Feeder Transport Analysis for Regional Intermodal Transport

Case Study: Mälaren Region

HANZHENG ZHU

Master of Science Thesis
Stockholm, Sweden 2012
Feeder Transport Analysis for Regional Intermodal Transport

Case Study: Mälaren Region

By Hanzheng Zhu
Abstract

Intermodal transport is characterized by the integration of more than one transport mode into a transport chain. The regional intermodal transport for inland logistics in short-distance distribution is our research target. The aim of this research is to analyze the bottleneck of regional intermodal transport – feeder transport, like the pre- and post-haulage to intermodal terminals. The author will provide an overview of feeder transport from a strategic and analytic perspective.

The discussion will be bisectional, concerning government policy and company strategy. The government and local municipalities will influence the feeder transport in the aspects of regional transport policy, regional infrastructure and railway network. Based on that, the company could outline their own feeder transport strategy with respect to vehicle routing and distribution cost mode.

The paper will study the distribution case from the retail company Coop in Mälardalen Region, as a pilot. We formulate the vehicle routing problem (VRP) as a mathematical program, based on Tabu method, with realistic input data from Coop. In the following section, based on the optimized vehicle routing, the cost model is built for analyzing related elements and variables in feeder transport operation. In results, a main conclusion could be safely drawn that the transport demand is the most significant element for feeder transport, especially in city logistics. In the final chapter of this thesis, the discussion will expand to a further idea - integrating the demand forecast with intermodal transport strategy.

Key words: intermodal transport, feeder transport, Mälardalen Region, transport policy, transshipment, vehicle routing problem (VRP), Tabu method, cost model, demand forecast
Acknowledgements

I would like to convey my deep gratitude to my thesis supervisors and examiner, Sebastiaan Meijer, Behzad Kordnejad, and Bo-Lennart Nelldal for their patient consultation and helps during my thesis work. I am also very grateful to thank Anders Lindahl who has helped me from the beginning. I want to express my appreciation to the Coop Company, which gave me their operation data to support my thesis research.

Besides, I want to thank all teachers, researchers and classmates from KTH transport system group. I have spent a great time in Stockholm and learned a lot in this period. It will be a remarkable memory in my life.

Finally, I want dedicate my appreciation to my family and friends. They have supported me during my stay in Sweden. They shine the summer and warm the winter. I will keep them all in the bottom of my heart.

Hanzheng Zhu

Stockholm, Sweden, October 2012
Contents

Abstract ............................................................................................................................................. 2
Acknowledgements ........................................................................................................................... 3
1. Introduction .................................................................................................................................. 6
   1.1. Background ........................................................................................................................ 6
   1.2. Goals ................................................................................................................................... 8
   1.3. Methodology ...................................................................................................................... 9
2. Regional Intermodal Transport and Feeder Transport Analysis .................................................. 11
   2.1. Definition .......................................................................................................................... 11
   2.2. Regional transport policy of feeder transport .................................................................. 11
   2.3. Regional intermodal transport ......................................................................................... 15
   2.4. Intermodal transport network ......................................................................................... 16
   2.5. Research Method of Feeder transport ............................................................................. 18
      2.5.1 Route Planning Method ......................................................................................... 18
      2.5.2 Cost Mode structure .............................................................................................. 24
3. Practical Intermodal Network Design and Analysis in Mälardalen Region ................................. 26
   3.1. Overview .......................................................................................................................... 26
   3.2. Transport mode choice in Mälardalen area ..................................................................... 26
   3.3. Terminals and terminal capacity ...................................................................................... 28
   3.4. Interface between road transport and rail transport ....................................................... 30
   3.5. Case Study: Feeder transport in Örebro ........................................................................... 31
      3.5.1. Route planning ...................................................................................................... 31
      3.5.2. Cost Model of Feeder transport ............................................................................ 35
      3.5.3 Further Study and Discussion of Route planning and Cost Model ......................... 41
4. Conclusion ................................................................................................................................... 45
5 Continue Work and Future Research ........................................................................................... 46
   5.1. Updated Method and Programming, Real-time management ........................................ 46
   5.2. Combined Time schedule and management ................................................................... 46
   5.3. Combining Demand forecast with Inventory management ......................................... 47
References: ...................................................................................................................................... 50
Appendices: ..................................................................................................................................... 53
   Appendix-1: The Overview of Coop shops and rail terminals in Mälardalen area from Arc GIS .......................................................... 53
   Appendix-2: Java code for Tabu method, adopted for feeder transport in Örebro ........... 54
   Appendix-3: Cost model of feeder transport presented in Excel ................................. 58
1. Introduction

1.1. Background

As the global trend, the urbanization is being accelerated, and 85% of the Swedish population resides in urban area. How to use the limited transport capacity to fulfill the increasing transport demand in a sustainable way is an emergent problem for every decision maker in business.

In this context, efficient intermodal transportation has emerged as essential for sustainable economic growth. Geographic regions are being expanded due to the fact that rapid options for transportation have expanded the range of action of people and businesses. Metropolitan regions require more frequent transports that are often categorized by an inflow of food and consumer goods and an outflow of recycled materials and waste that cannot always be taken care of locally. Besides, more tightly transport connection leads to the economic combination and alleviate overcrowding in urban area. The relocation of some functional area or industry region could light the population pressure that requires an efficient network as well.

Intermodal transport is no longer a new concept. Nowadays, it has been already widely adopted in international logistics and long-distance transport. Intermodal transport refers a transport method combined with at least two different transport modes. (William & Clinger, 2000) The reason to use intermodal transport is that it integrates the advantages from different transport modes. A typical intermodal transport structure is shown as the following figure.

![Figure 1. Typical structure of intermodal transport chain (Rodrique, 2012)]
As the figure shows above, there are four main components in a completed intermodal transport.

- **Composition.** The process of assembling and consolidating freight at a terminal that offers an intermodal interface between a local distribution system and a regional or long-distance distribution system. In a business logistics, it refers to the “first mile” which assembles loads of freight from different suppliers. Activities such as packaging and warehousing are also contained in the composition process.

- **Connection.** Involves one transport mode flow, such as a freight train in this thesis or a containership, between at least two terminals. It usually means a regional or long-distance freight distribution system.

- **Interchange.** The major intermodal function always takes place at terminals in order to provide an efficient transferring among different transport modes in supply chain.

- **Decomposition.** When reaching a terminal close to its destination, a load of freight has to be fragmented and transferred to the local freight distribution system. Commonly referred as City logistics, also known as the "last mile", and often represents one of the most difficult segments of distribution. This function dominantly occurs within metropolitan areas and involves unique distribution problems. This thesis will focus on this part. (Rodrigue, 2012)

There are many successful examples of using intermodal transport in international and long-distance distribution. The following figure shows the transport mode share of freight distribution in Sweden.

![Figure 2 Transport mode share in Sweden (Commission, 2012)](image_url)
It is obviously shown that the road transport still dominate the inland transport, with large share from regional transport. Nevertheless, it is not common to use intermodal transport in regional or short-distance distribution. The high cost and time of transshipment and management with much more risk keep many regional distributors away from intermodal transport. For these reasons, the pure road transport is still dominating the regional transport. However, it does not mean that the intermodal transport can not be used for regional transport.

In order to make the intermodal transport explicit in an economic way in a regional transport system, a good cost evaluation and management should be made in advance. So in this thesis, the feasibility of intermodal transport and a systematic analysis method will be discussed, to give a reference for shipper’s regional transport strategies.

1.2. Goals

The thesis argues that a strategic view of regional intermodal transport system. As the previous descriptions, the output from regional intermodal transport system is determined by regional transport policy, infrastructure, transport mode combination, network design, route planning, etc. These related elements will be concerned in the discussion, to provide a systematic way of analyzing. In this thesis, the combination of rail and road transport is primarily considered when referring to a regional intermodal transport. Thus, in this intermodal system, there are three main parts which form the transport chain: road transport (for first mile picking and last mile delivering), rail part and transshipment. The rail part is a quite fixed part, which has stable delivery frequency and time schedule, with low cost and high capacity, so the author will more concentrate on road transport, which is also called feeder transport, and transshipment.

Above all, the goals of this thesis should be achieved as below:
1. Give an introduction and a strategic overview of regional intermodal transport.
2. Provide a methodology in route planning and a corresponding cost model for feeder transport.
3. Apply data for a real case. Create an optimized route planning and a corresponding cost model in Mälardalen Region, specific in Örebro city.
4. Test sensibilities of variables in cost model.
5. Discuss the feasibility of regional intermodal transport as well as the methods of feeder transport.

To make the structure of thesis clear, the whole thesis contains two parts, theoretic part and practical case study. The theories and methodologies will be concentrated in the first part, and the following part will implement data from a real case to exam the methods which is stated in previous.
1.3. Methodology

Following the previous description, this thesis is formed by two important parts, theoretic part and practical case study. It results that the methodology in this two parts is different.

*Theoretic part*

In the theoretical part, all the related definitions, principles, transport policies and conditions will be defined. To clarify the regional transport policies and current transport conditions, all resources is checked from government websites and transport agencies’ reports. That makes the foundation of building regional transport scenario in Mälardalen area.

Then, a brief explanation of research methodology with all terminologies will be described as well as a comprehensive literature review. The author attempts to provide an analytic structure, which involves two dependent sections, route planning and cost mode, for regional feeder transport. The author will provide some popular solutions for route planning. One of the latest solutions, called Tabu method, will be presented more in depth.

Besides the basic principles of terminologies from the literature, the methodology part will go deeper into the mathematical aspect of the study. Some mathematic formulas are shown, in order to provide another direct view of our analytical structure.

*Practical case study*

Based on the method from theoretic part, a practical case study will be conducted. Our focus area is Mälardalen region, including the city of Stockholm and surroundings in Sweden. Most sources of maps, figures, current transport lines and terminal details are from internet and reports. The idea is to form a present scenario of regional transport and distribution.

For deeper analysis, a specific terminal, Örebro, is used as a pilot. All data, supporting our model in this case, is from Coop Retail Company. The data includes the location of Coop supermarkets, transport demand of each shop and the real delivery time. Follow the structure of theory part, the data analysis will be still formed by two sections, route planning and cost model. The map drawing and regional distance matrix are achieved by using Arc GIS, as the input of Route planning. Tabu method is selected for route planning, and Java program will help us to implement. When an optimized route planning is chosen, it will become a base scenario for cost model. A cost model, containing Capital cost, Maintenance cost, Fuel costs, Labour cost, Overhead cost and Mode transshipment, is established for economic measurement.
The author will test sensibilities of two independent variables from cost model by using regression function in Excel. More discussion and analysis will extend into the following work.
2. Regional Intermodal Transport and Feeder Transport Analysis

2.1. Definition

The term **Regional Intermodal Transport** refers to a combined transport system which includes at least two different transport modes in regional distribution. The modern regional intermodal transport management not only focuses on goods transport and logistics, but also concentrates on responses from marketing and business strategy. Some of reasons for adopting a regional intermodal transport system are:

- Reducing the costs
- Simulating regional business location decisions
- Assisting economic development and job creation
- Reducing regional congestion on the road network
- Improving service quality
- Contribute to sustainable development for society (reducing externalities)

Only by embracing the objectives above as their guiding principles, the shipper and distributor can make a process of the analysis for regional intermodal transport. In this process, many elements could be taken into account, such as regional transport policy, the design of transport network (nodes, route, terminals, etc.) and transport mode choice. In the following part, the discussion will extend into these parts to show a systematic analysis of intermodal transport.

2.2. Regional transport policy of feeder transport

Freight transport and logistics industry are quite dependent on government’s policies and regulations, because, usually, they are sharing the same road, rail and some infrastructures with passengers transport. Most of times, government is the largest infrastructure or equipment provider in the transport area. So, government and municipalities have the right to set rules and limitation for freight transport to ensure the public profit.

For the company’s roles in transport, there are two kinds of player in this field, operator (like Green Cargo) and shipper (like Coop) in Sweden. Both of them should take care of transport policy. Especially for shippers in regional intermodal transport, they are most sensitive players with any change of transport policy. They should look after the whole transport chain that any transport policy change from a single transport mode will influence the whole regional intermodal transport operation.

Swedish transport policy is established in order to achieve six subsidiary objectives
for safe traffic, good environment, accessible transport system, high transport quality, positive regional development and gender equality in the transport system (Brita, 2010). In this part, the discussion will go through Swedish transport rules and limitations for feeder transport from weight and scale limit, speed regulation, congestion charging and taxation.

- **Weight and Scale limitation**

Government and transport agencies will set some weight and scale limitations for long and heavy vehicles to:
1. Prevent the damage to roads and bridges
2. Ensure the safe on the road
3. Keep vehicles from wearing out quickly

In Sweden, the public roads have been classified into 3 bearing capacity classes, BK1, BK2 and BK3. Different bearing capacity class has different weight and scale limitations. Here, we just discuss about the most common class, BK1. (Swedish Transport, 2010)

According to the EU transport regulation from the European Parliament and Council, the dimension for articulated vehicles can not exceed 16.5 meters and for road trains 18.75 meters, with a maximum width of 2.55 meters. The maximum permitted weight is 40 tones, with the exception of domestic transport combined with railway where the weight may amount to 44 tones, when a 40 foot container is transported. (Mellin & Ståhle, 2010)

However, Sweden has exemptions from EU rules. The Swedish International Freight Association (SIFA) allows for cross-border traffic with weight or dimensions exceeding 40 tones or 18.75 meters. The maximum length of heavy vehicles is 25.25 meters, with a maximum gross weight of 60 tones. The pressure per Axle can not exceed 10 tones. (Vierth, 2008)

In some big cities, city managers make more strict rules to control the weight and dimension of heavy vehicles with the purpose of avoiding traffic congestion and accidents. In that case, some companies need to transfer goods to a smaller truck before entering the urban area, or use night delivery instead.

- **Speed limit**

Speed is another important factor in deciding the seriousness of an accident. The speed limits are different according to the situations of different areas. Speed limit for an area is reminded by the sign plates besides roads. Normally, the speed requires under a lower speed limit in urban area than countryside.
In Sweden, the Swedish Road Administration and certain municipalities are issued for managing them, with speed limits of 40, 60, 80, 100 and 120 km/h. They try to keep a balance between road safety requirements, the environment, accessibility, navigability, favorable regional development, and equality.

- **Congestion Charging**

Congestion charging, as one of the methods to reduce traffic congestions, has been adopted by many cities. Following Singapore that adopted congestion charge in urban area in 1975, London, Melbourne, Toronto, Stuttgart and Stockholm initiated their congestion charging programs on urban roads. (Quinn, 2001) The charging targets in urban area are private cars and freight transport vehicles. The economic effect from congestion charging should be also taken account into cost evaluation of feeder transport. The distributor also needs to consider the different charging cost for different period of a day when making delivering time schedule. The following table shows the congestion charging in Stockholm.

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00 – 06:29</td>
<td>0 SEK</td>
</tr>
<tr>
<td>06:30 – 06:59</td>
<td>10 SEK</td>
</tr>
<tr>
<td>07:00 – 07:29</td>
<td>15 SEK</td>
</tr>
<tr>
<td>07:30 – 08:29</td>
<td>20 SEK</td>
</tr>
<tr>
<td>08:30 – 08:59</td>
<td>15 SEK</td>
</tr>
<tr>
<td>09:00 – 15:29</td>
<td>10 SEK</td>
</tr>
<tr>
<td>15:30 – 15:59</td>
<td>15 SEK</td>
</tr>
<tr>
<td>16:00 – 17:29</td>
<td>20 SEK</td>
</tr>
<tr>
<td>17:30 – 17:59</td>
<td>15 SEK</td>
</tr>
<tr>
<td>18:00 – 18:29</td>
<td>10 SEK</td>
</tr>
<tr>
<td>18:30 – 23:59</td>
<td>0 SEK</td>
</tr>
</tbody>
</table>

- **Taxation**

Transport tax is a tool from government to control the transport activities. Taxation in transport has three main parts, oil tax, vehicle tax and road charging.

**Fuel tax**

Fuel tax not only owns basic function of taxation, as an import income of government, but also limits pollution and waste from environmental aspect. To encourage people to use clean and sustainable energy, some extra tax, like energy taxes and carbon dioxide tax, have been added into oil and diesel price. For example, in Sweden, for diesel oil of environmental class 1, energy tax is 1.06 SEK per litre and
carbon dioxide tax 2.66 SEK per litre from 1 January 2007.

Vehicle tax

Vehicle tax for heavy lorries varies according to weight, towing equipment, the number of axles and exhaust class. Vehicle tax is reduced for vehicles subject to road charges.

For lorries and lorries and trailers with a total weight of at least 12 tonnes, shall (with certain exemptions) pay road charges (Eurovignette). The charge varies between SEK 6,831 and SEK 14,117 per year depending on the number of axles and exhaust class. The road charge certificate for foreign vehicles can be purchased by day, week, month or year. (Tommy, 2007)

Road Charging

In Sweden, Road Charging only applied to vehicles over 12 tonnes. (a road charge after 2012 must include all vehicles over 3.5 tonnes (total weight) driven on the ten road network. Until 2012, it is, however, still voluntary to include vehicles between 3.5 and 12 tonnes in a charge system. There are two exceptions to this requirement:
1. If inclusion of vehicles under 12 tonnes has a negative effect on the traffic flow, the environment, noise or health, and
2. If the administrative costs exceed 30 per cent of the additional income.

In conclusion, government is an important rules maker as well as a participant in transport area. So, what is the role of government in regional intermodal freight transport?

When government realizes the potential economic benefit and social effect, the required role of the government is to briefly remove the barriers, create incentives for technological leadership and provide financial stimulation. Government can take a leadership position in this arena to:

- Bring the stakeholders together,
- Identify and eliminate institutional barriers to innovation,
- Exert leverage over technological issues (such as systems architectures and interoperability standards),
- Assure the developments of tools (such as simulations data bases and special-purpose communication links),
- Allow optimization among various modes of freight transportation,
- Efficiently affect the freight transportation modes interfaces,
- Insure that measurable progress is achieved.

(Abbasi, 1996)
2.3. Regional intermodal transport

Intermodal transport refers to the transportation from origin to destination by a sequence of at least two transportation modes, the transfer from one mode to another mode is being executed at an intermodal terminal. (Kim, December 9, 2005) The transport modes may contain road, rail and ocean shipping. The concept of intermodal transport is to exploit the advantages from different transport modes in order to achieve lower costs, better customer service and sustainability.

Generally speaking, the road transport takes advantages on accessibility and flexibility, rail transport (and shipping), in comparison, performing in lower unit transport cost and higher transport capacity. As the figure below, the intermodal transport integrate both advantages from rail and road.

![Accessibility vs Unit transport cost](image)

![Road transport vs Rail transport](image)

![Flexibility vs Transport Capacity](image)

Figure 3. Advantages comparison for rail transport and road transport

A typical intermodal transport structure normally contains two parts, long-distance transport and short-distance transport. As the discussed above, rail transport is responsible for long distance transport, and road is in charge of short distance transport, which is also called “the last-mile” delivery.

This kind of intermodal transport has been proved that very functional for cross-boarding delivery or long distance transport. It becomes a standard logistics mode in logistics companies for international transport. However, when adopting this intermodal way into regional delivery, some drawbacks of intermodal transport should be taken into account.

First of all, the biggest difference, from cost perspective, between intermodal and unimodal transport is interface costs. Frequently changing transport modes will take
big amount of costs and time. Moreover, the intermodal terminals require more investment on infrastructure and professional human labor. Hence, the interface cost will comprise a big part of the total costs of short distance transport.

Secondly, intermodal transport could increase the risk of the whole transport process. In a normal intermodal transport procedure, there are at least 6 times loading and unloading. Some accidents probably happened during interface period which would increase possibility of potential damage.

Third, the intermodal transport may need tight cooperation and coordination among different transport operators. Intermodal transport users do not expect long waiting time and delay, and they hope that every delivery will obey the restriction of each transport mode. Similarly, equipment that moves from one location to another empty also adds to the costs. A well-organized transport chain with good coordination with all participators is important for intermodal transport.

Finally, some change in the regional transport policy will give more influence for a short distance intermodal transport. An intermodal transport will concern more perspectives in different transport modes, traffic restriction, infrastructure construction and capital investment. Each policy change from every perspective above will affect the whole intermodal transport chain much more different.

Hence, intermodal transport is more sensitive with transport policy change than unimodal transport and as the number of modes increases so will the sensitivity.

2.4. Intermodal transport network

The first systematic and strategic overview of intermodal transport is the network design. The arrangement of intermodal transport will influence the modal share of unimodal transport. An improvement of intermodal transport could increase the cost-quality ratio in the intermodal transport. This serves all interests, especially the micro-economic ones of actors in the field of intermodal transport.

There are some typical designs for intermodal transport network, such as:
- **BE-network**: The direct operation between departures and end-terminals.
- **HS-network**: Spoke-and-hub network, which is normally used for distribution center.
- **TCD-network**: Trunk, distribution and collection network, applicable in long-distance transport.
- **TF-network**: Truck-and-feeder network. The one is suitable for regional intermodal transport. (Kreutzberger, 1999)
This network shows a typical goods flow in regional intermodal transport, which is combined with rail and road transport. The collecting nodes covered by the terminals’ catchment area are collected by feeder transport (road), and then travel along the rail. Inside each catchment area, the feeder transport will play an important role in charge of both delivering and collecting, to expand accessibility of intermodal transport system.

Normally, the network design is depend on infrastructure, transport policy and economic measurement. The infrastructure part includes rail, road, transport equipments, terminal design and capacity. Transport policy involves all limits of speed, weight, scale and environment, as we mentioned before. Nevertheless, the economic measurement is the only one that can be adopted and controlled in company’s level.

The reduction of transport costs could be achieved by:
- The increase of economies of scale of the link operations
- The increase of the loading degrees of trains, and of trucks in the pre- and end-haulage
- The increase of the circulation speed of trains, and of trucks in the pre- and end-haulage. The time advantage can (partly) be used for the exchange of load units at intermediate nodes and thus to support complex bundling;
- The increase of the quality of transport operations, such as;
- Offering higher transport frequencies;
- Shorter lead times through the complete chain;
- More destiny terminals form each origin terminal.
(Kreutzberger, 1999)

The following part will concentrate on analytic methods of feeder transport from economic aspect.
2.5. Research Method of Feeder transport

After confirming the network structure of intermodal transport, the cost of rail part is quite fixed. The most efficient way of cutting total costs is control the costs of feeder transport, which is the most flexible part in intermodal transport. To achieve this goal, there are two methods will be introduced in the following parts: Route planning and Cost modal.

2.5.1 Route Planning Method

One of important parts in this thesis is route planning that optimizes the feeder transport costs. Considering the total cost of rail part is quite constant in the intermodal transport, according to Behzad Kordnejad's research, the author will mainly focus on costs of feeder transport, which is more flexible and changeable.

The best route planning could save the delivery time, cut labour cost and transport cost, avoid any delay and traffic jam, and control the transport risk. Today, there are already many solutions for route planning, like real-time route planning. For an important element in supply chain planning, most of the time, route planning will integrate with Enterprise Resource Planning (ERP), Customer services and Inventory control.

In this part, the author provides a strategic solution for route planning for regional supply chain planning. A real case will be shown as a pilot to study the whole process of a route planning method.

Travelling Salesman Problem (TSP)

The basic statement of route planning can be presented in an interesting story. A salesman wants to find the shortest way, for visiting each customer once and then return to the starting point. It is called Travelling Salesman Problem (TSP). This problem was first formulated as a mathematical problem in 1930. It is used as a benchmark for many optimization methods. However, the difficulty of this problem is a large number of heuristics and exact methods for thousands of collecting point. (Bryan, April 18, 2009)

Vehicle Routing Problem (VRP)

In this case, a more realistic description of route planning, with the same principle of TSP, presents as Vehicle routing problem (VRP). Since Dantzig and Ramser proposed VRP principle in 1959, it has become an important problem in logistics and distribution. (Dantzig & Ramser, 1959)The VRP problem can be understood as a
multi-TSP problem. There is one or several TSP routes in a delivering plan. Every truck has same departure and destination, which is normally the same depot.

![Figure 5. The basic network structure of TSP and VRP.](image)

In reality, there could be multi-route for thousands of collecting or delivering point with delivery time and truck capacity constraints. Different operational constrains combined with VRP could make various advanced Vehicle Routing Problem.

- **VRP with time windows (VRPTW):** Customers should be served within a certain time window.
- **Multiple Depots VRP (MDVRP):** There is more than one depot as the departure and destination of vendors.
- **VRP with Pick-Up and Delivering (VRPPD):** In the return way, the vendor would take some goods back from customers.
- **Split Delivery VRP (SDVRP):** Delivery requests can be split between several vehicles.
- **Periodic VRP - (PVRP):** A temporary Vehicle Routing planning for particular days (Kordnejad & Cats, August 2011)

The mathematic description for VRP problem:

Let us set an assumption of original settings as follow:

K: the total number of trucks.
N: the number of distribution point.

C_{ij}: The transport cost from point I to point j. I, j ∈ \{0,1,2,...N\}, 0 stands for the depot.

D_i: the demand of customer i. I ∈ \{0, 1 .... N\}

Q_k: the capacity of truck

\( X_{ijk} = \begin{cases} 
1, & \text{truck k deliver to point j after delivering to point i.} \\
0, & \text{others.} 
\end{cases} \)

So, the VRP problem can be described like:

\[
\text{Min } \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{N} C_{ij}X_{ijk}
\]

Subject to:

1. The total number of route should not exceed K, because of the number of trucks K.

\[
\sum_{k=1}^{K} \sum_{j=1}^{N} X_{ijk} \leq K, \text{ for } i=0
\]

2. For every route, the departure and destination should be the same depot.

\[
\sum_{i=1}^{N} X_{ijk} = \sum_{j=1}^{N} X_{ijk} \leq 1 \text{ for } i = 0 \text{ and } k \in \{1,2, ... k\}
\]

3. Every customer should be visited and not be repeated.

\[
\sum_{k=1}^{K} \sum_{j=1, i \neq j}^{N} X_{ijk} = 1 \text{ for } i \in \{1,2, ... k\}
\]

\[
\sum_{k=1}^{K} \sum_{i=1, j \neq i}^{N} X_{ijk} = 1 \text{ for } j \in \{1,2, ... k\}
\]

4. The total picked goods of one route can not exceed Q_k.

\[
\sum_{i=1}^{K} D_i \sum_{j=0, i \neq j}^{N} X_{ijk} \leq Q_k \text{ for } k \in \{1,2, ... k\}
\]

(Laporte, May, 1991)

**Methods for VRP**

As the description above, the VRP is a typical NP-hardness (non-deterministic polynomial) problem, because no exact algorithm can be guaranteed to find optimal tours within reasonable computing time when the number of cities is large. Basically speaking, there are three methods: **Exact Approaches**, **Heuristics** and **Metaheuristics**.

For the Exact Approaches, this method suggests to calculate every possible ways to find the best solution. This kind of methods, typically like **Branch and Bound**, **Branch and Cut**, is capable for small-scale distribution network with few nodes. So, most of time, in reality, the following two methods are being used.
Heuristics

Heuristic methods make a limited exploration of the search route and typically produce good quality solutions within short computing times. The nearest neighbor algorithms, insertion algorithms and tour improvement procedures can be performed to VRP almost automatically. The only problem is to check every feasible route with many constrains. The following figure is the basic procedure of heuristic algorithm.

![Flowchart of heuristic algorithm](Image)

In this section, two heuristics specifically developed for VRP will be simply described as below.

**Constructive Methods**

Constructive methods gradually give a best suggestion of route planning while focusing on solution cost, but do not contain an improvement phase.

- Savings: Clark and Wright algorithm (1964)
- Matching Based
- Multi-route Improvement Heuristics
  - Thompson and Psaraftis
  - Van Breedam
  - Kinderwater and Savelsbergh
2-Phase Algorithm

The problem is separated into its two parts. Step 1: gathering of near nodes into feasible routes and Step 2: actual route building, with possible feedback loops between the two stages.

- Cluster-First, Route-Second Algorithms
  - Fisher and Jaikumar
  - The Petal Algorithm
  - The Sweep Algorithm
  - Taillard
- Route-First, Cluster-Second Algorithms

(Laporte, The vehicle routing problem: An overview of exact and approximate algorithms, 1991)

Meta-heuristics

In a recent 20 years, another advanced heuristics, called Meta-heuristics, have been rapidly developed. This kind of methods takes big advantage on finding multiple optimized routes with large amount of nodes and broad catchment area. Meta-heuristics also provide a smart way for VRP integrated with other limitations, like time window and capacity constrain. Here are some meta-heuristic methods:

- Ant Algorithms
- Constraint Programming
- Deterministic Annealing
- Genetic Algorithms
- Simulated Annealing
- Tabu Search
  - Granular Tabu
  - The adaptative memory procedure
  - Kelly and Xu

(Goodson, 2010)

Among these methods, there are three latest methods which are most successful in VRP, Genetic Algorithms, Simulated Annealing and Tabu Search. These three methods are capable for a more complicated network with many delivering nodes. Especially for Tabu method, it can efficiently reduce the repeat of calculation for multiple vehicle routing plans. In the following real case in the next section, we are going to use Tabu method to solve the Vehicle Routing Problem in feeder transport. So, we make a brief description of Tabu method here.
Tabu Search

The description of Tabu search was firstly proposed by Glover in 1977. In his research, a best route solution of “neighbors” was successfully examined. To prevent repeating and cycling, this method creatively makes a constantly updated tabu list to contain forbidden test. The first example to use this method is searching VRP in Willard in 1989. (Michel, Alain, & Gilbert, 1994)

For most heuristic used for VRP, their mathematic theory is a kind of improvement of 2-opt interchanges while satisfying the VRP constraints. The principle of 2-opt interchanges is that:

1. Setting 2 random nodes of delivering tour as I, j. The initial link could be (I, j), with the distance \( D_{ij} \).
2. The neighborhoods of I, j could be I + 1, j + 1.
3. Substitute the any two of links (I, i+1) and (j, j+1) with two other links, like (I, j) and (I + 1, j + 1).

Such an interchange results in a route improvement if and only if the following condition holds:

\[
D_{i, i+1} + D_{j, j+1} > D_{i, j} + D_{i+1, j+1}
\]

(Savelsbergh, 1985)

Nevertheless, for this 2-opt interchanges method, there will be many repeating and cycling for the large number of distributing points on route. To avoid this situation, a tabu list is made to records some forbidden moves. Tabu restrictions are subject to an important exception. When a tabu move has a new output value where it would result in a solution better than any visited so far, then its tabu classification may be ignored. A condition that allows such an override to occur is called an aspiration criterion. (Glover, Kelly, & Laguna, 1995) (Hillier & Lieberman, 2005)

A typical Tabu procedure should be formed in 5 steps:

Step 1: Choose an initial solution \( i \) in \( S \). Set \( i^* = i \) and \( k = 0 \).
Step 2: Set \( k = k + 1 \) and generate a subset \( V^* \) of solution in \( N(i,k) \) such that either one of the tabu conditions \( D_r(i,m) \in D_t \) is violated (\( r = 1, ..., t \)) or at least one of the aspiration conditions \( D_r(i,m) \in D_a \) holds (\( r = 1, ..., a \)).
Step 3: Choose a best \( j \) in \( V^* \) and set \( i = j \).
Step 4: If \( f(i) < f(i^*) \) then set \( i^* = i \).
Step 5: Update Tabu and aspiration conditions.
Step 6: If a stopping condition is met then stop and output result. Otherwise, go to Step 2.

(Alain, Eric, & Dominique, 1995)
2.5.2 Cost Mode structure

As another important part in this thesis, the cost mode determines whether the transport cost is accepted from economic aspect. Cost modal is always a useful way to measure the final transport cost as well as tests the sensibility of each cost item. In that case, the company could decide to minimize the important cost effective item to raise the profit.

The cost mode in this thesis is seemed as the Activity-Based Approach (ABA). Transport activities impacted by the trip demand and supply have been formed as input components of cost modal. The following figure shows the process of building an activity-based cost modal. (Hossain, 2009)

![Diagram of building a cost modal and measurement](image)

**Figure 7. Work flow of building a cost modal and measurement**

The process can be concluded like:
1. Identify all the related cost components in transport chain
2. Build calculation formula for each cost item
3. Input necessary data from route planning and transport demand
4. Check whether the output cost is the minimum cost per unit
5. If it is, then end the process; otherwise, modify the cost modal.

In this thesis, we mainly focus on cost of feeder transport, but also the transshipment cost is taken into consideration. The reason is that, in intermodal transport, the cost
of rail part is quite fixed, with high transport capacity, limited number of trips, fixed route and certain time schedule. The most flexible part, which is also easy to minimize the cost, should be the cost of feeder transport and transshipment. These two costs are impacted by

- Terminal catchment area
- Terminal type,
- Vehicle type,
- Route planning,
- Location of delivering point
- Demand of transport.
3. Practical Intermodal Network Design and Analysis in Mälardalen Region

3.1. Overview

Mälardalen region is an important cultural, economic and political centre for the Nordic countries. Currently, 3.24 million inhabitants stay in Mälardalen region which covers an area of 34,452 km². The region has several counties, which includes Stockholm, Uppsala, Södermanland, Örebro, and Västmanland.

A completed railway network already exists around Mälaren Lake, to connect all metropolitan regions. The following feeder transport has been promoted to enhance the accessibility of this transport system. The idea has been handed out by local municipalities that make the whole Mälardalen region as a highly combination area of economy, logistics and inhabitants. It means the current transport system will be much more improved in future.

In company’s level, as a specific case from Coop Company, their warehouses, transport terminal and distribution center around Mälaren lake requires incoming and outgoing transport. Possible transport mode choices should be discussed by decision makers.

3.2. Transport mode choice in Mälardalen area

As we discussed above, there are three transport modes existing in Mälardalen area, pure road transport, pure rail transport and intermodal transport which combined with road and rail. The purpose of using intermodal transport in Mälardalen area is to take the advantage from rail transport, which could transport large amount of goods with low cost. Also from environmental aspect, the difference between these two transport modes may be more obvious. The table below shows the transport mode comparison between road and rail from economic aspect and environmental aspect.

Table 2 Marginal external cost comparison, € per 1000 t*km (Kreutzberger, Macharis, Vereecken, & Woxenius, 2003)

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Road/(highway)</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>5.4</td>
<td>1.5</td>
</tr>
</tbody>
</table>
So, as we can see, the transport among cities could use rail transport instead of road transport to cut costs and increase sustainability. If we optimize the management, organize the time schedule and cut transshipment costs, railway transport is definitely a better choice than road way in Mälardalen area.

On the other hands, the road transport will be still the only choice that responsible for feeder transport to connect rail terminals and delivering nodes. In Mälardalen area, the distribution areas are mainly urban areas. As we discussed in transport policy section, there could be some limitation of truck type for urban freight transport from scale and weight. In the feeder transport in Mälardalen area, the most possible truck types that could be used are Swap body, Semitrailer and Containers.

The following comparison of capacity and general costs shows the difference of these three types of truck.

### Capacity

<table>
<thead>
<tr>
<th></th>
<th>Swap body</th>
<th>Semitrailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 EU pallets</td>
<td></td>
<td>34 EU pallets</td>
</tr>
</tbody>
</table>

### Economics

<table>
<thead>
<tr>
<th></th>
<th>Capital</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactor unit</td>
<td>0.82 SEK/km</td>
<td>3.20 SEK/km</td>
</tr>
<tr>
<td>Semi trailer</td>
<td>30 300 SEK/year</td>
<td>0.38 SEK/km</td>
</tr>
</tbody>
</table>
In retail industry, the urban delivery most time uses swap body for the last mile. Especially in Stockholm city, the type of swap body dominates the final city distribution.

### 3.3. Terminals and terminal capacity

As we discussed before, the connection between road and rail is each terminal, which integrate and transfer two different transport modes in a transport system. To short the transport chain and respond market quickly, network designers always locate the warehouses or distribution centers near these terminals.

In our target area, Malaren region, the main terminals along the rail are plotted in the following map. As we can see, there are 10 conventional terminals including 2 of them are still on the plan.

![Terminals in Mälardalen area (Kordnejad, 2012)](image)

In the following part, three main distribution and consolidation centers of Coop Retail Company will be introduced.
**Bro**

In Bro, a coop logistics center was built in Nygård. It mainly handles the “dry products”, which need to be transported within 5°C to 25°C. From coop logistics center (Nygård) to Bro train station, it is near 3 km.

The current delivery frequency is around 50 trucks per day, from logistics center to Bro terminal. Every day, except Sundays, a train with a capacity of 36 trailers goes to Helsingborg, in the region of Skåne, where most of their suppliers are located, and another train set departures daily on the opposite direction i.e. from Helsingborg to Bro. (Coop, 2011)

**Enköping**

In early 2011, Coop’s new freezer terminal in Enköping was completed. Coop Logistics Ltd has signed a multi-year partnership with Logent AB for the operation and development of the business. The distance from Coop freezer terminal to Enköping center is around 6 km.

The transport condition for frozen products should be kept under 18°C. Normally, the total loading time in Enköping is near 3 hours (even 4 hours for both Monday and Tuesday). (Coop, coop-frysterminal, 2011)

![figure 9 coop new freezer terminal in Enköping](Coop, coop-frysterminal, 2011)

**Västerås**

In Västerås, Coop owns another big logistics center (Stenbygatan 3-5), which distribute and provide fresh products for whole Mälardalen area. The feeder transport distance from logistics center to Västerås center station is approximately 4.5 km. The temperature during delivering period should be in the range of 2°C to 4°C. (Coop, 2010)
3.4. Interface between road transport and rail transport

The transport section should pay more attention on a cross-modal basis in order to establish coherent infrastructure networks. The reason is that the transshipment process could become the bottleneck of the whole intermodal transport system, especially for regional transport. The high cost of transshipment will lead to that the transport users abandon intermodal transport solution.

The transfer points between transport modes will be the nodes of intermodal transport network. Any activities and services there should add the value of the overall transport chain. Some big nodes could be developed to distribution or consolidation centers, even economic centers. The nodes are not only to transfer goods between different transport modes, but also to make an interface between high volume transport corridors and low volume regional and local networks.

For conventional intermodal terminals, it requires large capital investment on gantry-crane or heavy reach-stackers for transshipment. If we use conventional intermodal terminal for regional transport whose transport volume is very low, it could not achieve good cost-efficient utilization. As the development of transshipments, there are many new technologies and methods adopted to support interface function. There is a new type of terminal which is called *cost-efficient small-scale intermodals terminals* - *CESS terminals*: CESS 1A, CESS 1B, CESS 1C, CESS 2, CESS 3. Comparing conventional terminals, they are cheaper in the lifting cost per TEU.

<table>
<thead>
<tr>
<th>Transshipment Technology</th>
<th>Cost/TEU (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Terminal</td>
<td>268</td>
</tr>
<tr>
<td>CESS 1A</td>
<td>257</td>
</tr>
<tr>
<td>CESS 1B</td>
<td>159</td>
</tr>
<tr>
<td>CESS 1C</td>
<td>170</td>
</tr>
<tr>
<td>CESS 2</td>
<td>82</td>
</tr>
<tr>
<td>CESS 3</td>
<td>106</td>
</tr>
</tbody>
</table>

1. Conventional Intermodal Terminal - Medium sized
2. CESS Terminal 1a: Forklift trucks stationed at transfer terminals
3. CESS Terminal 1b: Engineer also handles the forklift truck, thus reducing the operator cost.
4. CESS Terminal 1c: Multipurpose forklift trucks are used half of the time for other purposes at terminals, thus reducing the cost for transloading equipment.

Table 5 Transshipment cost for different transshipment technologies (Kordnejad, 2012)
5. CESS Terminal 2: Novel wagon technology - Megaswing
6. CESS Terminal 3: CCT technology

3.5. Case Study: Feeder transport in Örebro

In order to evaluate the feasibility of route planning method and cost model structure, a real case is chosen as a study pilot. We selected distribution information from Coop, the biggest supermarket company in Sweden. Considering that Coop, as an ambition company, owns its own trucks and trains for transportation and distribution, we think this case study will be a practical analysis for company regional supply chain strategy.

In Sweden, Coop normally builds 4 distribution lines in each region for 4 different types of foods: Dry foods, Fresh foods, Fruits & Vegetables, and Frozen foods. Different type of foods requires different types of transport tools with different transport strategy.

Because the fruits & vegetables need more frequent and fast delivery, enjoying high priority in distribution, they are chosen as an example in our case study. Their delivery destination is 7 Coop shops in Örebro, a small town in the western part of Marlaren area.

3.5.1. Route planning

In this case, Arc GIS has been used as an input of this method, because:

- ArcGIS will present the real distance of each node instead of straight distance.
- ArcGIS will consider the road condition, traffic situation and some geographic elements.
- ArcGIS could handle large number of nodes with specific details showing on the map.

In the first step, the Swedish map as well as road and rail network has been set into a new GIS layer. Then, the coordinates of seven Coop shops have been introduced into GIS, showing as below.
By using the function of Utility Network Analyst from ArcMap, the following conditions have been set:
1. The location of each collecting and delivering point.
2. The road condition with fuel consumption, traffic condition and so on (Weight in ArcMap)
3. Find the real shortest route between any random 2 points. (Find Shortest Path in ArcMap)

In the data we got from Coop, there are 7 Coop shops located in Örebro area. For more convenient description, they are marked with numbers:

1 - CF LILLÅN
2 - CK SVAMPEN
3 - CE ÖSTERPLAN
4 - CK BRICKEBACKEN
5 - CN ÄNGGATAN
6 - CN ROSTA
7 - CF MARIEBERG

So from the output of Arc Info, we got the Distance Matrix in Örebro:

Table 6 Distance matrix for seven coop shops and transport terminal

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>7.255</td>
<td>0.996</td>
<td>2.309</td>
<td>6.102</td>
<td>2.476</td>
<td>2.941</td>
<td>10.534</td>
</tr>
<tr>
<td>1</td>
<td>7.255</td>
<td>0</td>
<td>6.876</td>
<td>8.235</td>
<td>12.01</td>
<td>8.406</td>
<td>10.194</td>
<td>17.724</td>
</tr>
<tr>
<td>2</td>
<td>0.996</td>
<td>6.876</td>
<td>0</td>
<td>1.928</td>
<td>5.81</td>
<td>2.157</td>
<td>3.979</td>
<td>11.51</td>
</tr>
</tbody>
</table>
The five shops are located in the eastern part of Örebro, and other two shops are set in the west. So, they are generally divided into two transport routes firstly, according to geographic overview. Then the number of routes should also rely on transport demand.

The transport demand of fruits & vegetables for each shop in Örebro on Saturday:

<table>
<thead>
<tr>
<th>Shop</th>
<th>Demand (EU-pallet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

In this case, because lack of data about opportunity costs, we will not set time window for this route planning. We will use vendor with 1 tractor and 1 swap-body which is most popular truck type used in urban distribution, with enough space in handling our case. It is assumed that there is only one truck running in each route. For Coops fruit & vegetables pallet, one swap-body container could be loaded with two layers. **So the capacity constraint for each route will be 18 * 2 = 36 EU-pallets.**

From the following map, the shops are separated by train terminal into two groups according to Cluster method. From geographic analysis, Shop 6 and 7 are located along road E20 in west, and other shops stay together in the eastern part of Örebro. So, the initial setting arranges two delivery routes in Örebro. One route contains delivering to shop 6 and 7, and another one covers other shops.
Figure 11 Geographic overview of seven Coop shops in Örebro (Google map)

It means only one route, which covers shop 1, 2, 3, 4, 5, needs route planning. Here, we use Java program to implement Tabu method. Firstly, we input the distance matrix above. The initial solution is set like 0-1-2-3-4-5. Then a Tabu list is made following the description in the previous section. Limitec number of iteration is 100, with a Tabu length 10.

So, from Tabu Java program, the best solution is 0-1-2-3-4-5-0, with total length **29.693 km**. Tabu method is successful used in fruits & vegetables delivery in Örebro. The final optimized route planning is shown as below:

Table 8 The final optimized route planning for seven Coop shops in Örebro

<table>
<thead>
<tr>
<th>Route</th>
<th>Distance (/km)</th>
<th>Load (/EU-pallet)</th>
<th>Load rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 1: 0-1-2-3-4-5-0</td>
<td>29.693</td>
<td>30</td>
<td>83.33</td>
</tr>
<tr>
<td>Route 2: 0-6-7-0</td>
<td>21.107</td>
<td>14</td>
<td>38.89</td>
</tr>
<tr>
<td>Total</td>
<td>50.8</td>
<td>44</td>
<td>-</td>
</tr>
</tbody>
</table>
3.5.2. Cost Model of Feeder transport

The following part will describe the cost model building and analysis in feeder transport. The author will make some assumptions from realistic and apply these data in cost modal. It will show a whole process of measurement of cost model for feeder transport. Even any value of data changed in future, it will not influence the result which is based on the most optimized route planning.

3.5.2.1. Data Source

The cost data related to feeder transport cost of any regional distributor is a kind of business secret. Most companies prefer not to provide or print their cost inputs publicly because of the market competitiveness. It makes some difficulties in academic research. The data assumptions in this part are generally from two aspects: one way is from my thesis supervisor, a relevant expert, Behzad Kordnejad, who has cooperated with Coop retail for their logistics project, and another way is searching from related website, i.e. “Swedish Transport Administration”. In the end, the author compared the data assumption with the latest and related researches on cost model for pre- and post haulage road freight transport, to modify our assumptions.

3.5.2.2. Cost Model Building and Data input

After defining the delivering route, the input of distance could be used for cost modal. In this section, the cost modal is built only for feeder transport costs and terminal transshipment cost in Örebro with a certain type of vendor (1 tractor + 1 swap-body). Following the description of cost modal structure in chapter 2, we built the cost formulas for each cost item.

Total costs of feeder transport includes

**Capital cost + Maintenance cost + Fuel costs + Labour cost + overhead cost + Mode transshipment**

To make the formulas feasible, some assumptions of variables were made based on realistic. We try to take every cost component into account in this specific case.

1. Capital cost

   Capital cost integrates investment on vehicles and depreciation. Despite of vehicle price, depreciation refers to the loss in value of a vehicle which can be considered as the opportunity cost of vehicle ownership. The capital cost is a significant part of the vehicle operating cost.

   Assumptions of price and interest rate:
Investment per vehicle = 600,000 SEK
Investment per swap-body = 300,000 SEK
Annual interest rate I = 5%
Depreciation time t = 10 year

The calculation formula of the depreciation is:
Total depreciation cost per truck per year $DC = \frac{i}{(1+i)^t - 1} * \text{Investment per vehicle} * (1+i)^t$
(Bennet & Greenwood, 2003)

So, as we can find,

Daily Capital Cost: $CC_{km} = \frac{\text{Total depreciation and interest cost per truck per year}}{10 \text{ year} / 365 \text{ day/year}}$

2. Fuel cost

Fuel consumption is another necessary attribute of vehicle operation. Vehicle type acts an important character in this part. As we defined before, a tractor with one swap-body will be used in this case. Another factor is the price of fuel, which directly determines the fuel cost. The speed, however, as another essential factor, is always assumed 50 km/hour in this case. To simplify the case, some minor factors, such as geography, load factor and so on, had not taken into account. So according to the current situation, the following assumptions have been made:

Fuel price FP = 15.5 sek/l
Average Fuel consumption per km per truck F = 16.8 l/100km

Fuel cost per km per truck: $FC_{km} = \text{Average Fuel price} * \text{Average Fuel consumption per km per truck} = 15.5 \text{ sek/l} * 0.168 \text{ l/km} = 2.6 \text{ SEK/km}$

3. Maintenance cost

Maintenance cost is consisting of repair and service cost of tractors, dollies, tyres and swap-bodies. This part should include the mechanic parts consumption and labour cost. Normally, the company will do maintenance for trucks regularly. We assume:

Maintenance cost per hour $MC = 5.5 \text{ SEK / hour}$
Average Speed AS = 50 km/hour

Maintenance cost per km per truck: $MSC_{km} = \frac{\text{Maintenance costs per hour}}{\text{Average speed per truck}} = \frac{5.5 \text{ SEK / hour}}{50 \text{ km/hour}} = 0.11 \text{ SEK/km}$
4. Labour cost

Labour cost always comprises a big part from operational cost, especially in developed countries like Sweden. Considering we already put other labour costs into maintenance cost, the labour cost here is just driver payment. As a major cost, labour cost concerns the average driver salary and the working hours. Based on the salary standard in Sweden and previous speed limit, we made the following assumptions:

Average monthly wage per driver \( W = 20000 \) SEK
Working hours per day \( H = 6 \) hours/day
Average Speed = 50 km/hour
Working days per month = 22 days/month
The total km per truck driver per month \( D = 6 \) working hours * 50 km/h * 22 days/month = 6600 km

Labour cost per km: \( LC/km = \frac{\text{Average monthly wage per driver}}{\text{the total km per truck driver per month}} = \frac{20000 \text{ SEK}}{6600 \text{ km}} = 3.03 \text{ SEK/km} \)

5. Overhead Cost

Overhead Cost generally includes all taxes, insurances and administrative costs that as a part of fixed cost. Here are the assumptions:

All Taxes fee per year \( T = 21,000 \) SEK
Annual Administrative and Planning cost \( A = 96,000 \) SEK
Annual Insurance Cost \( I = 50,000 \) SEK
Total number of truck in overhead = 10 trucks

So, Overhead Cost per day: \( OV/km = \frac{(\text{All Taxes fee} + \text{Administrative and Planning cost} + \text{Insurance Cost})}{(365 \text{ days/year} \times \text{Total number of truck in overhead})} \)
= \( \frac{(21,000 \text{ SEK} + 96,000 \text{ SEK} + 50,000 \text{ SEK})}{365 \text{ days/year} \times 10 \text{ trucks}} = 45.75 \text{ SEK/day} \)

6. Mode transshipment

Strictly speaking, Mode Transshipment Cost is not the part of feeder transport cost. Considering the transshipment cost is one of the most important costs, to determine whether adopt intermodal transport in short distance, we still decided to take it into our feeder transport cost model.

As we know, there are possibilities for a CESS terminal in Örebro. So the terminal can handle loading and unloading with a cheap price by using CESS 1B technology. It is assumed that:
Cost per lift = 159 SEK
Number of lift per trip = 2

The mode transshipment cost $TC = \text{Cost per lift} \times \text{Number of lift per trip} = 159 \text{ SEK} \times 2 = 318 \text{ SEK/trip}$

So, here we can see, in this cost mode for feeder transport, the cost items can be defined as two groups, operational fixed costs and operational variable cost. Obviously, capital costs and overhead costs belong to fixed costs. This part of costs is fixed no matter how long the vehicle running per day. In comparison, variable costs contain fuel costs, maintenance costs and labour costs. The daily variable costs are distance-dependent and delivery demand-dependent costs. It has closed relationship with distance and transport demand. Then, we divide feeder transport in Örebro into two part.

The daily **fixed costs (FC):**
\[
FC = \text{Capital costs} + \text{Overhead costs} = 21.13 \text{ SEK/day} + 45.75 \text{ SEK/day} = 66.88 \text{ SEK/day}
\]

The **variable cost (VC) per km:**
\[
VC = \text{Fuel costs} + \text{Maintenance costs} + \text{Labour costs} = 2.6 \text{ SEK/km} + 0.11 \text{ SEK/km} + 3.03 \text{ SEK/km} = 5.74 \text{ SEK/km}
\]

Combined with transshipment cost, the cost model in Örebro can be formulated as below:

**Total cost per day** = \text{Fixed costs (FC) + Variable costs (VC) * Number of trips (N) * Distance per route (D)} + \text{Transshipment costs (TC) * Number of trips (N)}
\[
= 66.88 \text{ SEK} + 5.74 \text{ SEK/km} \times N \times D + 318 \text{ SEK/trip} \times N
\]

3.5.2.3. Cost Model Analysis

In order to gets a better view of the cost model above, the data for fruits & vegetables delivering in Örebro is introduced in this model. The delivering route 1 (0-1-2-3-4-5-0) is firstly chosen as a pilot that having transport distance 29.693 km and 1 trip per day. So, the daily cost items have been got as the following table.

<table>
<thead>
<tr>
<th>Capital cost</th>
<th>Fuel cost</th>
<th>Maintenance cost</th>
<th>Labour cost</th>
<th>Overhead Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.13</td>
<td>77.2</td>
<td>3.27</td>
<td>89.97</td>
<td>45.75</td>
</tr>
</tbody>
</table>

Then we put these cost items into a pie figure to get a general view. As we can see, in this case, the main costs in feeder transport are mainly from fuel cost and labour cost, which respectively comprise 33% and 38%. Because of the short-distance feeder
transport, the maintenance cost, related to usage of vehicle, only takes 1% in total.

**Operational cost items**

![Pie chart showing Operational cost items]

Figure 12 Operational cost items share

Moreover, classifying the cost items into fixed costs and variable costs, the following pie map could be got. As we mentioned before, fixed costs include overhead cost and capital cost, and variable costs contain fuel cost, maintenance cost and labour cost. In Örebro feeder transport, variable costs dominate the big part in total cost that comprise 72% in total, and fixed costs only take 28% in comparison. Because daily fixed costs stay stable, when the delivery distance and running time are being increased, the variable costs will take much more percentage of total cost.

![Pie chart showing Fixed Costs and Variable Costs]

Figure 13 The cost share between fixed costs and variable costs

From the cost mode we got above, there are two direct variables in this mode, distance of delivering route and number of trips. Basically speaking, these two variables are quite independent. The distance per route is decided by route planning,
as discussed thoroughly in previous sections. The number of trips is limited by transport demand, because:

The number of trips \( N = \text{Demand of transport} / \text{Capacity constrain of Vehicle (36 EU-pallet)} \)

In conclusion, in this case, if one of these two variables remains constant, another variable will have liner relationship with feeder transport cost.

In this case, when Coop delivering fruits & vegetables in Örebro on Saturday, total transport demand in each route does not exceed capacity limitation of our truck type (1 swap-body). So the number of trips for each route is \( N=1 \). The following formula shows the liner relationship between distance of route and feeder transport cost:

Liner formula for distance-costs: \( C = 384.88 + 5.74 \times D \), when \( N = 1 \).

Figure 14 The liner relationship between costs and transport distance

On the other hands, in this case, the distance of each route is also kept stable in Örebro. When transport demand changed, the number of trips will make a liner relationship with feeder transport costs as well. The following formula shows the relationship between number of trips and feeder transport costs in route 1 (0-1-2-3-4-5-0).

Linear formula for Number of trips-cost: \( C = 66.88 + (170.44 + 318) \times N = 66.88 + 488.44 \times N \)

However, because the number of trips (N) should always be integer, in fact, the cost model line corresponding change of number of trips should be a stepping figure. The cost for each trip keeps constant.
3.5.3 Further Study and Discussion of Route planning and Cost Model

3.5.3.1. A more realistic cost model and Significance of variables

In this part, the discussion will expand to a deeper and more realistic situation. Normally, the route planning and cost items in cost model will be taken into account as a combined strategy, to optimize the total cost of feeder transport.

Theoretically, as the discussion in previous, the two variables existing in cost model of feeder transport should be independent. However, in real case, the situation is not always like that. The distance of each trip will be, somehow, a little bit different. For example, we always assign goods in average for each trip. But, in the last trip, the vehicle could finish delivery in the last second or third delivering node. The average distance of route will be shorter. Furthermore, the traffic condition of each trip is also different. In practice, the driver would like to choose another longer route to avoid traffic-jam. In this situation, the average distance per trip could be longer. So, as we can see, there will be several stochastic components affecting the running distance per trip. When the number of trips increased, the average distance per trip will be much different with the distance we measured in route planning.

Considering these two variables are not so independent with each other, an ajustive value is introduced into cost model. Because the changes happen randomly and accidentally, an ajustive value has been randomly chosen in a small range.
For example, still in the case of Örebro on Saturday, based on the previous delivering data and experience, the adjusitive value for route 1 is set with (-3,+3). So, except only one trip situation whose distance is 29.693 km, as we calculated from Tabu method, other average distance per trip should randomly choose a value in the range of (26.693, 32.693).

Following the Cost Model: \( C = 66.88 \text{ SEK} + 5.74 \text{ SEK/km} \times N \times D + 318 \text{ SEK/trip} \times N \)

Here we got a table of number of trips (N), distance per trip (D), and total cost (C).

<table>
<thead>
<tr>
<th>N</th>
<th>D</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.693</td>
<td>555.318</td>
</tr>
<tr>
<td>2</td>
<td>27.563</td>
<td>1019.303</td>
</tr>
<tr>
<td>3</td>
<td>28.134</td>
<td>1505.347</td>
</tr>
<tr>
<td>4</td>
<td>30.129</td>
<td>2030.642</td>
</tr>
<tr>
<td>5</td>
<td>30.264</td>
<td>2525.457</td>
</tr>
<tr>
<td>6</td>
<td>26.987</td>
<td>2904.312</td>
</tr>
<tr>
<td>7</td>
<td>31.546</td>
<td>3560.398</td>
</tr>
<tr>
<td>8</td>
<td>28.944</td>
<td>3939.988</td>
</tr>
</tbody>
</table>

The data above seems as a more realistic case for cost model. The following question is which of the variables has a greater impact on cost model?

In order to test the sensibilities of these two variables, a regression analysis is introduced to test relationship of the variables above. The regression analysis will estimate a function of the independent variables called the regression function. In our case, the number of trips and transport demand is input in cost mode as X value, and the total cost output from cost model can be seemed as Y value. Then, a summary output of regression is taken from Excel as below.

Table 11 The regression analysis among the number of trips, distance and the total transport cost

<table>
<thead>
<tr>
<th></th>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-812.618</td>
<td>138.0498</td>
<td>-5.89</td>
<td>0.002</td>
</tr>
<tr>
<td>N</td>
<td>485.059</td>
<td>3.013857</td>
<td>160.94</td>
<td>1.76E-10</td>
</tr>
<tr>
<td>D</td>
<td>30.351</td>
<td>4.807507</td>
<td>6.31</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

In regression analysis, the value of R Square indicates how a regression line fits a set of data. The R square should be between 0 and 1. An R square near 1 proves that a regression line match the data well. The value of t stat and P-value stand for the sensibility of variables. The higher t stat value means the more significant that the variable is. If the P-value is closer to 0, this variable plays a more important role in
the model.

For this regression analysis, The R Square of this formula is 0.9997, which prove the total cost is only related to these two variables. As we can see, the t-stat of N is 160.94, and P-value of N is 1.76 E-10. In comparison, the t-stat and P-value of D are respectively 6.31 and 0.0015. So the conclusion is that the number of trips is a more significant variable than the distance per route. This conclusion is also proved by the previous study.

3.5.3.2. Flexible route planning strategy combined with transport demand

Because the cost model only depends on distance of transport route and the number of trips, the way to minimize the total cost of feeder transport is to shorter distance of transport route and decrease the number of trips. Furthermore, as the previous analysis, the number of trips is a more significant variable than the distance of route, so cutting the number of trips enjoys the priority in our distribution strategy.

The way of optimizing distance of transport route is fully described in previous section. Nevertheless, the most optimized route planning does not always reach the most minimized total feeder transport cost. Let us take a real case as an example.

Still the delivering of fruits & vegetables in Örebro, the following table shows the demand of fruits & vegetables for each shop in Örebro on Thursday:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>9</td>
<td>9</td>
<td>14</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

If we still use the optimized route planning as before, for the route 1, the total delivering demand is: 9 + 9 + 14 + 3 + 3 = 38 EU-pallet, which is 2 EU-pallets more than truck’s capacity (36 EU-pallet). That means Coop needs to assign at least 2 trips for route 1. However, in the route 2, 1 truck with 1 trip can handle the transport demand.

Implementing original route planning, where
Route 1 (0-1-2-3-4-5-0), with distance 29.693 km
Route 2 (0-6-7-0), with distance 21.107 km

So, the total feeder transport cost in Örebro on Thursday is:
\[
\begin{align*}
C &= 66.88 \text{ SEK} + 5.74 \frac{\text{SEK}}{\text{km}} \times N \times D + 318 \frac{\text{SEK}}{\text{trip}} \times N \\
&= 66.88 + 5.74 \times 2 \times 29.693 + 318 \times 2 + 66.88 + 5.74 \times 1 \times 21.107 + 318 \times 1 \\
&= 1549.79 \text{ SEK}
\end{align*}
\]

As we can see above, following the existing optimized route planning, when the transport a little higher than capacity constraints, the total cost output from cost
model will be much increased because of adding extra trip. So a better way is to rearrange the delivering routes. The principle of Tabu research is to test nearest node in network, so we switch the nearest shop 5 to the route 2. Another alternative route planning has been handed out like:

Route 1: Contain delivery nodes 1, 2, 3, 4.
Route 2: Contain delivery nodes 5, 6, 7

From Tabu Java program, the best solution for route 1 is 0-1-2-3-4-0, with total distance 26.028 km, and for route 2 is 0-6-7-5-0, with total distance 26.059 km. The new route planning should be described as the following table.

Table 13 New route planning for the transport demand change

<table>
<thead>
<tr>
<th>Route</th>
<th>Distance (/km)</th>
<th>Load (/EU-pallet)</th>
<th>Load rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1-2-3-4-0</td>
<td>26.028</td>
<td>35</td>
<td>97.22</td>
</tr>
<tr>
<td>0-6-7-5-0</td>
<td>26.059</td>
<td>12</td>
<td>33.33</td>
</tr>
<tr>
<td>Total</td>
<td>52.087</td>
<td>47</td>
<td>-</td>
</tr>
</tbody>
</table>

So, the new total feeder transport cost in Örebro on Thursday is:

\[
C = 66.88 \text{ SEK} + 5.74 \text{ SEK/km} \times N \times D + 318 \text{ SEK/trip} \times N = 66.88 + 5.74 \times 1 \times 26.028 + 318 \times 1 + 66.88 + 5.74 \times 1 \times 26.059 + 318 \times 1 = 1069.05 \text{ SEK}
\]

Sometimes, the manager from shipper might think that the load rate of route 1 is so high that do some risk in distribution. The idea load rate is between 80% and 20% from both risk management and economic consideration. So, in another plan, we could also move next nearest shop from route 1 to route 2.

This case proves that a cut of total cost can be achieved by rearranging route planning, when the transport demand of any route exceeding a little of capacity constraints. A flexible route planning could be considered as a feasible solution, combined with transport demand, in regional distribution.
4. Conclusion

In the study, a brief description of intermodal transport firstly comes out to give a general overview. It can be realized that intermodal transport is also capable for regional deliveries. Then, the author provides a strategic analysis way to measure whether implementing the intermodal transport for short-distance transport is an economic viable solution. According to the analysis in this thesis, it can be found that feeder transport is an important part of the total regional intermodal transport. A good route planning as an input of distance, achieved by Tabu method, can efficiently cut the total costs and risks. Based on that, the shipper and distributor can make a simple cost mode to estimate the general feeder transport cost. In this thesis, a realistic cost mode has been built in order to fulfill the feeder transport of the retail company Coop in Örebro. Through test this cost mode, the author found the most two important variables in cost mode, the distance per route and the number of delivering trips. As a result of regression analysis, the number of trips obviously dominates the total costs of feeder transport. Because the number of trips is determined by transport demand, the cost mode that we built proves that transport demand is the most significant element deciding the total regional feeder transport costs. So, it can even extend the conclusion that transport demand determines the total costs in urban distribution and city logistics. This result reminds the companies that are related to urban distribution to pay more attention on the demand forecast and city logistics management.

Furthermore, with the purpose of fulfilling the fluctuation of demand with limited transport capacity, the discussion in this thesis expands to some feeder transport strategies and management, like:
1. Updating the route planning method and using a flexible route planning integrated with demand planning.
2. Using real time transport management.
3. Combining Demand forecast with Inventory management

As changing demands in today’s industry require more transport and reliable deliveries, the transport industry is looking at alternative ways to satisfy the customer demand. This thesis try to remind us that regional intermodal transport can be always an economical and sustainable alternative for matching companies’ requirements and constraints. Besides, it also provides a feasible way to evaluate the feeder transport in intermodal transport from economic aspect. The methods of route planning and cost mode in the case study can be also adopted in other similar cases of feeder transport.
5 Continue Work and Future Research

5.1. Updated Method and Programming, Real-time management

Even though practical regional distributions case from Coop supports the feasibility of our logistics methods and strategies, it is not enough for a more complicated case. More and more constraints and components could probably be taken into account in a future realistic case, such as time constraints or the limited number of trucks. The complexity of the network could also be increased by growing number of delivering nodes and setting multiple depots in one region. That needs not only updating the mathematic method for new situation, but also asking for professional regional distribution software.

Moreover, the method discussed in this thesis is more practically used for strategic measurement rather than daily transport planning. There are always some accidental elements out of expectation during delivery procedures, e.g. new customer orders, change in demand, traffic conditions, vehicle status, accidents etc. This kind of dynamic VRP is said to be a real-time vehicle routing problem. (Leyva, 2011) To solve this kind of VRP, the decision maker requires a real-time management system, handling updated information. Normally, it should be a standard regulation to deal with accidental elements. A stable real-time communication channel is established between drivers and control center. Even, sometimes, there is not existing rule for the situation, there should be a person, either a manager or a driver, to make an experience based route planning.

5.2. Combined Time schedule and management

On the other hands, when deciding to choose intermodal transport in regional supply chain, the company should arrange a reasonable time schedule to avoid too much waiting time and delay in each step. A bad time schedule will lead to high opportunity costs. Instead, a good time schedule not only cut the total costs but also reduces the system risk. The author makes an example for fruits and vegetables delivery to Örebro in the way of intermodal transport.
As an integrated transport system, containing at least two transport modes, intermodal transport should be managed under a systematic consideration and evaluation. When making the strategy for one transport mode, decision makers need to take the risks, constrains, limitation, economy from other transport modes into account. The final result should achieve a system optimization with good economy, stability and sustainability.

5.3. Combining Demand forecast with Inventory management

From a supply chain management level, the company may consider the transport chain as a part of its business strategy. It is necessary to make a trade-off between transport costs and other related costs. Moreover, the risk management could be taken into account as well.

The first step in business strategy, the author suggests, is that adopting a demand forecast for both regional level and the whole, especially for retail industry. The demand planning could also be a short-term or seasonal strategy as well as a long-term forecast. To fulfill the fluctuation of demand with limited transport ability, the way of increasing the transport capacity is that adding more vehicles and transport equipments and increasing the frequency of deliveries. No matter which solutions we used for increasing transport ability, the costs of both management and new procurement will be much higher than before. If the change of demand is a kind of temporary situation, a better way is to use transport management combined with inventory strategy.

For example, the Coop retail company faces demand increasing for some certain type

<table>
<thead>
<tr>
<th>Time (04:30)</th>
<th>Location</th>
<th>Transport Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enkoping</td>
<td>Loading</td>
<td>Coop Retail</td>
</tr>
<tr>
<td>Sdgsrs</td>
<td>Unloading</td>
<td></td>
</tr>
<tr>
<td>Orebro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malmo</td>
<td>Loading</td>
<td></td>
</tr>
<tr>
<td>Sdgsrs</td>
<td>Unloading</td>
<td></td>
</tr>
<tr>
<td>Orebro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stockholm</td>
<td>Loading</td>
<td></td>
</tr>
<tr>
<td>Sdgsrs</td>
<td>Unloading</td>
<td></td>
</tr>
<tr>
<td>Vasteras</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sdgsrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orebro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stoping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeder transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transshipment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 16 An example of time schedule arrangement for the whole regional intermodal transport chain
of products during Christmas period every year. The customers would rush to buy some products in one or two weeks before Christmas. As we estimated, the demand of one product could be forecasted as the following figure:

![The fluctuation of estimated demand during Christmas period](image)

**Figure 17** The fluctuation of estimated demand during Christmas period

As we found, the demand will be pushed to the highest point until 24\textsuperscript{th} of December. The largest demand of this type of product could be more than double of the normal demand.

The normal transport demand of this type of products is around 60 per day. The maximum transport ability is 100 per day. To handle the drastic demand increase of this product, the Coop Company could order more of this type of product one or two months in advance, because that increasing is predictable. The shipper can use idle transport space for this extra order during this one or two month, without too much extra investment. The transport and delivery strategy can be shown as below.
Figure 18 Possible transport strategy from demand forecast

The increasing part of goods will be stored in local warehouses or centralized warehouses. A “smart” shop owner will spread out their demand before demand peaks. Comparing the increasing costs of combined strategy with possible extra costs from pure transport solution, it can be found that the combined strategy is a more optimized solution in most cases.

Moreover, if the inventory strategy and management integrated with regional intermodal transport chain, some intermodal terminals could be built near warehouses or distribution centers as big picking or distribution centers to light the safety stock, for high capital cost in urban area, in each shop and build a quick response transport system. This is also an efficient way to reduce the risk from fluctuation of demand. Because this method asks for high investment in or near urban area, it should go through comprehensive evaluation. As a similar example from Coop, they have already built their intermodal terminal in Bro, with high investment cost and low utilization as a result.

However, it is not quite functional for fresh foods or fruits. In this situation, a quick response from transport chain and a flexible transport management are still the most functional way.
References:


Goodson, J. C. (2010). *SOLUTION METHODOLOGIES FOR VEHICLE ROUTING PROBLEMS WITH STOCHASTIC DEMAND.*


Hossain, K. S. (2009). *Cost Modal for Pre- and Post Haulage Road Freight Transport to and from the Intermodal Terminal.* KTH.

Kim, K. H. (December 9, 2005). *Intermodal Transportation.*


Highway Improvements in Relation to Freight Transportation: Microeconomic Framework.


Appendices:

Appendix-1: The Overview of Coop shops and rail terminals in Mälardalen area from Arc GIS
Appendix-2: Java code for Tabu method, adopted for feeder transport in Örebro

Tabu Search

```java
public class TabuSearch {
    public static int[] getBestNeighbour(TabuList tabuList,
                                         TSPEnvironment tspEnviromnet,
                                         int[] initSolution) {
        int[] bestSol = new int[initSolution.length];  //this is the best Solution So Far
        System.arraycopy(initSolution, 0, bestSol, 0, bestSol.length);
        double bestCost = tspEnviromnet.getObjectiveFunctionValue(initSolution);
        int city1 = 0;
        int city2 = 0;
        boolean firstNeighbor = true;
        for (int i = 1; i < bestSol.length - 1; i++) {
            for (int j = 2; j < bestSol.length - 1; j++) {
                if (i == j) {
                    continue;
                }
                int[] newBestSol = new int[bestSol.length];  //this is the best Solution So Far
                System.arraycopy(bestSol, 0, newBestSol, 0, newBestSol.length);
                newBestSol = swapOperator(i, j, initSolution);  //Try swapping cities i and j
                // , maybe we get a bettersolution
                double newBestCost = tspEnviromnet.getObjectiveFunctionValue(newBestSol);
                if ((newBestCost > bestCost || firstNeighbor) &&
                    tabuList.tabuList[i][j] == 0) {  //if better move found, store it
                    firstNeighbor = false;
                    city1 = i;
                    city2 = j;
                    System.arraycopy(newBestSol, 0, bestSol, 0, newBestSol.length);
                    bestCost = newBestCost;
                }
            }
        }
        if (city1 != 0) {
```
tabuList.decrementTabu();
    tabuList.tabuMove(city1, city2);

    return bestSol;
}

//swaps two cities
public static int[] swapOperator(int city1, int city2, int[] solution) {
    int temp = solution[city1];
    solution[city1] = solution[city2];
    solution[city2] = temp;
    return solution;
}

public static void main(String[] args) {
    TSPEnvironment tspEnvironment = new TSPEnvironment();

    tspEnvironment.distances = //Distance matrix, 5x5, used to represent
distances
    new double[][]{{0, 7.255, 0.996, 2.309, 6.102, 2.476},
                   {7.255, 0, 6.876, 8.235, 12.01, 8.406},
                   {0.996, 6.876, 0, 1.928, 5.81, 2.157},
                   {2.309, 8.235, 1.928, 0, 3.867, 3.424},
                   {6.102, 12.01, 5.81, 3.867, 0, 7.291},
                   {2.476, 8.406, 2.157, 3.424, 7.291, 0}};

    //Between cities. 0,1 represents distance between cities 0 and 1, and
so on.

    int[] currSolution = new int[]{0, 1, 2, 3, 4, 5, 0};  //initial solution
    //city numbers start from 0
    //the first and last cities' positions do not change

    int numberOfIterations = 100;
    int tabuLength = 10;
    TabuList tabuList = new TabuList(tabuLength);

    int[] bestSol = new int[currSolution.length];  //this is the best Solution
    System.arraycopy(currSolution, 0, bestSol, 0, bestSol.length);
    double bestCost = tspEnvironment.getObjectiveFunctionValue(bestSol);
    for (int i = 0; i < numberOfIterations; i++) {  //perform iterations here
        currSolution = TabuSearch.getBestNeighbour(tabuList,
          tspEnvironment, currSolution);
        double currCost =
          tspEnvironment.getObjectiveFunctionValue(currSolution);
//System.out.println("Current best cost = " + tspEnvironment.getObjectiveFunctionValue(currSolution));
if (currCost < bestCost) {
    System.arraycopy(currSolution, 0, bestSol, 0, bestSol.length);
    bestCost = currCost;
}
System.out.println("Search done! \nBest Solution cost found = " + bestCost + "\nBest Solution:");

printSolution(bestSol);
}
public static void printSolution(int[] solution) {
    for (int i = 0; i < solution.length; i++) {
        System.out.print(solution[i] + " ");
    }
    System.out.println();
}

Tabu environment

public class TSPEnvironment {
    //Tabu Search Environment
    public double [][] distances;
    public TSPEnvironment(){
    }

    public double getObjectiveFunctionValue(int[] solution){
        //returns the path cost
        //the first and the last cities'
        // positions do not change.
        // example solution : {0, 1, 3, 4, 2, 0}

        double cost = 0;
        for (int i = 0 ; i < solution.length-1; i++){
            cost+= distances[solution[i]][solution[i+1]];
        }
        return cost;
    }
}
Tabu list

public class TabuList {

    int[][] tabuList;
    public TabuList(int numCities){
        tabuList = new int[numCities][numCities]; //city 0 is not used here, but left for simplicity
    }

    public void tabuMove(int city1, int city2){ //tabu the swap operation
        tabuList[city1][city2] += 5;
        tabuList[city2][city1] += 5;
    }

    public void decrementTabu(){
        for(int i = 0; i<tabuList.length; i++){
            for(int j = 0; j<tabuList.length; j++){
                tabuList[i][j] = tabuList[i][j]<=0?0:1;
            }
        }
    }
}

## Appendix-3: Cost model of feeder transport presented in Excel

<table>
<thead>
<tr>
<th>Variable Cost</th>
<th>sek-km</th>
<th>Total distance</th>
<th>number of trips</th>
<th>total road cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>0.11</td>
<td>29.693</td>
<td>1</td>
<td>3.26623</td>
</tr>
<tr>
<td>Fuel</td>
<td>2.6</td>
<td>21.107</td>
<td>1</td>
<td>77.2018</td>
</tr>
<tr>
<td>Labour</td>
<td>3.03</td>
<td></td>
<td></td>
<td>89.96979</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.74</td>
<td></td>
<td></td>
<td><strong>170.43782</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed Costs</th>
<th>sek-day</th>
<th>Daily road cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead</td>
<td>45.8</td>
<td><strong>237.31982</strong></td>
</tr>
<tr>
<td>Capital</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>66.9</td>
<td></td>
</tr>
</tbody>
</table>