95	245.48	544.24	245.97	861.72	641.59	257.50	572.35	4462.54	10
Truck No. 9	692.84	267.87	307.13	986.87	298.71	648.99	754.21	356.73	918.24	575.93	5807.51	13
Truck No. 10	497.56	491.02	310.96	209.01	496.27	485.91	251.85	209.01	212.08	208.67	3372.36	8
Truck No. 11	426.37	431.45	426.37	426.37	426.37	428.86	157.53	428.86	426.37	426.37	4004.93	9
Truck No. 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
Truck No. 13	0.00	0.00	68.92	0.00	0.00	0.00	74.69	0.00	0.00	0.00	143.61	2
Truck No. 14	57.92	0.00	0.00	0.00	57.92	0.00	57.92	0.00	0.00	0.00	173.77	3
Truck No. 15	253.18	271.85	574.69	312.73	323.20	253.18	0.00	495.94	341.18	253.18	3079.12	7
Truck No. 16	238.69	0.00	136.37	166.66	204.25	208.17	0.00	208.17	238.59	0.00	1400.89	4
Total	5543.60	5503.72	5684.28	5712.80	5583.69	5747.84	5511.39	5744.02	5717.09	5542.50		
average	346.47	343.98	355.27	357.05	348.98	359.24	344.46	359.00	357.32	346.41		

Table 21 says there are 7 vehicles which are not used at all in some solutions. For vehicle No.12, its total travel distance is always 0, which means it has never been used among 10 solutions.

Table 22: Total travel distance for each vehicle when fleet size is 16 on week 41

run	1	2	3	4	5	6	7	8	9	10	sum	rank
tour number	61	60	60	60	61	59	61	60	61	61		
total distance	10340.1	10686.6	10634.3	10605.5	10573.1	10432.5	10379.1	10644.2	10359.8	10553.9		
Truck No. 1	815.72	619.34	753.09	760.22	653.66	1159.15	726.54	648.05	621.28	985.06	7742.11	12
Truck No. 2	1172.89	1407.96	1037.21	1186.34	1184.83	1548.58	1228.57	1101.49	1447.63	1447.53	12763.03	15
Truck No. 3	1079.61	1236.05	1150.41	1010.05	934.57	1073.07	727.82	1063.98	1040.82	1058.09	10374.47	13
Truck No. 4	769.83	731.13	783.25	827.38	836.88	811.35	777.54	491.49	632.79	797.34	7458.99	11
Truck No. 5	342.00	329.53	329.26	329.32	342.00	320.85	342.60	329.52	345.66	320.36	3331.09	3
Truck No. 6	1374.45	1128.34	1137.03	1168.63	1076.19	819.65	1104.03	1160.68	1090.94	912.15	10972.09	14
Truck No. 7	353.17	356.60	338.83	340.40	335.48	335.48	335.39	358.50	344.27	335.48	3433.59	5
Truck No. 8	487.44	487.44	1130.79	487.44	487.44	0.00	877.06	487.44	487.44	487.44	5419.91	8
Truck No. 9	503.08	547.50	447.06	755.31	679.15	776.52	207.33	409.76	316.69	227.31	4869.69	7
Truck No. 10	1289.62	1319.76	1400.84	1302.18	1350.07	1388.03	1314.96	1383.96	1300.17	1373.72	13423.31	16
Truck No. 11	543.70	420.92	841.27	703.75	853.45	709.27	907.70	619.70	1008.00	680.73	7288.48	10
Truck No. 12	352.24	592.98	374.64	310.12	713.99	194.09	402.19	655.20	399.82	381.47	4376.73	6
Truck No. 13	153.01	64.38	62.84	126.85	133.79	127.67	207.32	190.48	190.39	190.76	1447.50	1
Truck No. 14	304.27	468.93	371.06	620.53	184.09	348.25	280.10	317.27	174.00	320.36	3388.87	4
Truck No. 15	201.01	201.01	207.69	201.01	201.01	254.17	226.09	275.34	212.16	274.56	2254.04	2
Truck No. 16	598.04	774.74	269.04	476.00	606.47	566.35	713.86	1151.36	747.69	761.52	6665.06	9
Total	10340.1	10686.6	10634.3	10605.5	10573.1	10432.5	10379.1	10644.2	10359.8	10553.9		
average	646.25	667.91	664.64	662.85	660.82	652.03	648.69	665.26	647.48	659.62		

Firstly, from Table 21 and 22, it is easy to find out the average distance of a tour (total distance/tour number) for week 35 is around 310 while the counterpart for week 41 is around 170. This fact confirms that a vehicle has to travel longer to obtain enough load when the demand is dispersed.

The two tables also show the utilizations of each vehicle at the two weeks are different. Most vehicles have to perform more tours on week 41 compared with week 35 because week 41 has much larger volume of demand. In addition, the different distribution of demand during the two weeks provokes the different utilization of each vehicle. For example, truck No.12 is the last one to use on week 35, but it is not on week 41. By considering the outcomes of the two weeks, Vehicle No.13, No.14 and No.12 are selected to abolish first. The reason for the decision is that all the three trucks locate near the slaughterhouse. The orders they can collect are proper targets for other trucks to perform their second or third tour. But it is costly for them to collect orders far from slaughterhouse. The location of each vehicle is showed in Figure 8.

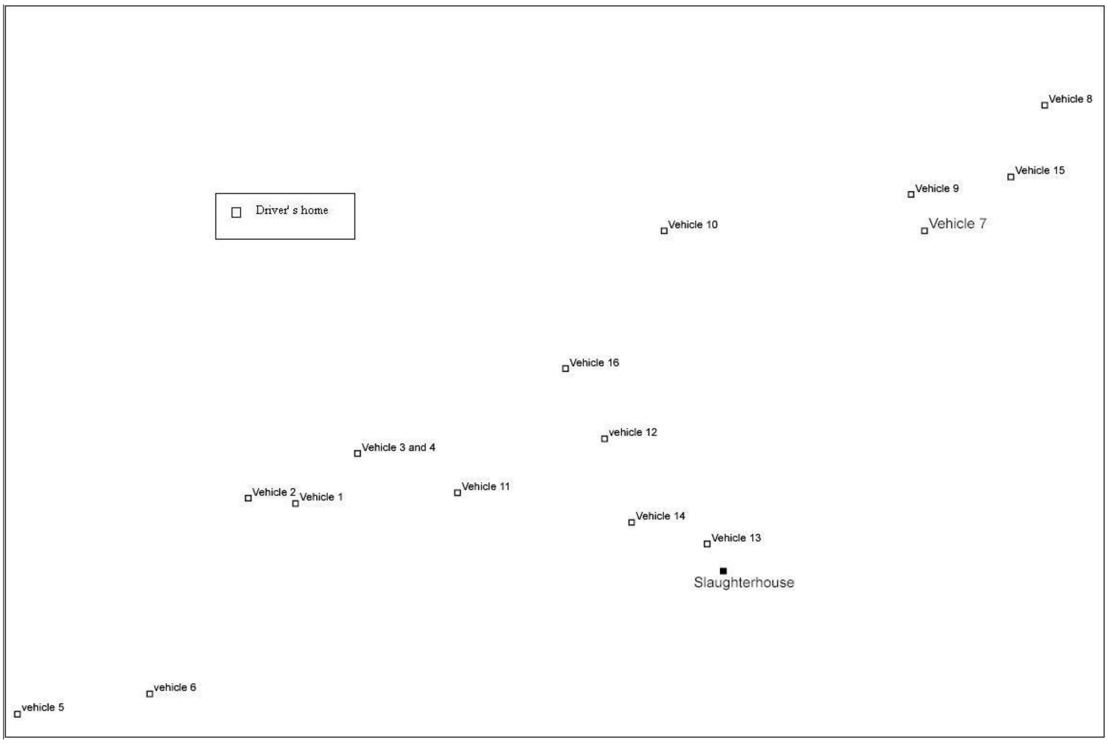

Figure 8: Starting locations of vehicles for the slaughterhouse at Oppdal

Step 2: follow the same method, a new list can be obtained as follows.

Table 23: Results of routes with 13 vehicles

rank of vehicles with least distance	Oppdal Week35	Oppdal Week41
1	No.7	No.11
2	No:15	No.16
3	No.8	No.1
4	No.9	No.10
5	No.11	No.4
6	No.16	No.9
7	No.3	No.15
8	No.4	No.2
9	No.6	No.8
10	No.10	No.3
11	No.5	No.6
12	No.1	No.5
13	No.2	No.7

According to Table 23, vehicle No. 11, No.16, No.4, No. 9 and No.15 are selected to get rid of.

Step 3: Repeat the same procedures as previous steps, we have a new list.

Table 24: Results of routes with 8 vehicles

rank of vehicles with least distance	Oppdal Week35	Oppdal Week41
1	No.2	No.7
2	No.7	No.5
3	No.3	No.10
4	No.6	No.3
5	No.10	No.8
6	No.5	No.6
7	No.1	No.1
8	No.8	No.2

At this step, we select to abolish vehicle No.7, No.10, No.3

.

Step 4: Repeat the same procedure as previous with 5 vehicles. It turns out, for week 41, there are 4 runs which can not find feasible solution. The results are presented in Table 25.

Table 25: Results of week 41 when fleet size is 5

run	1	2	3	4	5	6	7	8	9	10		
random seed	333	877	116	952	293	363	978	506	584	676	sum	rank
Solution	2	4	0	no	no	0	0	no	0	no		
tour number	61	62	61	feasible	feasible	63	62	feasible	64	feasible		
total distance	12764.70	13436.10	12338.70	solution	solution	13214.80	14138.10	solution	13880.70	solution		
Truck No. 1	2386.21	2725.90	2221.10			2525.79	2879.46		2534.18		15272.64	1
Truck No. 2	2430.60	2946.31	2712.98			3082.62	2734.05		2801.79		16708.35	5
Truck No. 5	2605.54	2681.58	2309.93			2464.19	2627.16		2779.67		15468.07	2
Truck No. 6	2566.85	2415.57	2595.56			2436.87	2970.66		2921.16		15906.67	3
Truck No. 8	2775.49	2666.78	2499.10			2705.36	2926.73		2843.93		16417.39	4
Total	12764.69	13436.14	12338.67	0.00	0.00	13214.83	14138.06	0.00	13880.73	0.00		
Average	2552.94	2687.23	2467.73	0.00	0.00	2642.97	2827.61	0.00	2776.15	0.00		

The fact may hint 5 vehicles should be the minimum fleet size for the slaughterhouse. Through further testing, there is no feasible solution when fleet size decreases to 4 for week 41. For week 35, 4 trucks can still be feasible. It becomes infeasible when there are only 3 trucks.

Step 5: Comparison with other possible vehicle combinations

Through the above procedures, a fleet composition has been found. How about other vehicle combinations? Two other combinations are tested for comparison:

Table 26: Total travel distance of the best solution in 10 runs

vehicle composition	total distance		sum of
	week35	Week41	two weeks
No.1, 2, 5, 6, 8	5877.36	12338.70	18216.06
No.1, 2, 3, 5, 10	6128.62	11474.10	17602.72
No.5, 6, 7, 8, 10		infeasible	
difference	4.3%	-7%	-3.4%

The difference between the two fleet compositions is around 4%.

6.3.4 Change of cost when fleet size changes

During the above testing, it has also been found out that total travel costs go up when fleet size decreases. The comparison is listed in Table 27 and Table 28.

Table 27: Change of the total cost for Ålesund

vehicle composition	total costs		sum of
	week35	week41	two weeks
No.1, 2, 3, 4	76826.2	85542.3	162368.5
8 vehicles	67390.8	79864.4	147255.2
Increase	14.0%	7.1%	10.3%

Table 28: Change of the total cost for Oppdal

vehicle composition	total costs		sum of
	week35	week41	two weeks
No.1, 2, 5, 6, 8	58773.6	123387.0	182160.6
16 vehicles	55037.2	103401.0	158438.2
Increase	6.8%	19.3%	15.0%

The reason for the increase is because the fleet is heterogeneous due to the location of each vehicle. For a small fleet, each vehicle has to perform more routes to collect the orders which could be collected more efficiently by one of the trucks abolished. Thus, extra costs are induced. However, this just increases the variable cost of the fleet, it will reduce the fixed cost of a fleet when the fleet size goes down.

In addition, it is noticeable that the percentages of cost increase for week 35 and week 41 are so different. The main reason for this phenomenon is probably the fleet composition. A certain fleet may match the demand of one week more than another one. Different fleet compositions will cause dissimilar results. Another example is present in Table 29 and Table 30.

Table 29: Another fleet composition for Ålesund

vehicle composition	total costs		sum of
	week35	week41	two weeks
No.0, 2, 4, 7	78538.5	92299.0	170837.5
8 vehicles	67390.8	79864.4	147255.2
Difference	16.5%	15.6%	16.0%

Table 30: Another example for Oppdal

vehicle composition	total costs		sum of
	week35	Week41	Two weeks
No.0, 1, 2, 4, 9	61286.20	114741.00	176027.20
16 vehicles	55037.20	103401.00	158438.20
Difference	11.4%	11.0%	11.1%

6.4 Possibility of using trailer

In general, it is acknowledged that adding a trailer to a vehicle can increase its cost efficiency when the vehicle can collect enough load. A truck with a trailer will usually cause more cost per unit travel distance but its bigger capacity will compensate the cost and realize the lower cost per animal collected. Table 31 compares the cost efficiency of standard trucks and trucks with trailer. The travel costs per unit distance for the two types of vehicles are evaluated according to the experience of the relevant professionals.

Table 31: Cost of two types of vehicles

vehicle type	capacity			cost per unit distance	cost per animal		
	Bovine	Pig	sheep		bovine	pig	Sheep
standard vehicle	14	98	158	10	0.714	0.102	0.063
vehicle with trailer	26	174	270	16	0.615	0.092	0.059

It should be pointed out that trucks with trailer can only realize its cost efficiency when they have enough load, otherwise the cost per animal can be as the same with standard trucks or even worse. For example, when a truck with trailer collects less than 23 bovines for a tour, it is less efficiency compared with a standard truck which collects 14 bovines for a tour with the same distance.

In addition, trucks with trailer travel a little slower and require more time to load and unload live animals than standard trucks. Therefore, it will take more time to collect the same amount of animals.

Trucks with trailer can be regarded as bigger vehicles compared with standard trucks. Some of the following research findings can be applied to the larger trucks.

Research conclusions found in this section are based on the current cost structure (The travel costs per unit distance are 10 and 16 respectively for the standard vehicles and trucks with trailer). The research results may differ if the cost structure changes.

6.4.1 For Ålesund case

For the slaughterhouse at Ålesund, is it possible to use trailers for its fleet? Some testing results are presented as follows:

Test 1: The impact of adding a trailer to every vehicle.

Table 32 shows the results of this test. In order to reduce the impact of randomness, we use the best solution of ten runs to represent a certain scenario in this section.

Table 32: Comparison of costs while adding trailers

	cost of best solution		difference
	8 trucks with trailer	8 trucks no trailer	
week 35	77784.80	67390.80	15.4%
week41	84984.78	79864.40	6.4%

The above results indicate it is not economical to add trailers to all vehicles. What is the reason for this phenomenon? The attention has to be paid to the loads of the routes.

From Table 33 (next page), among 27 routes of week 35, there are 5 routes (highlighted in red) whose loads are no more than 14 bovines, which can be collected by standard trucks. The fact indicates that it may be more efficient to use trucks with trailer only for some routes of a vehicle.

In addition, there are also some other routes whose loads are less than 23 bovines. These facts complain the loads are too small, not economical enough for trucks with trailer. The reason trucks with trailer can not pick up enough load is because no animals are allowed to stay more than 8 hours on a vehicle. Those trucks often have to go back with less-than-truckload so as to meet the 8- hour rule. In this kind of tables containing information of routes, tour duration equals to the time a truck arrives at the slaughterhouse minus the time of first load. It should never exceed 8 hours. It is obvious that most tour durations are close to 8 hours. Thus, for week 35, adding trailers to all the fleet can not reduce transportation cost, instead, the total costs increase 15.4%.

Table 33: Load of each route for week 35

Vehicle	Date	tour	distance	cost	tour duration	animal load		number of orders delivered
						type0	type1	
Truck No. 1	Wednesday	1	304.98	4879.75	7:51	21		5
	Thursday	1	242.53	3880.40	8:00	15	64	6
Truck No. 2	Tuesday	1	226.85	3629.57	7:21	8	103	6
	Wednesday	1	137.80	2204.72	6:42	26		6
	Wednesday	1	37.79	604.63	1:29	2		2
	Wednesday	1	30.93	494.91	2:18	17		2
	Thursday	1	220.68	3530.80	7:07	16	30	4
Truck No. 3	Sunday	1	327.94	5247.01	7:57	8	20	5
	Monday	1	172.60	2761.60	7:13	10	54	6
	Monday	1	37.60	601.63	2:03		100	2
	Tuesday	1	237.51	3800.13	8:00	9	94	5
	Wednesday	1	158.71	2539.34	7:32	25		7
	Friday	1	206.13	3298.05	7:39	18		7
Truck No. 4	Sunday	1	186.89	2990.20	8:00	20		8
	Monday	1	181.32	2901.04	5:37		169	4
	Tuesday	1	246.19	3939.01	7:53	26		5
	Wednesday	1	254.40	4070.46	7:39	24		4
	Thursday	1	213.92	3422.69	7:37	7	56	6
	Friday	1	153.75	2460.07	7:20	21		6
Truck No. 5	Sunday	1	160.76	2572.12	7:21	26		6
	Wednesday	1	166.27	2660.23	7:22	13	40	7
	Thursday	1	260.07	4161.10	7:50	7	40	6
Truck No. 6	Thursday	1	167.88	2686.12	7:26	21		6
	Friday	1	174.43	2790.85	6:25	12		6
Truck No. 7	Thursday	1	64.07	1025.19	4:20	15	52	4
Truck No. 8	Tuesday	1	141.01	2256.18	6:49	10	82	6
	Wednesday	1	148.55	2376.85	4:45	4	98	3
Sum		27	4861.55	77784.66		381	1002	140
Average			180.06	2880.91				5.2

Table 34: Load of each route for week 41

Vehicle	date	tour	Distance	cost	duration	animal load		number of orders delivered
						type0	type1	
Truck No. 1	Sunday	1	145.78	2332.45	6:09	23		4
	Monday	1	158.38	2534.15	7:04	16	35	6
	Tuesday	1	236.43	3782.88	7:36	20		4
	Wednesday	1	216.22	3459.53	7:34	23		6
	Thursday	1	167.71	2683.31	6:01	22		5
Truck No. 2	Monday	1	223.25	3571.96	7:51	15		7
	Tuesday	1	159.66	2554.63	7:58	25		7
	Wednesday	1	248.94	3982.99	7:32	26		5
	Thursday	1	144.00	2304.02	7:45	26		7
	Thursday	1	121.83	1949.35	5:27	14		5
	Friday	1	169.03	2704.50	7:31	26		6
Truck No. 3	Sunday	1	223.53	3576.55	7:36	9	74	5
	Monday	1	211.16	3378.56	7:37	26		5
	Tuesday	1	158.67	2538.64	5:57	25		4
	Wednesday	1	265.70	4251.17	7:54	22		5
	Thursday	1	309.16	4946.56	7:58	13		5
	Thursday	1	59.61	953.74	3:38	22		3
	Friday	1	168.47	2695.52	6:53	25		6
Truck No. 4	Monday	1	307.01	4912.17	7:43	24		4
	Tuesday	1	229.46	3671.27	7:56	25		6
	Wednesday	1	206.23	3299.62	7:58	25		7
Truck No. 5	Monday	1	163.87	2621.94	6:06	6	48	5
	Wednesday	1	166.35	2661.58	7:57	21		7
	Thursday	1	151.84	2429.51	7:18	19		7
	Friday	1	144.33	2309.31	4:46	25		3
Truck No. 6	Friday	1	136.11	2177.71	5:00	18		4
Truck No. 7	Sunday							
Truck No. 8	Monday	1	172.35	2757.55	7:27	10	70	7
	Tuesday	1	159.61	2553.76	7:35	20		8
	Wednesday	1	86.87	1389.85	4:16	12		4
Sum		29	5311.55	84984.78		583	227	157
Average			183.16	2930.51				5.4

For week 41, situation is similar to week 35. Four routes have loads of a standard truck. Some other routes have loads less than 23 bovines. Only 4 routes have maximum load (26 bovines). From Table 14, there are 28 routes of total 48 having maximum load (14 or even more bovines) when the fleet consists of the standard trucks. Low loading rate of most routes cause the whole costs increase compared with using the standard trucks.

In addition, it is worth mentioning that adding trailers to all the fleet on week 35 gives a higher increase of the total costs than week 41 (15.4% versus 6.4%). One reason for this could be that fact week 35 has more mixed load. Table 33 and 34 show week 35 has 381 bovines and 1002 pigs while week 41 possess only 227 pigs apart from 583 bovines. Consequently, there are 14 routes of 27 in total collecting two types of livestock on week 35 (There are only 4 among 29 tours on week 41). Mixed load decreases the utilization of big trucks, thus causing a higher increase in cost.

Test 2: How much it may reduce the travel costs by adding trailers?

In order to find out the possible improvement of adding trailers to the fleet, the following tests have been performed. Apart from the current 8 vehicles, another 8 trucks with trailer are placed at each driver's home respectively. For example, driver 1 currently has truck no. 1, we assume another truck no. 1 with trailer is available at his home. The driver can use either the standard truck or the truck with trailer when it is necessary. This measure produces a fleet with 16 vehicles. Then the total costs of this fleet can be found through testing. This test is kind of like a linear relaxation of the adding trailer problem. If it could be solved optimally, we could get a lower bound. The results from the solver can also give us some insights about how much it may reduce the travel costs by adding trailers. Table 35 presents ten solutions of week 41 with 16 vehicles.

Table 35: Results of the assumed fleet (16 vehicles for Ålesund week 41)

Run	1	2	3	4	5	6	7	8	9	10	sum
tour number	38	36	37	38	36	36	39	41	39	37	
total distance	6455.93	6295.37	6334.06	6307.95	6286.02	6087.48	6546.91	6535.26	6667.74	6376.24	
total cost	75648.7	74036.3	74812.3	72441.0	74400.7	74713.0	73404.0	73663.0	74593.9	74357.6	
Truck No. 1	666.06	858.36	1034.90	1083.56	569.77	728.50	904.06	991.84	781.90	887.33	8506.27
Truck No. 2	755.15	761.01	402.12	643.34	1002.42	820.44	735.94	793.85	858.88	538.58	7311.72
Truck No. 3	719.04	720.99	928.44	1048.32	553.39	952.18	1210.57	1083.64	1202.44	867.32	9286.34
Truck No. 4	1287.16	807.68	807.97	577.34	884.40	226.56	712.53	723.65	922.49	987.84	7937.61
Truck No. 5	405.91	101.62	223.36	469.13	385.68	386.28	403.10	346.40	305.66	584.86	3611.97
Truck No. 6	214.55	326.62	110.28	187.36	135.78	118.08	365.14	539.76	466.80	270.00	2734.37
Truck No. 7	0.00	151.86	323.72	249.15	177.24	110.04	322.46	0.00	143.92	0.00	1478.40
Truck No. 8	559.83	720.14	591.31	489.49	653.92	439.06	570.64	671.07	666.23	474.45	5836.14
Truck No. 1 with trailer	157.02	284.76	362.66	467.69	126.76	126.92	243.73	275.84	126.92	252.84	2425.14
Truck No. 2 with trailer	541.20	284.35	609.74	291.39	704.53	384.39	464.55	264.15	342.66	501.50	4388.45
Truck No. 3 with trailer	159.81	509.42	0.00	180.79	505.62	650.18	176.79	567.51	324.40	242.03	3316.55
Truck No. 4 with trailer	487.91	244.26	466.24	494.68	310.22	493.39	307.01	0.00	307.01	499.46	3610.18
Truck No. 5 with trailer	352.52	189.95	339.20	0.00	144.33	351.32	0.00	151.84	151.50	144.33	1824.99
Truck No. 6 with trailer	0.00	144.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	144.33
Truck No. 7 with trailer	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Truck No. 8 with trailer	149.79	190.02	134.14	125.71	131.95	300.16	130.41	125.71	66.94	125.71	1480.53

Some features can be observed from these solutions. Firstly, most routes of trucks with trailer are shorter than their counterparts. Some trucks with trailer are not assigned any routes all the time. Secondly, there are 3 trucks with trailer which are assigned several routes longer than their counterparts. The features indicate it may reduce the total travel costs if trucks with trailer perform some of the routes whose load can be big enough. However, most time it seems standard trucks are more economical.

From the testing, the total travel costs of two instances are showed in Table 36.

Table 36: The total travel costs of the assumed fleet (16 vehicles)

	Cost of best solution		difference
	fleet of 16 vehicles	8 trucks without trailer	
week 35	64876.80	67390.80	-3.73%
week41	72441.00	79864.40	-9.30%

According to the above results, it seems adding trailer can not reduce the transportation costs to a large extent for the slaughterhouse at Ålesund. Probably adding trailer to the fleet can reduce the costs to some extent on week 41.

Test 3: Results of adding trailer to each vehicle

To verify the outcome of test 2, some testing has been done. We add trailer to one of the 8 vehicles one by one and find out the total travel costs from the solver. The results are listed in Table 37.

Table 37: The change of costs for each scenario

Scenarios	week 35		week 41	
	Costs	improvement	costs	improvement
only truck no. 1 with trailer	66610.20	1.16%	75100.40	5.97%
only truck no. 2 with trailer	67316.50	0.11%	75463.40	5.51%
only truck no. 3 with trailer	66861.40	0.79%	75065.80	6.01%
only truck no.4 with trailer	66804.50	0.87%	76256.20	4.52%
only truck no. 5 with trailer	67905.80	-0.76%	78843.60	1.28%
only truck no. 6 with trailer	67434.00	-0.06%	80064.70	-0.25%
only truck no. 7 with trailer	67357.00	0.05%	79896.30	-0.04%
only truck no. 8 with trailer	69454.30	-3.06%	79828.90	0.04%

For each scenario, only one truck has an added trailer, the remaining vehicles of the fleet are the standard trucks. The improvement refers to how much the total travel costs can be reduced compared to the fleet with 8 standard trucks. Negative improvement means the costs increase.

Considering the deviation of solutions, no certain conclusions can be drawn for the scenarios whose improvement is very small. In general, on week 35, adding trailer to any of the 8 vehicles may not improve the costs noticeably. For week 41, it may reduce the total travel costs by adding trailer to truck no 1, 2, 3 and 4.

6.4.2 for Oppdal case

For the slaughterhouse at Oppdal, similar testing has been performed. The relevant findings are summarized subsequently.

Test 1: What happens if adding trailers to all the fleet?

Like the Ålesund case, first we add trailer to all the vehicles of the fleet. Table 38 states the cost changes.

Table 38: Comparison of costs while adding trailers

	cost of best solution		difference
	16 trucks with trailer	16 trucks without trailer	
week 35	110100.32	55037.20	100.05%
week 41	155665.16	103401.00	50.55%

Surprisingly, the total travel costs rise hugely for the 2 weeks. Especially for week 35, the total travel costs ascend over 100%. What facts invite this effect? The route information will provide some explanations. First examination goes to the week 35. The results of week 35 are different from another 3 cases. For the cases of Ålesund week 35, week 41 and Oppdal week 41, adding trailers to all the fleet brings shorter travel distance but higher cost. On the contrary, the case of Oppdal week 35 has both distance and cost increased. Table 39 compares the routes of the two types of the fleet.

Table 39-a: Load of each route for week 35 when all the 16 vehicles have trailers

Vehicle	date	tour	Distance	cost	tour duration	route load	number of orders delivered
Truck No.1	Wednesday	1	178.32	2853.10	6:43	54	6
	Thursday	1	216.89	3470.22	7:56	158	5
Truck No.2	Tuesday	1	254.11	4065.71	7:31	119	4
	Wednesday	1	239.57	3833.14	7:23	89	4
	Thursday	1	373.39	5974.20	7:50	69	4
Truck No.3	Wednesday	1	337.26	5396.10	7:47	45	5
Truck No.4	Sunday						
Truck No.5	Monday	1	306.18	4898.83	7:49	39	3
	Wednesday	1	389.38	6230.00	7:41	29	2
	Thursday	1	301.87	4829.98	7:46	44	3
Truck No.6	Monday	1	326.09	5217.41	7:27	19	3
	Thursday	1	361.44	5782.96	7:56	30	3
Truck No.7	Tuesday	1	227.29	3636.60	7:20	119	5
Truck No.8	Monday	1	378.56	6056.88	7:59	52	3
	Tuesday	1	258.50	4135.98	7:37	113	4
	Thursday	1	357.79	5724.63	7:33	100	4
Truck No.9	Monday	1	428.45	6855.14	7:39	95	2
	Wednesday	1	249.36	3989.78	6:59	79	4
Truck No.10	Wednesday	1	208.67	3338.78	5:49	126	2
Truck No.11	Sunday						
Truck No.12	Monday	1	101.23	1619.72	5:49	135	5
	Thursday	1	420.21	6723.39	7:45	89	3
Truck No.13	Thursday	1	74.69	1195.05	3:15	26	3
Truck No 14	Sunday						
Truck No.15	Monday	1	311.29	4980.64	7:29	37	4
	Tuesday	1	248.45	3975.21	7:18	87	4
	Wednesday	1	332.30	5316.81	7:59	57	4
Truck No. 16	Sunday						
Sum		24	6881.27	110100.26		1810	89
Average			286.72	4587.51		75	3.7

(Empty line means no route)

Table 39-b: Load of each route for week 35 when having 16 standard vehicles

vehicle	date	tour	distance	cost	tour duration	Route Load	number of orders delivered
Truck No.1	Thursday	1	227.38	2273.80	6:15	97	6
Truck No.2	Thursday	1	374.94	3749.36	7:50	123	7
Truck No.3	Thursday	1	305.82	3058.21	7:48	143	7
Truck No.4	Wednesday	1	340.97	3409.71	7:23	110	7
Truck No.5	Wednesday	1	302.88	3028.76	7:45	60	4
	Thursday	1	397.84	3978.38	7:47	41	3
Truck No.6	Tuesday	1	372.65	3726.52	7:38	145	5
	Thursday	1	359.23	3592.32	7:58	41	5
Truck No.7	Monday	1	445.71	4457.07	7:43	90	3
	Tuesday	1	360.60	3605.96	7:27	71	6
Truck No.8	Monday	1	248.95	2489.50	7:33	144	6
	Tuesday	1	304.58	3045.79	8:00	107	6
Truck No.9	Thursday	1	267.87	2678.66	7:45	128	8
Truck No.10	Tuesday	1	282.35	2823.50	7:31	138	4
	Wednesday	1	208.67	2086.74	5:20	126	2
Truck No.11	Wednesday	1	431.45	4314.50	7:58	119	4
Truck No.12	Sunday						
Truck No.13	Sunday						
Truck No.14	Sunday						
Truck No.15	Monday	1	271.85	2718.45	7:35	127	6
Truck No.16	Sunday						
Sum		17	5503.72	55037.23		1810	89
Average			323.75	3237.48		106	5.2

(Empty line means no route)

From Table 39, the fleet of trucks with trailer has to perform more tours (24 versus 17) in order to collect the total 1810 ovine. The average tour distance declines from 323.75 to 286.72. More important, the average tour load decreases from 106 to 75. The trucks with trailer have the capacity of 270 sheep. However, none of routes can collect more than 158 ovine, which is the capacity of standard trucks. Apparently, big trucks function like the standard trucks but induce high cost.

The situation of case Oppdal week 41 is not as worse as week 35, but still most of tours do not have enough load (see Table 40).

Table 40: The loads of tours for week 41(all vehicles with trailer)

vehicle	Date	tour	distance	cost	tour duration	route load	number of orders delivered
Truck No.1	Tuesday	1	169.16	2706.57	7:56	180	6
	Tuesday	1	21.5154	344.246	4:27	245	4
	Thursday	1	230.438	3687.01	7:35	155	5
	Friday	1	255.131	4082.1	7:47	136	5
Truck No.2	Sunday	1	184.605	2953.68	7:32	185	5
	Monday	1	258.327	4133.23	7:48	144	5
	Tuesday	1	181.325	2901.2	7:52	174	6
	Wednesday	1	179.458	2871.33	7:13	168	5
	Wednesday	1	10.1924	163.078	3:18	249	2
	Thursday	1	224.405	3590.48	7:50	193	6
	Friday	1	337.254	5396.07	8:00	117	5
Truck No.3	Sunday	1	185.114	2961.83	7:53	195	5
	Monday	1	295.423	4726.76	7:44	135	8
	Tuesday	1	181.988	2911.81	5:41	249	5
	Wednesday	1	392.652	6282.44	7:48	148	4
	Thursday	1	195.265	3124.24	8:00	209	6
Truck No.4	Monday	1	245.884	3934.15	6:03	61	3
	Tuesday	1	147.147	2354.36	7:41	267	8
	Wednesday	1	208.298	3332.77	7:39	203	5
	Thursday	1	254.673	4074.77	8:00	100	8
	Friday	1	189.585	3033.36	7:58	207	6
Truck No.5	Thursday	1	330.132	5282.12	7:56	183	5
Truck No.6	Sunday	1	281.55	4504.8	7:54	91	4
	Tuesday	1	250.673	4010.77	7:55	154	5
	Wednesday	1	248.079	3969.27	7:31	122	5
	Thursday	1	250.093	4001.49	6:38	152	4
	Friday	1	294.61	4713.76	7:28	112	4
Truck No.7	Monday	1	335.389	5366.22	7:58	125	7
Truck No.8	Sunday	1	487.438	7799.01	7:47	30	1
	Monday	1	353.653	5658.45	7:46	177	3
Truck No.9	Wednesday	1	173.848	2781.57	7:26	222	5
Truck No.10	Sunday	1	230.147	3682.36	7:23	214	3
	Monday	1	179.068	2865.09	7:34	200	6
	Tuesday	1	209.490	3351.84	8:00	180	5
	Wednesday	1	216.832	3469.31	7:25	249	3
	Thursday	1	220.434	3526.95	7:09	195	3
Truck No.11	Monday	1	131.218	2099.49	7:20	237	6
	Tuesday	1	137.837	2205.39	7:37	177	7
	Wednesday	1	130.321	2085.13	7:35	244	6
	Thursday	1	148.210	2371.37	7:32	231	6
Truck No.12	Monday	1	98.002	1568.03	6:58	258	7
Truck No.13	Monday	1	85.265	1364.24	6:45	255	6
Truck No.14	Friday	1	64.6685	1034.7	6:54	224	7
Truck No.15	Thursday	1	204.525	3272.4	7:33	249	3
Truck No.15	Wednesday	1	175.362	2805.8	7:58	195	6
	Thursday	1	144.382	2310.12	5:35	247	6
Truck No.16		46	9729.0662	155665.16		8443	235
Average			211.50	3384.03		184	5.1

From Table 40, it is obvious that most of the tours do not have enough loads. The capacity is 270 sheep for each vehicle with trailer. Compared with standard trucks, it will not be economical unless the load of trucks with trailer is more than 252 sheep. Only 3 tours have load more than that. In addition, 15 tours (highlighted in red) have load less than the capacity of the standard truck.

Test 2: Is it possible to reduce cost by adding trailers to the fleet?

The test 1 demonstrates it is not beneficial at all when adding trailers to all vehicles. We still have to find out whether adding trailers to some vehicles can reduce the costs. The similar test (like the one mentioned in Ålesund case) is done to find the lower bound. Here, a fleet of 32 vehicles (assume each driver has another truck with trailer at his home) is assigned for the two weeks. The results are showed in Table 41.

Table 41: The total travel costs of the new fleet (32 vehicles)

	Cost of best solution		Difference
	fleet of 32 vehicles	16 trucks without trailer	
week 35	57236.40	55037.23	4.00%
week41	99592.90	103400.58	-3.68%

The results of this test indicate it is not possible for case Oppdal week 35 to reduce travel cost by adding trailer to any vehicle. In solution routes, most trucks with trailer are not assigned any tours, which also signal no cost reduction can be derived from using trailers. For case Oppdal week 41, the results show there might be a slight possibility for cost improvement.

Test 3: Results of adding trailer to each vehicle

Like the Ålesund case, some tests have been done to find out what will happen if we add a trailer to a vehicle. Firstly, the outcome of the previous 2 tests illustrate that adding trailers will not bring any improvement for case Oppdal week 35, so only 3 scenarios are tested so as to verify again. For case Oppdal week 41, most vehicles are tested. The procedures for each scenario are the same as Ålesund case, adding a trailer to one vehicle of the fleet, the remaining vehicles keep unchanged. Table 42 shows the results.

Table 42: Results of adding trailer to each vehicle (the fleet of 16 trucks)

Scenarios	week 35		week 41	
	costs	improvement	costs	improvement
only truck no. 1 with trailer	55703.30	-1.21%	102635.00	0.74%
only truck no. 2 with trailer			104015.00	-0.59%
only truck no. 3 with trailer			103395.00	0.01%
only truck no.4 with trailer			100302.00	3.00%
only truck no. 5 with trailer	57224.20	-3.97%	103533.00	-0.13%
only truck no. 6 with trailer			105427.00	-1.96%
only truck no. 10 with trailer			102824.00	0.56%
only truck no. 12 with trailer			102172.00	1.19%
only truck no. 13 with trailer	55283.30	-0.45%	105788.00	-2.31%
only truck no. 14 with trailer			102625.00	0.75%
only truck no. 15 with trailer			99741.10	3.54%
only truck no. 16 with trailer			103547.00	-0.14%

For Oppdal week 35, the truck with trailer in the 3 scenarios does not have any load. This fact verifies that adding trailer to the fleet can not reduce the travel costs.

For Oppdal week 41, the changes in cost are quite small. It is difficult to make a clear prediction for each scenario owing to the fact the solutions deviation is around 5%.

6.4.3 Factors discourage using trailer

In previous parts, it has been found out that using trailer will not benefit the company much. Here, the facts which cause the consequence will be the focus of attention.

In principle, it is efficient to use trucks with trailer (or big vehicles) when they can collect adequate load, otherwise, the standard trucks are more economical. For the Livestock Collection Problem, the 8-hour rule places a restriction on the tour duration. A vehicle has to go back within 8 hours after the first animal is loaded. If the volume of animals at each farm is small, the vehicles will not be able to collect sufficient load within such a limited time period. In addition, some farms may be located quite far from each other or from the slaughterhouse. It takes quite long time to travel from one place to another. To sum up, small orders plus dispersed farms discourage the utilization of trucks with trailer. The following figures illustrate the attribute of the orders of each data case.

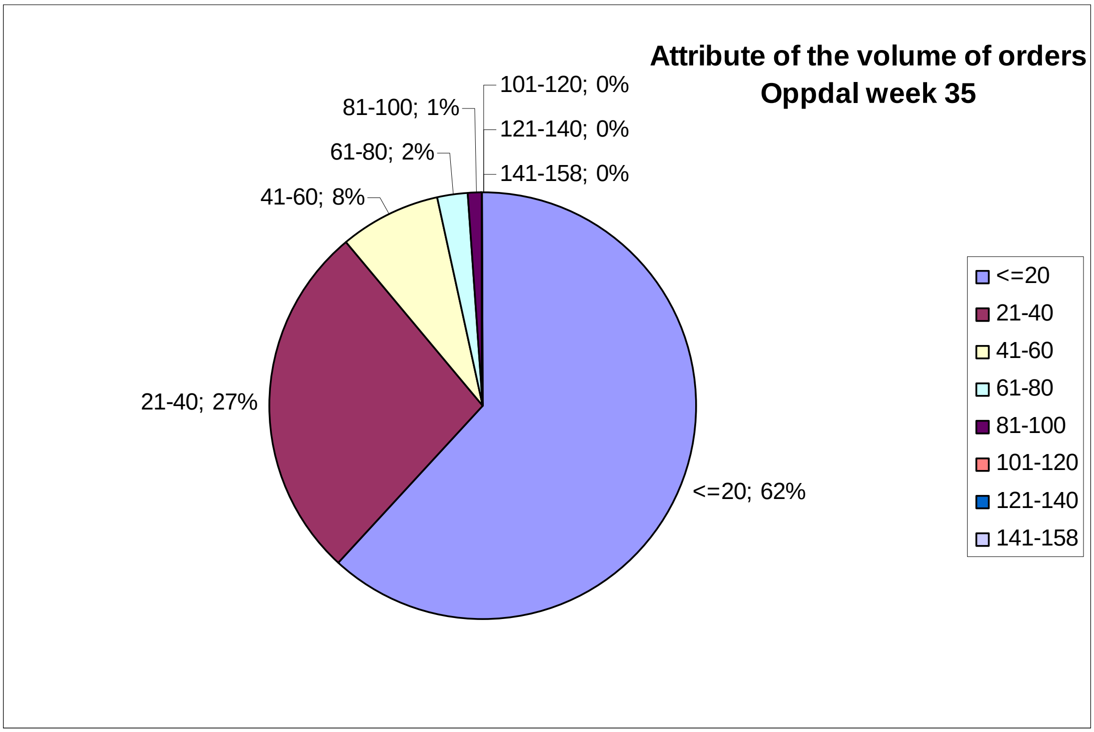

Figure 9: Attribute of the volume of orders for Oppdal week 35

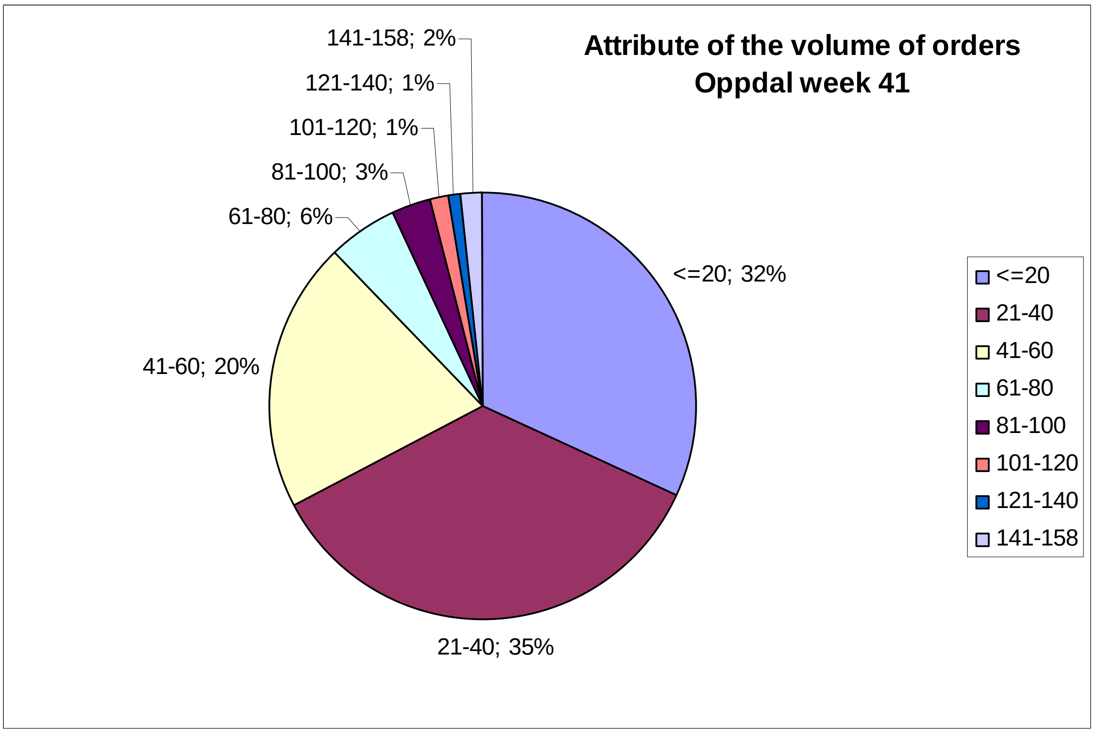

Figure 10: Attribute of the volume of orders for Oppdal week 41

From Figure 9 and 10, it is clear that most of the orders (the amount of animals available for collection at each farm) are less than 61 ovine, 96.6% and 87.7% for week 35 and week 41 respectively. In particular, the orders on week 35 are even smaller, 62% of orders are less than 21 ovine. About 89% of orders are smaller than 41 ovine. From previous part, the average number of orders visited on a tour for most cases is around 5, thus it is not possible to collect enough load for trucks with trailer for most tours ($5\times 40=200$ is smaller than 270). The fact that the orders on week 35 are more dispersed makes the situation even worse.

As for the Ålesund cases, since most of orders are bovines (117 among 140 for week 35 and 147 among 157 on week 41 respectively), only the attribute of orders of bovines is examined here.

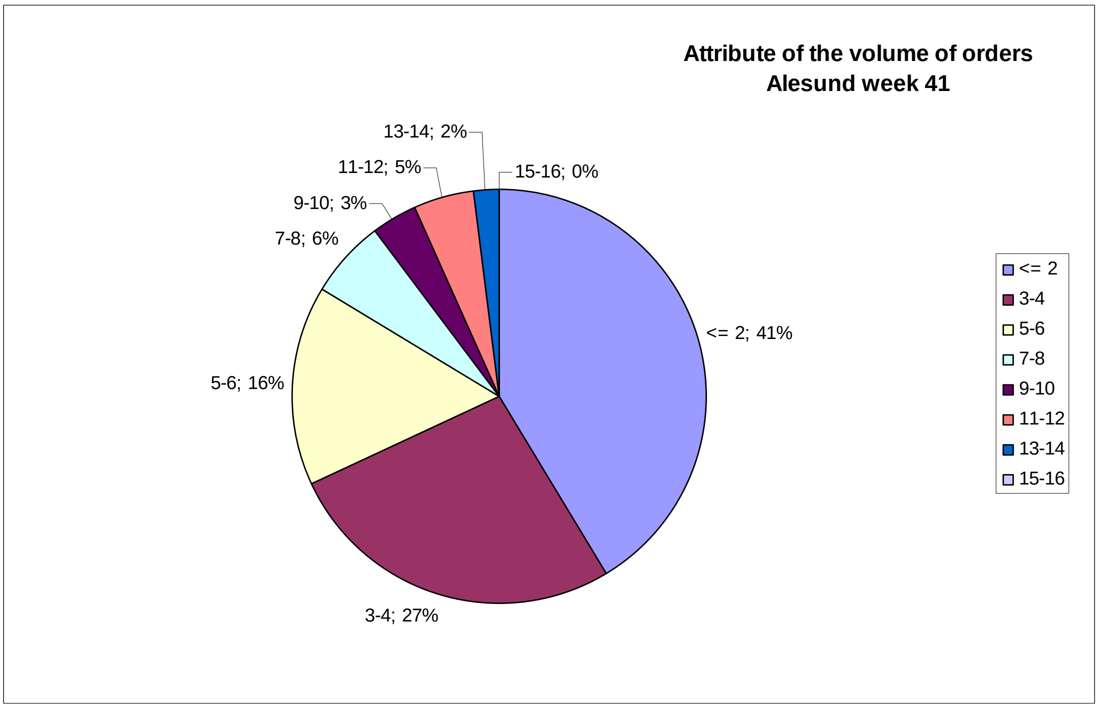

Figure 11: Attribute of the volume of orders for Ålesund week 35

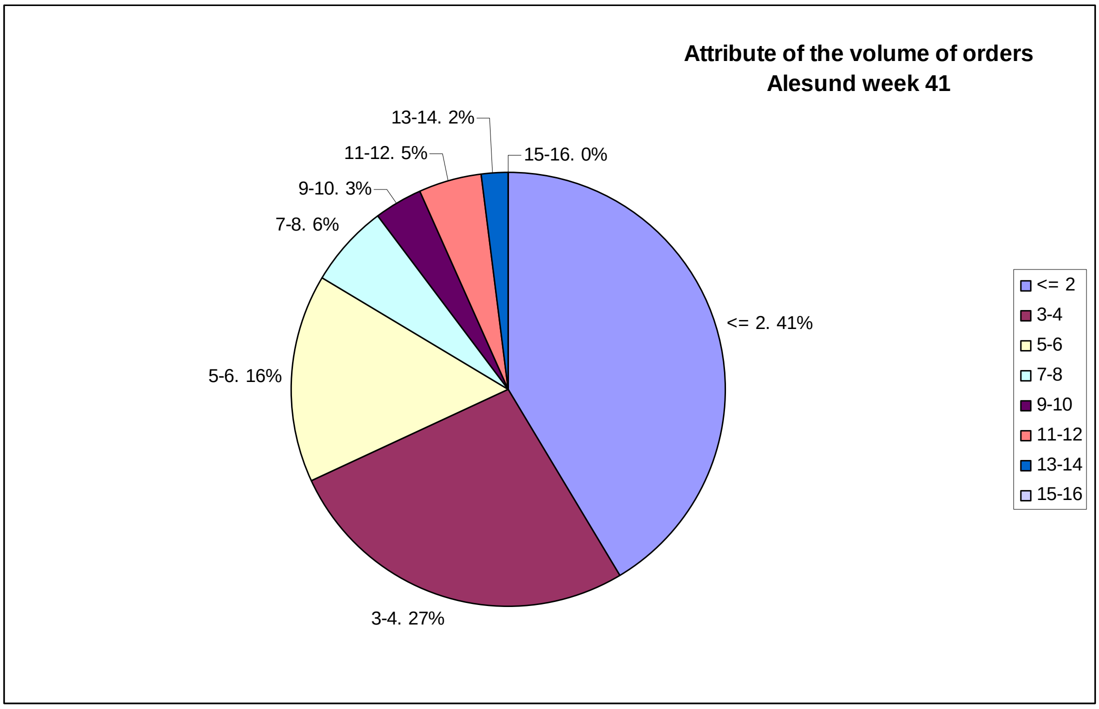

Figure 12: Attribute of the volume of orders for Ålesund week 41

From Figure 11 and 12, there are 53% and 41% of orders where the amount is 2 or less bovines for week 35 and week 41 respectively. In general, most of orders are small for both weeks. Orders whose amount is from 1 to 4 account for 80% and 68% for week 35 and week 41 correspondingly. This fact explains it is not efficient to use trucks with trailer for the two weeks. In addition, week 41 has more big orders than week 35. This should be the reason why week 41 has higher opportunities of taking the advantage of using trailers.

6.4.4 Impact of fleet size

The fleet size probably affects the utilization of trailer (or bigger vehicles) as well. For the Livestock Collection Problem, while using a fleet with fewer vehicles, each vehicle has to collect more orders thus performs more tours. Some of the tours are less efficient compared with a fleet with more trucks. When trailers are added to the small fleet, the mismatch of vehicle capacity can be magnified owing to the fact each vehicle has to perform more tours. The Ålesund cases are tested with several scenarios in order to verify this argument. The testing results are illustrated in Table 43.

Table 43: The total costs at different fleet size

scenario	fleet composition	total travel costs	
		Ålesund week 35	Ålesund week 41
1	8 standard trucks	67390.80	79864.40
2	8 trucks with trailer	77784.80	84984.78
3	4 standard trucks	76826.20	85542.30
4	4 trucks with trailer	90633.60	96651.21
difference between scenario 2 and 4		16.5%	13.7%

According to the above table, while adding trailers to the fleet of 8 vehicles, the total travel costs for both weeks increase. When the fleet size is 4, adding trailers raises the costs as well. It should be pointed out that the total travel costs of scenario 4 are higher than scenario 2 for both week 35 and week 41. This fact indicates adding trailers to a smaller fleet may cause a higher cost increase.

6.5 Possibility of using small vehicles

Last step shows it is not a beneficial option to use vehicles with trailer. Here we explore the possibility of using small trucks. Table 44 compares the costs of standard trucks with small ones.

Table 44: Cost of two types of vehicles

vehicle type	capacity			cost per unit distance	cost per animal		
	bovine	Pig	sheep		bovine	pig	sheep
standard vehicle	14	98	158	10	0.714	0.102	0.063
small vehicle	10	68	112	8	0.800	0.118	0.071

Table 44 states that in general small vehicles are less efficient as they generate higher cost per animal transported. However, it can be economical to use small vehicles when standard trucks can not pick up enough load within the tour duration.

In addition, small trucks are set to have the same travel speed as the standard vehicles in the solver. Thus, the difference between small vehicle and the standard vehicle is only the capacity.

The similar tests with those performed for trailer issues have been fulfilled and the relevant results are summarized a follows.

Test 1: What if the fleet consists of all small vehicles?

For the four data cases (data case 2, 3, 4, 5), assume the fleet is made up of all small vehicles, the testing results are showed in Table 45.

Table 45: Results of using small vehicles

data case	cost of best solution		Difference
	fleet of standard vehicles	fleet of small vehicles	
Ålesund week 35	67390.80	no feasible solution	
Ålesund week 41	79864.40	no feasible solution	
Oppdal week 35	55037.20	47516.80	13.7%
Oppdal week 41	103401.00	no feasible solution	

Among the four data cases, only for Oppdal week 35 it is feasible and economical to use small vehicles. There is no feasible solution for the remaining three data cases.

The reason why it is infeasible to use small vehicles for the three data cases could be that it is too slow for small vehicles to collect a large amount of animals. Thus they can not meet the time requirement of production. Just for Oppdal week 35, it is feasible since there are only a small amount of sheep (or goats) to be collected. Besides, most orders during that week are quite small, which is the reason why it is economical to using small vehicles.

Test 2: How much it may reduce the travel costs by using small vehicles?

Like previous tests, run the solver with the assumed fleet (For Ålesund week 35 and 41, the assumed fleet consists of 8 standard vehicles plus 8 small vehicles. For Oppdal week 35 and 41, the assumed fleet is made up of 16 standard vehicles and 16 small vehicles.), the testing results can indicate how much the total travel costs may decrease for each data case. Table 46 shows the relevant outcomes.

Table 46: The total travel costs of the assumed fleets

data case	cost of best solution		improvement
	fleet of standard vehicles	fleet of both standard and small vehicle	
Ålesund week 35	67390.80	65330.30	3.1%
Ålesund week 41	79864.40	75678.10	5.2%
Oppdal week 35	55037.20	46481.30	15.5%
Oppdal week 41	103401.00	101329.00	2.0%

The outcomes of test 2 confirm that for Oppdal week 35 using small vehicles may reduce the total travel costs up to 15.5 %. However, there is only a small scope (less than 5.2%) for improvement for the other three cases.

Test 3: What if a standard vehicle is replaced with a small one in a fleet?

For each scenario, replace a standard vehicle with a small one in a fleet, run the solver and find out how much the total travel costs the new fleet mat reduce. Table 47 and 48 demonstrate the outcomes.

Table 47: Results for Ålesund week 35 and 41

Scenarios	week 35		week 41	
	costs	improvement	costs	improvement
only truck no. 1 is small vehicle	67822.50	-0.64%	81836.30	-2.47%
only truck no. 2 is small vehicle	69077.10	-2.50%	82165.00	-2.88%
only truck no. 3 is small vehicle	66634.20	1.12%	80981.70	-1.40%
only truck no. 4 is small vehicle	67564.40	-0.26%	80771.10	-1.14%
only truck no. 5 is small vehicle	66587.50	1.19%	79626.10	0.30%
only truck no. 6 is small vehicle	66740.30	0.97%	79130.20	0.92%
only truck no. 7 is small vehicle	67049.30	0.51%	79789.50	0.09%
only truck no. 8 is small vehicle	69053.00	-2.47%	79905.40	-0.05%

In the above table, negative improvement means the costs go up. The improvement of each scenario is quite insignificant, which proves again that it is not promising to use small vehicles for the slaughterhouse at Ålesund.

Table 48: Results for Oppdal week 35 and 41

Scenarios	week 35		week 41	
	costs	improvement	costs	improvement
only truck no. 1 is small vehicle	53414.90	2.95%	101938.00	1.41%
only truck no. 2 is small vehicle	53014.80	3.67%	100289.00	3.01%
only truck no. 3 is small vehicle	52481.30	4.64%	102886.00	0.50%
only truck no. 4 is small vehicle	52968.50	3.76%	101144.00	2.18%
only truck no. 5 is small vehicle	53112.60	3.50%	103217.00	0.18%
only truck no. 6 is small vehicle	54123.80	1.66%	103117.00	0.27%
only truck no. 7 is small vehicle	52802.50	4.06%	101710.00	1.64%
only truck no. 8 is small vehicle	53260.80	3.23%	98416.90	4.82%
only truck no. 9 is small vehicle	53002.80	3.70%	101387.00	1.95%
only truck no. 10 is small vehicle	53349.00	3.07%	104677.00	-1.23%
only truck no. 11 is small vehicle	52790.80	4.08%	100316.00	2.98%
only truck no. 12 is small vehicle	53538.00	2.72%	102463.00	0.91%
only truck no. 13 is small vehicle	54807.70	0.42%	101401.00	1.93%
only truck no. 14 is small vehicle	53875.60	2.11%	101311.00	2.02%
only truck no. 15 is small vehicle	53518.20	2.76%	101659.00	1.68%
only truck no. 16 is small vehicle	53078.70	3.56%	101508.00	1.83%

From Table 48, it is clear that for Oppdal week 35, replacing a vehicle with a small truck usually can reduce the total travel costs to some extent (0.42%-4.64%). For Oppdal week 41, most figures are quite small (less than 3%). To sum up, it may be economical to replace some standard vehicles with small ones for this slaughterhouse. For example, replacing truck no. 8 with small vehicle will reduce the total travel costs for the two weeks.

In Table 48, for Oppdal week 41, there are 5 scenarios in which the improvement is bigger than 2%, the result of test 2. This is because with the same running time (or the same number of iterations), the solver often found better solutions for small test instances compared with large instances. Here, Oppdal week 41 with 32 vehicles is much large for the solver than the scenario with 16 vehicles.

6.6 Summary of capacity issues

In this section, we found out the minimum fleet size for the slaughterhouse located at Ålesund is 4 standard trucks and the one at Oppdal requires 5 standard vehicles. This minimum fleet size is affected by the starting location of each vehicle. For example, not any 5 vehicles can perform the task for the slaughterhouse at Oppdal, the vehicles have to start their first tour from the right positions. This minimum fleet size is conditional on the company designing its livestock collection routes with the method used in the solver. With the current manual planning system, the company will require a bigger fleet.

Basing on the 4 data cases (Ålesund week 35 and 41, Oppdal week 35 and 41), we found out it can not reduce transportation costs to a large extent for most cases when using either trucks with trailer or small vehicles. This outcome is decided by the attributes of the demand (the volume and the distribution of orders). The standard truck is the right choice to collect the current demand. In addition, our finding is based on our evaluation of the unit travel costs of the three types of vehicles. If the unit travel cost of each vehicle changes, the finding may differ as well.

7. Feasibility analysis of setting up holding pens

7.1 Purpose of research

Since the volume of ovine at each farm is often small, a vehicle may have to visit many farms in order to collect enough load. Due to the 8-hour rule, it is quite common that some vehicles can not collect full truck load, thus, the efficiency of transportation is low. To improve this situation, one solution is to set up a certain number of holding places, which can temporarily keep the livestock until the volume of ovine reaches the full truck load of a large vehicle. In such way, Gilde could use big vehicles to perform the collection, therefore, improve the efficiency of the livestock collection.

According to the location theory, in order to find out how many holding places are necessary or economical, and where to locate those holding places, some data are indispensable, including the candidate positions for locating the holding pens; the cost of setting up and maintaining the holding pens. We also have to know how the livestock can be moved from each farm to a holding pen and the related cost. In addition, it often requires a certain time period to compensate the fixed cost of a holding pen, thus it is necessary to evaluate the weekly volume of ovine at each farm during the time period. Currently Gilde does not seriously consider this issue. Therefore, the data mentioned above are not available. In this master thesis, based on the two weeks' data of the slaughterhouse at Oppdal, a few assumptions have been made and some testing has been done so as to explore how and where to locate the holding pens and how much cost can be saved if some pens exist.

7.2 Assumptions

Since the farms have the facilities and experience of keeping ovine, it is reasonable to assume the holding pens can be set up at some farms. For example, Gilde can rent some farms' holding facilities or hire some farms to operate the holding pens. We also assume the farmers will transport their sheep or goats to the holding pens if they can get a certain number of money from Gilde to cover the cost. Usually farmers have tractors or vehicles of other types which enable farmers to deliver their livestock at low cost. The distance between each farm and its holding pen can not be too far; otherwise it will be difficult for farmers to deliver their sheep or goats. In this thesis, we assume the maximum distance should be less than 50 kilometres. According to these assumptions, to set up holding pens, Gilde will have to pay the fixed cost and the maintenance cost of the holding places. In addition, the company will also have to pay the cost of transporting the livestock from farms to the holding pens. On the other hand, the cost of transporting the livestock from the holding pens to the slaughterhouse will decrease due to the fact that the existence of the holding pens enables the company to transport sheep in big batches and to perform fewer tours. Therefore, whether or not to build up a holding pen will depend on the trade-off of the saving and the expense of the holding pen, namely, the saving of the cost of transporting sheep from the holding pen to the slaughterhouse must be larger than the sum of the cost of the holding pen and the cost of transporting sheep from farms to the holding pen.

7.3 How and where to locate the holding pens

Currently there are hundreds of farms supplying ovine for the slaughterhouse at Oppdal. Firstly it is necessary to find out which farms are close to each other so as to group the farms and select the candidate farms for holding pens. In this thesis, a commercial data mining software, GhostMiner (GhostMiner 2008), is used to cluster farms into groups according to their geographical locations. Data mining is the process of sorting through large amounts of data and picking out relevant information. It is usually used by business intelligence organizations, and financial analysts, but is increasingly being used in the sciences to extract information from the enormous data sets generated by modern experimental and observational methods (Dunham 2003). GhostMiner is unique data mining software from Fujitsu that not only supports common databases (or spreadsheets) and mature machine learning algorithms, but also assists with data preparation and selection, model validation, multimodels like commitees or k-classifiers, and visualization (GhostMiner 2008). GhostMiner also supplies Dendrogram method for the purpose of clustering. Clustering is the classification of objects into different groups, or more precisely, the partitioning of a data set into subsets (clusters), so that the data in each subset (ideally) share some common trait - often proximity according to some defined distance measure (Dunham 2003). With such a tool, the farms can be divided into groups (or clusters) according to their coordinates. The farms geographically close to each other are put into one cluster.

7.3.1 The distribution of farms

During the clustering, it is easy to notice that the farms distribute unevenly. Some farms stay alone and far from others. For example, with the data of Oppdal week 41, if all the farms are divided into 5 groups, the number of members in each cluster will be 1, 15, 91, 7, and 121 respectively. Cluster 1 only has one member while cluster 5 contains 121 farms. The segmentation of the clusters is showed in Figure 13 (North and East are the coordinates of each farm).

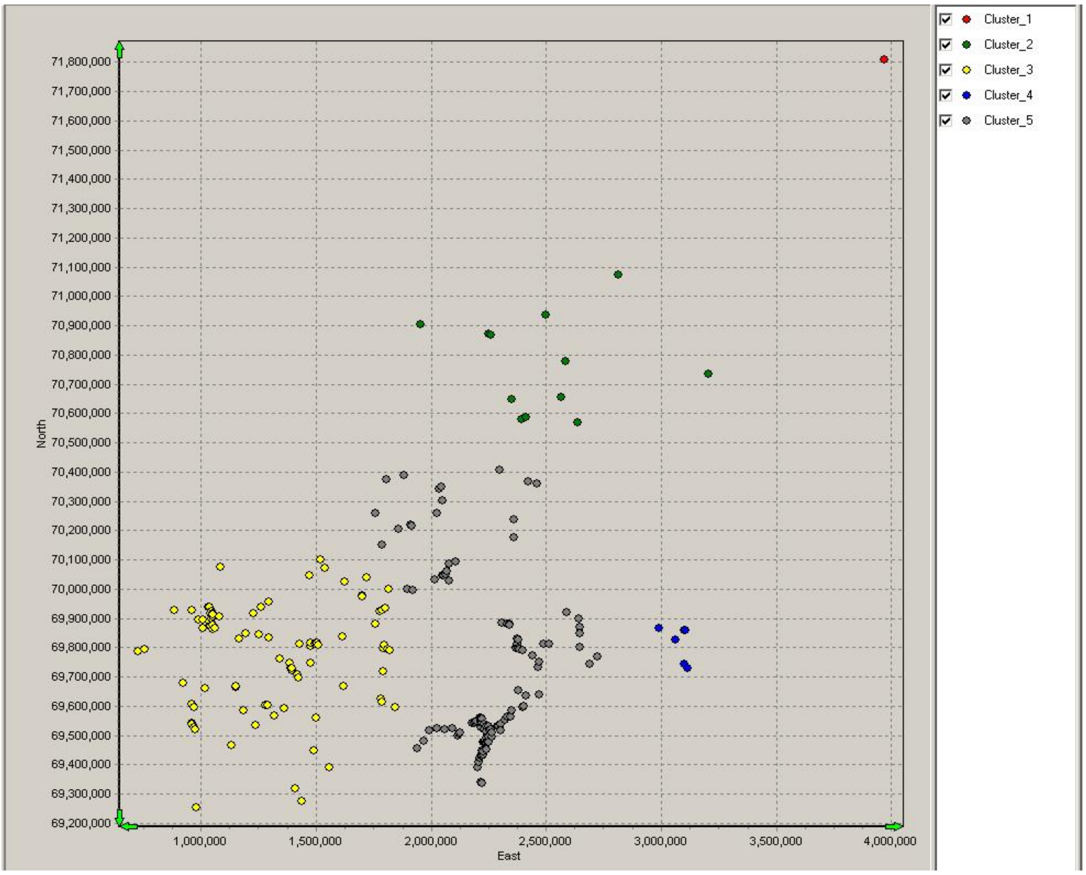

Figure 13: The locations of 5 clusters

Among these five clusters, the maximum distance between a farm and the centre of the cluster can be up to 150 kilometres.

If we cluster the farms into 20 groups, the number of members in each group is showed in Table 49.

Table 49: The number of members of 20 clusters

cluster	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
number of members	1	1	1	7	60	1	5	2	1	5	6	17	21	9	28	6	18	3	17	26

Compared to the situation of 5 clusters, the difference of the number of farms in each cluster is smaller. The biggest group have 60 members while there are 5 clusters which only have 1 farm. The location of each cluster is showed in Figure 14.

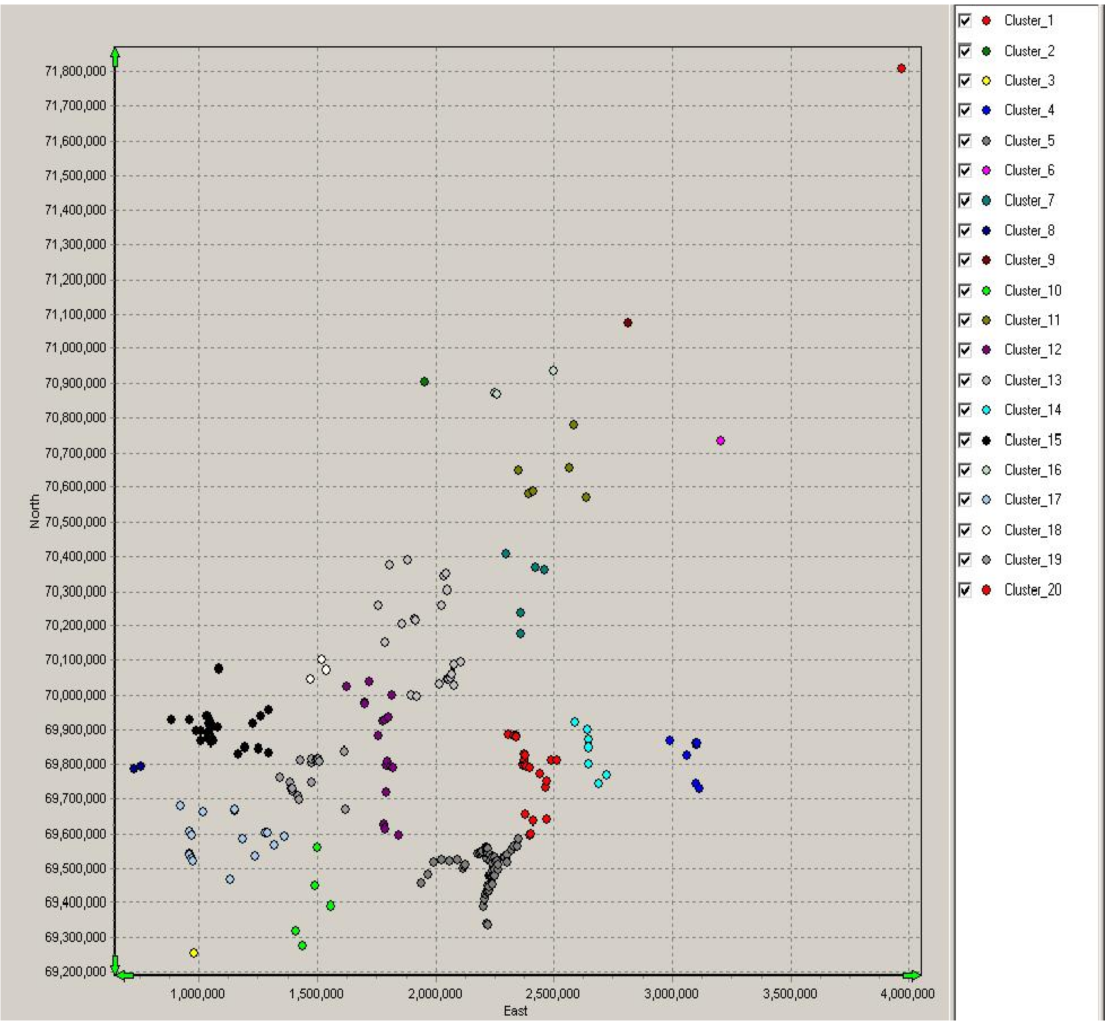

Figure 14: The locations of 20 clusters

For this situation, the maximum distance between a farm and the centre of the cluster is around 60 kilometres.

Owing to the uneven distribution of farms, some farms stay alone as a cluster. Thus, it is not possible to set up holding pens to cover all farms since it is not economical to set up holding places for those remote farms. Their livestock has to be collected the normal way. Only clusters with many members can be considered to set up holding pens.

7.3.2 The volume of ovine in each cluster

In addition to the uneven distribution, the volume of available ovine for collection at each farm varies as well. For example, when grouping the farms into 40 clusters, the volume of ovine in each cluster is showed in Table 50. Only 7 clusters have more than 270 sheep (enough load for a truck with trailer). The remaining clusters are quite small. The situation for week 35 is even worse. Most clusters are quite small. This is probably because of the size of the farms or the different mature time of ovine at each farm.

If the holding pens will be visited every week (since the current planning horizon is one week), it is not economical to set up holding pens for the clusters with a small volume of live animals. Those farms should be visited directly. Another way of tackling those small clusters is to extend the planning horizon. For instance, some holding pens can be visited once every two weeks or even every 4 weeks. In such way, it may be possible to accumulate enough ovine so as to compensate the cost of holding pens.

7.3.3 Locating a holding pen for each cluster

As shown in Table 50, the farms which delivered ovine to the slaughterhouse at Oppdal in week 41 are grouped into 40 clusters. Each cluster has a various amount of farms (from 1 to 50). The volume of ovine in each cluster also differs to a large extent.

The largest volume is 2388 while the smallest is only 10.

Table 50: Summary of 40 clusters

Cluster	Number of Farms	Total volume of ovine	Location of holding pen	Maximum distance
1	1	30	-----	-----
2	1	82	-----	-----
3	1	6	-----	-----
4	7	125	65530	24.55
5	50	2388	66965	19.16
6	1	14	51740	-----
7	2	86	61606	12.10
8	2	30	63260	7.44
9	1	21	-----	-----
10	2	22	65235	6.35
11	3	101	50137	14.64
12	9	249	53211	26.70
13	2	73	66881	6.63
14	9	136	65681	17.38
15	7	192	67382	19.13
16	1	62	-----	-----
17	9	232	61680	19.63
18	3	112	57848	13.38
19	15	285	64621	44.43
20	5	174	69967	10.56
21	4	79	63415	15.25
22	1	10	-----	-----
23	2	531	64714	1.00
24	3	69	53345	8.07
25	1	143	-----	-----
26	1	52	-----	-----
27	2	51	66358	11.21
28	3	121	50821	13.38
29	21	917	52444	18.37
30	10	336	66453	17.10
31	20	727	51191	28.59
32	2	43	69597	0.95
33	1	16	-----	-----
34	3	63	60652	37.56
35	5	185	61103	46.54
36	5	160	57818	38.84
37	1	26	-----	-----
38	2	33	61914	25.66
39	8	290	61122	7.96
40	6	171	61852	15.49
Sum	232	8443		

According to location theory, locating a holding pen for each cluster is a 1 median problem. For a cluster containing n farms (n>1), the farm i which minimize $\sum_{n-1} demand_j \times distance_{ji} \quad (j \neq i)$ should be the location of the holding pen. In Table 50, the farm IDs of holding pens are listed in column 4. In addition, the maximum distance between farms and the holding pen in each cluster is showed in Table 50 as well.

Since all the maximum distances are less than 50 kilometres, in accordance with our assumption, this set of clusters will be used for further cost reduction testing.

7.4 Cost reduction testing

With the 40 clusters, some scenarios have been designed so as to find out how much transportation cost can be saved when there are some holding pens. The first scenario is to assume there is a holding place for every cluster with more than 1 farm. There are 29 clusters, thus 29 holding pens. For each cluster, put all sheep (or goats) at the holding pen and make a new instance. Therefore, the number of orders for the new instance decreases while the volume of each order increases. The new instance is then computed by the solver. Since it is difficult to find an optimal mixed fleet (containing both standard truck and truck with trailer), we still use the fleet which is made up of standard trucks in this subsection. From the solver, the total transportation cost of the new instance is 78042.8, compared with the scenario without holding pens (see section 6, Table 28, the total transportation cost is 103401), the cost of new instance decreases 24.5%. Considering the cost of 29 holding places and the cost of transporting 6395 ovine (the total volume of ovine of that week minus the volume at farms as holding pens) from farms to the holding pens, it may not be beneficial to set up so many holding pens.

In general the big clusters should be the candidates for setting up the holding pens. Next, 4 big clusters are tested separately in order to find how much cost can be reduced if there is a holding pen for that cluster. Like the first test, a new instance is made for each cluster, the travel cost of the new instances is computed with the solver, and the results are showed in Table 51. Besides, the cost of transporting ovine from farms to the holding pen are computed with the solver as well, which should be a upper bound of the cost of transporting ovine from farms to the holding pen.

Table 51: The results of setting up a holding pen for cluster 5, 19, 29 and 31

Scenario	Transportation Cost	Saving of transportation cost	Percentage	Cost of transporting sheep from farms to holding pen
only a holding pen for cluster 5	91811.3	11589.7	11.2%	4643.5
only a holding pen for cluster 19	97759.3	5641.7	5.5%	1437.5
only a holding pen for cluster 29	97773.5	5627.5	5.4%	1472.5
only a holding pen for cluster 31	97146.6	6254.4	6.0%	1452.4
Sum		29113.3		9005.9

The above results indicate that it seems to be beneficial if a holding pen is built up for cluster 5, 19, 29 and 31 respectively. Since these 4 scenarios are tested separately, it is necessary to test how much transportation cost can be reduced when the 4 holding pens are set up at the same time. An instance for this was made and computed by the solver. The total transportation cost is 88048.2. The saving is 15352.8, which is smaller than the sum of savings of the 4 scenarios (29113.3 in Table 51). This phenomenon indicates the collection cost of an instance is affected by all orders. When the volume and distribution of some orders are changed, the cost of collecting the other farms will also be affected. Therefore, it is necessary to evaluate the cost change of the whole instance when try to decide whether or not to set up some holding pens.

In addition, since the saving (15352.8) is bigger than the sum of the cost of transporting sheep from farms to the holding pens (9005.9), it will be profitable to set up holding pens for these 4 clusters when the cost of holding pen is not too high.

Compare the saving of setting up 4 holding pens with the result of the first scenario (with 29 holding pens), see Figure 15, it is clear that it is not beneficial to build up holding pens for those small clusters since the remaining 25 holding pens only reduce the total transportation cost by (25358.2-15352.8=10005.4).

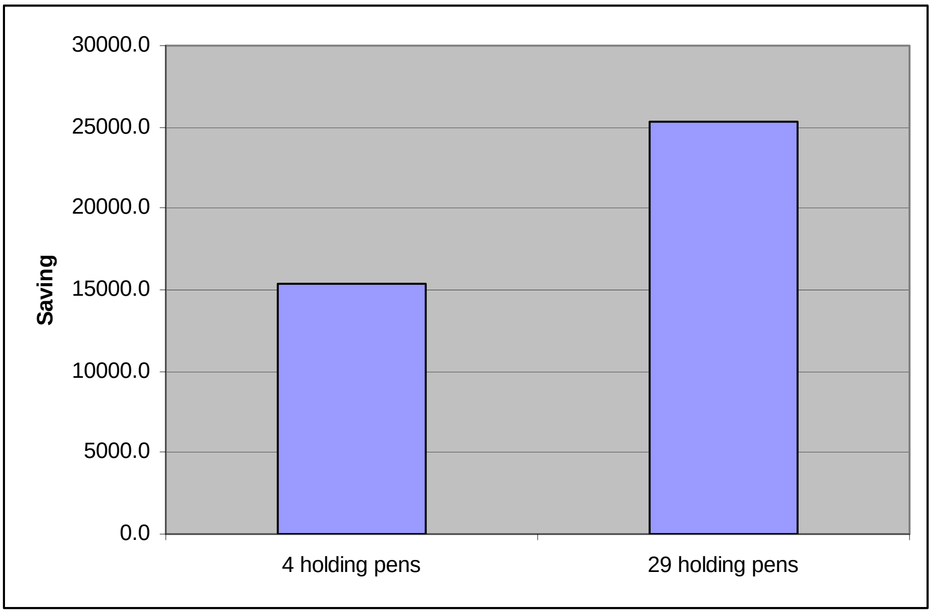

Figure 15: Comparison of the saving of two scenarios

The above tests are mainly focused on these big clusters, but it is also necessary to see the result if holding pens are set up for clusters with small volume of ovine. Three new scenarios are designed and computed for this purpose. The results are showed in Table 52.

Table 52: Results for cluster 14, 21 and 36

Scenario	volume of ovine in the cluster	transportation cost	saving of transportation cost
only a holding pen for cluster 14	136	101878	1523
only a holding pen for cluster 21	79	103836	-435
only a holding pen for cluster 36	160	102804	597

From Table 52, the savings of the total transportation cost for these three scenarios are not noteworthy, which confirms it is not beneficial to set up holding pens for these clusters with small volume of ovine.

7.5 Summary on this location problem

In order to decide whether or not to set up a holding pen for a cluster of farms, there are several factors which should be considered.

7.5.1 Distance from the slaughterhouse

For a cluster of farms, if a holding place is built up, the available sheep will be accumulated to the same place, thus it will require fewer tours to transport the same amount of sheep. When the farms are far away from the slaughterhouse, to reduce one tour can save more than for farms close to the slaughterhouse. For example, cluster 31 is further from the slaughterhouse than cluster 29 (see Figure 16). The average distance from the slaughterhouse is 45 and 165 for cluster 29 and 31 respectively. Even though cluster 29 has more farms and more sheep, the saving of its holding place is smaller than the one for cluster 31 (see Table 51). Thus, farms far from the slaughterhouse should be considered first to set up holding pens.

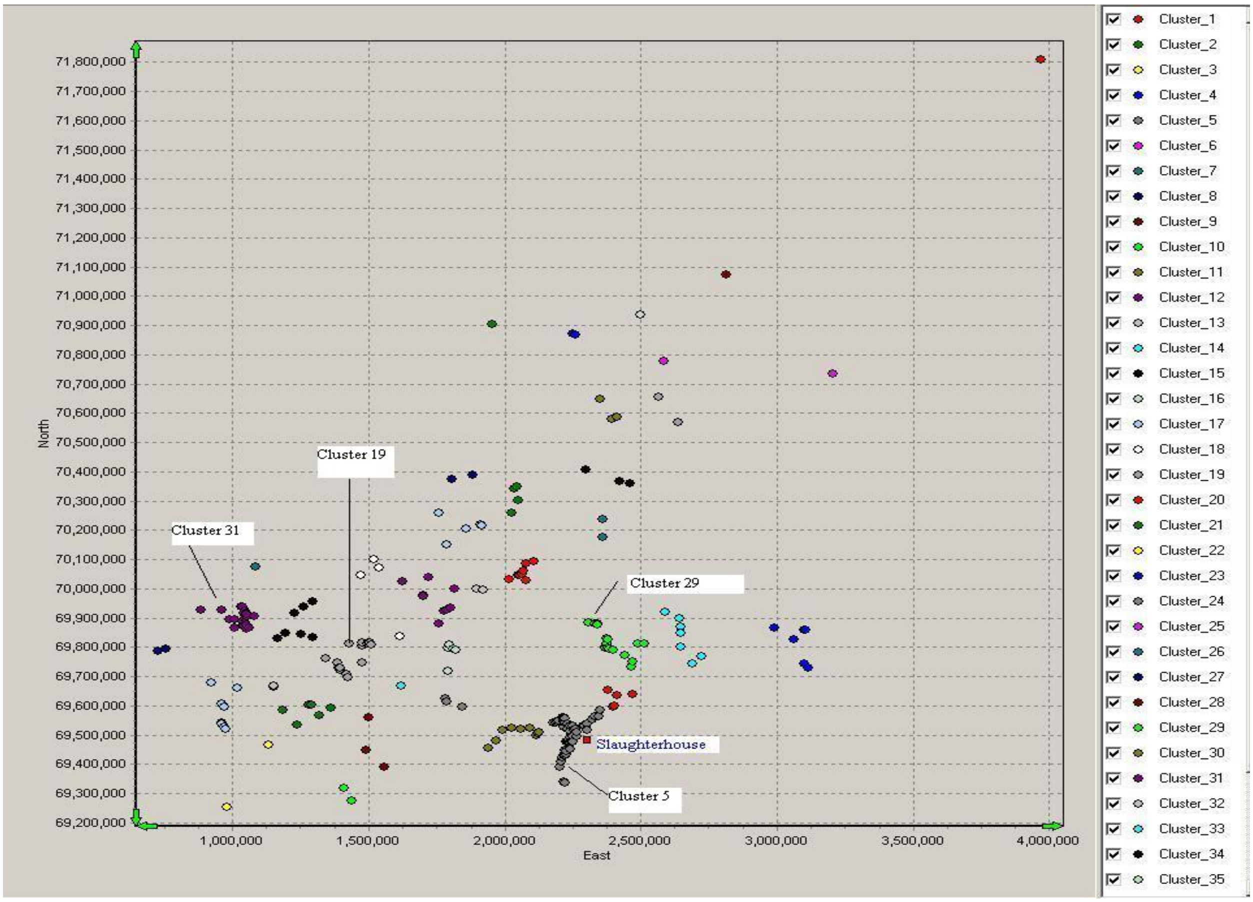

Figure 16: Locations of each cluster

On the other hand, a holding pen can not be built up too far from the slaughterhouse since the sum of travelling time and loading time can not exceed 8 hours.

7.5.2 The volume of ovine in a cluster

In general, there should be enough amount of ovine for a holding pen so that the fixed cost of the holding pen can be compensated. The more sheep, the more beneficial the holding pen could be. As shown in the above tests, it is not so beneficial to set up holding pens for small clusters, such as cluster 14, 21 and 36. But it may be profitable to build up holding pens for big clusters, like cluster 5, 19, 29 and 31.

The volume of ovine in a cluster is affected by the planning horizon. The situation can be improved if the planning horizon is prolonged.

7.5.3 The perspective of the entire instance

As mentioned above, the transportation cost is not only affected by the feature of individual farms, but also impacted by the interaction among farms, perhaps the interaction between farms and vehicles as well. It is important to evaluate the cost change of the whole instance when considering this location problem.

8. Conclusion

In this master thesis, I have explored the capacity issues of transporting the livestock to two slaughterhouses of Gilde Norsk Kjøtt, the largest meat processing company in Norway. Even though it currently does the transportation planning manually, Gilde has been seeking to adopt better planning methods for years.

With the livestock route planning system developed by Oppen and Løkketangen, I have tested 5 sets of data provided by Gilde. The first set of data has been used to compare the differences between the manual method and the solver based technique. It has been found the solver based planning system can reduce the total transportation costs to a large extent.

The major task of thesis is to find the proper fleet size and mix for the two slaughterhouses. From their current fleet, the least efficient vehicles are abolished step by step, finally, it turns out that 4 standard trucks will be enough for the slaughterhouse at Ålesund while the slaughterhouse at Oppdal will only require 5 standard vehicles. In addition, I have also explored whether it is beneficial to use trailer and small capacity vehicles. Through data testing, it shows the standard vehicle is the proper choice for the current livestock collection system. To use trailer or small vehicle can not reduce the transportation cost significantly.

At last, some testing has been performed in order to analyse the feasibility of setting up holding places for the slaughterhouse at Oppdal. Since there is not enough data, only a few tests have been done. Testing results indicate it may be profitable to set up some holding pens for the farms close to each other and with enough sheep.

To sum up, I will be very happy if the finding of this thesis could help improve the transportation operations at Gilde.

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