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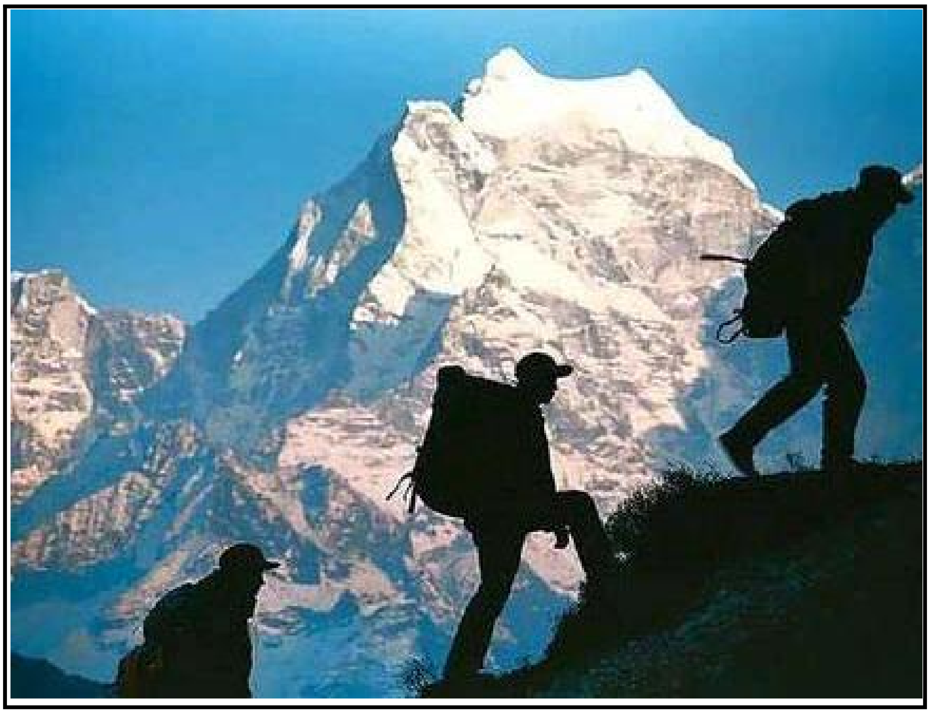
Backhauling; the Optimal Road to Everest



A study on the Optimisation Opportunities for the Unilever European Routing Network

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Backhauling; the Optimal Road to Everest

A study on the Optimisation Opportunities for the Unilever European Routing Network

Master's thesis of S.P.J.W. Verhoeven

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Management Summary

This research contributes to the Everest team of the European Logistics Deliver department, belonging to the Unilever Supply Chain Company. The main objective of this research is to identify opportunities to optimise the European cross-border routing network. A savings application, specifically developed for Unilever's routing network, demonstrates that more than *XXX Euro savings (*i.e. XXX of total costs) on a yearly basis could be realised with backhauling on a small routing network. Moreover, a *reduction of XXX on kilometres driven* could be established, contributing to Unilever's carbon footprint reduction. Since these savings concern a small network, it is relevant to investigate the savings potential of the entire European routing network.

Transparency of product movements and a good understanding of relevant *network constraints* are two fundamental points of attention when optimising a routing network. Currently, transparency is lacking and responsibilities are fragmented, which makes that Unilever cannot take advantage of its large scale. Where the Everest team aims to create full transparency and centralisisation of Unilever's transport management across Europe, this research looks one step ahead and focuses on optimisation opportunities for a fully transparent network. In this network, *location constraints* concern the specific requirements of the supply and delivery locations. *Freight constraints* concern the characteristics of the products to be transported. For a routing problem, the importance of various constraints highly depends on the level of decision making. Since this research is focused on the optimisation of the routing network on *tactical level*, we consider the following constraints: the lane price, temperature control requirements, the transit time, the distance, and the frequency of a lane on a yearly basis.

Consolidation and backhauling are two major tactical routing optimisation strategies. Where *consolidation* aims at using truck capacity at full potential through consolidating less than truckload lanes (LTL), *backhauling* is focused on minimising empty driven kilometres in a network of full truckload lanes (FTL). The developed savings application focuses on backhauling. The tool generates proposals for beneficial backhaul loops in specified FTL routing networks. With key performance indicators, such as costs- and kilometre savings, we validate the solutions from different perspectives. Moreover, the model also provides insight into the impact of constraints and environmental factors. For example, the import-export balance of a region highly influences the benefits of creating backhaul loops. Once feasible backhaul loops are appointed, in-depth consultation with the involved locations on operational level is required to succesfully merge backhaul loops into the day to day routing schedules.

For further research, we recommend to investigate the savings opportunities of consolidation and of transport with other modalities than road. Also, hub networks and real-time scheduling are two areas of research that potentially lead to further savings on the routing network.

Preface

When Unilever offered me the opportunity to graduate on a pan-European logistics project, I realised it would be by far the most challenging subject to write my thesis on. Excitement was in place from start to end, due to both the assignment I was working on and also the Switzerland experience as itself. I would like to thank Simon Smith and Richard Tyler for offering me this chance of graduating at the Unilever Supply Chain Company.

It has been a six-months learning experience, in which being part of the Everest team enabled me to understand the relevance of my assignment during writing my academic thesis. Translating the problems the team dealt with into general scientific problems was not always easy. However, participating in discussions, meetings, and workshops has led to a master's thesis that is strongly linked to the real situation. I would like to express my appreciation towards Tilmann Spohn, who guided me in Switzerland successfully through the process and supported me also to join as much activities as possible. Besides Tilmann, I would like to emphasise that Alistair Taylor and Baer Adriaens have had valuable contributions to my understanding of the transport world and the context of my assignment.

Besides that the USCC was a perfect place to write this thesis, also my two supervisors from University, Marco Schutten and Leo van der Wegen, have had a great contribution. Structuring my thoughts, suggesting other parts of the literature, and keeping me focused on the academic level were the main areas in which I found their guidance very useful.

Personally, these six months in Switzerland have been a value added experience in my life. The various activities with USCC colleagues and also the visits of friends and family made Switzerland a home away from home. This clearly contributed to a better performance on my professional work. I would like to end this preface with expressing my appreciation towards Joost, whose motivating conversations and refreshing views helped me during the process.

Enjoy reading!

Simone Verhoeven
Amsterdam, May 2008

Table of Contents

1. Introduction

Freight transportation is one of today's most important activities, with the increasing influence that transportation and distribution of goods have on the performance of all other economic sectors [Crainic, Laporte, 1997]. The Fast Moving Consumer Goods sector (FMCG) radiates a growing awareness on the impact of transportation costs on the total spend of companies. Freight prices increase due to several factors, such as decreasing truck availability, increasing fuel prices, and strict driver regulations. Moreover, mondial attention to global warming forces companies to think about their carbon footprint. These factors make that there is an increasing interest in investigating the opportunities to optimise routing networks. Also Unilever decided to focus on its actual spend on transport throughout Europe. As the opportunities within this business are substantial, there is a huge challenge to find the most suitable optimisation strategy. To be able to appoint the right strategy, an in-depth study of today's network is required. This thesis aims at gaining insight in the relevant characteristics of Unilever's transportation network and providing a model for improvements.

This chapter describes the background and the focus areas of this research. First, Section 1.1 describes the context of this thesis. Continuing, Sections 1.2 and 1.3 elaborate on the research field and clarify the project goal and research questions. Section 1.4 discusses the stakeholders involved, and Section 1.5 concludes this chapter explaining the applied research methodology.

1.1 Context

Unilever is a multinational company in the FMCG sector with its origin in both the Netherlands and the United Kingdom. As the soap company Lever Brothers in the UK and the margarine company Van den Bergh in the Netherlands both used the same raw materials and cooperation would benefit both, they decided in 1930 to merge. Unilever was born. Unilever's mission is to add vitality to daily life: A healthier way of living through using vital and healthy products.

Unilever has production facilities in about 100 countries and employs about 180,000 people. The company has 400 main brands, of which some are internationally known and others are only locally exploited. The brands are assigned to 9 categories: Home Care (e.g., Omo, Sunsilk), Personal Care (e.g., Dove, Axe), Dressings, Savoury (e.g., Knorr), Spreads & Cooking, Tea (e.g., Lipton), Other Foods (e.g., Calvé), Ice cream (e.g., Ola), and Frozen Foods. These categories are grouped into three main business groups: Foods, Ice Cream and Frozen Foods (ICF), and Home and Personal Care (HPC).

1.1.1 Unilever Supply Chain Company

In 2005, the Unilever Supply Chain Company (USCC) was established in Neuhausen, Switzerland. This company within Unilever controls the European supply chain and has decision taking authority. The USCC aims to create 'one Unilever' through identifying synergies and cooperation in the supply chain, aiming at generating costs savings. Within Unilever, the supply chain is divided in three main working streams:

- Source (± 60% spend); buying ingredients that sourcing units (i.e. factories) use for manufacturing,
- Make (± 30% spend); manufacturing of end products in sourcing units,
- Deliver (± 10% spend); get the ingredients and products at the right places.

The USCC employs approximately 150 people, of whom 70 are European buyers of raw and pack materials (Source), 60 employees work on the planning and manufacturing side (Make) and approximately 20 employees are working on logistical optimisation projects (Deliver). One of those is project Everest. Everest focuses on transport. Since this research is related to this project, the next section elaborates on the objectives and rationale of Everest.

1.1.2 Project Everest

Project Everest aims to deliver a complete restructuring of European cross-border transport operations for buying, planning, and execution. *European cross-border transport* contains each and every transportation lane that goes from one country to another within Europe. Everest will change the way of managing transportation, improving customer service, and profiting from economies of scale on a European basis. The objective of this project is to create savings on transport costs in Europe and deliver a higher service level to the stakeholders.

The rationale of the project is threefold:

- There are a lot of inefficiencies and a lack of transparency in Unilever's European transport, due to independently working country organisations and business groups.
- Stock-out problems exist in multiple regions, due to unreliable transport providers and poor collaboration between different sourcing units and distribution centres within the regions.
- Transport providers take a substantial margin on managing transport for Unilever.

Having these observations verified, intensive research on the European routing network is justified. An in-depth understanding of the transport market, the constraints regarding the supplier and delivery locations and the products that are transported, is required. In the past, several suggestions for optimisations have been proposed, but were immediately rejected, since several constraints could not be met. Clarity on these constraints and their impact on efficiencies is a topic that requires fundamental research.

1.2 Project Description

As described in Section 1.1.2, there is a desire within the Everest team to create a better understanding on how the current routing network looks like, what optimisation options could be applied, and what the impact of logistical constraints is on the savings potential of the network.

Therefore, the goal of this master thesis is:

To provide a better understanding of Unilever's European cross border routing network and relevant opportunities to optimise this network, in order to realise cost savings.

1.3 Research Questions

To reach the goal, it is necessary to formulate research questions that address concrete research areas. The main research question of this thesis is:

How is the European cross-border routing network of Unilever organised and what are applicable and beneficial options to optimise this network?

In the remainder of this thesis, we refer to the 'European cross-border routing network' with the shorter term: 'routing network'.

This main research question is divided in the following sub research questions (RQ.):

RQ.1: How is the routing network currently organised and what is the desired situation?
RQ.2: Which constraints need to be considered when optimising the routing network?
RQ.3: Which methods does the literature suggest to optimise a routing network?
RQ.4: How could a model calculate the savings that are generated by the optimisation options?
RQ.5: How do constraints have an impact on savings and how could this impact be measured?
RQ.6: What are concrete proposals for efficiency improvements in the routing network?

Throughout this report, we touch upon the sub research questions and aim at finding an answer to the overal research question. Section 1.5 discusses how the report is structured and where the different sub research questions are discussed.

1.4 Stakeholders

Stakeholders are people and organisations that have a direct interest in or are affected by a project. This section discusses the stakeholders that will notice consequences in their ways of working, due to routing network optimisations within Unilever.

Sourcing Unit (SU)

Unilever has 77 European sourcing units (SU), which are factories that produce in total approximately 50,000 SKUs divided over approximately 1,000 brands. For optimising the routing network, flexibility and cooperation from the sourcing units are required.

Marketing and Sales Organisation (MSO)

Within Unilever, every country or country group (e.g., Benelux) has its own marketing and sales organisation (MSO). This organisation is responsible for the marketing of national products and representation of European brands into the local market. Besides, the sales departments of the MSOs is in contact with the end customers (e.g., supermarkets, canteens, restaurants) and determines demand for products for the entire country, which they communicate to the SUs. The MSOs are responsible for transport from the distribution centres (DCs) to the customers. For the Ice Cream and Frozen Foods business group (ICF), the MSO also manages transport between the SUs to the DCs.

European Supply Management (ESM)

ESM is the buying department of Unilever and is part of the USCC. The department buys raw and packaging materials from suppliers for all SUs in Europe. Supply managers have in-depth knowledge of agreements amongst suppliers and SUs. The department is concerned with inbound transport from suppliers to SUs.

Unilever Transport Planning Office (UTPO)

This organisation, based in Poland, is a fourth party logistics provider (4PL) within Unilever, established to manage transport in Central Eastern Europe (CEE) countries. Where Project Everest aims at establishing a 4PL for the entire European routing network, this is already in place for this region.

Transport Service Providers (TSP)

Transport service providers are companies that either provide or manage transport. On the one hand, there are traditional companies with trucks. On the other hand, there are ‘non-asset-TSPs’, i.e. freight forwarders, which subcontract asset-TSPs to arrange transport. The prices they ask for transport depend, e.g., on the flexibility of the supply and delivery location, the order lead times, and the payment terms.

1.5 Thesis Outline

Figure 1.1 gives an overview of the methodology that we use in this report. Starting from the bottom of the figure, Chapter 2 elaborates on the current situation of the routing network and gives an impression on the scale. Also, Chapter 2 touches upon the environment of the transportation market nowadays. Chapter 3 steps into detail in the relevant constraints of the network. Interviews with various Unilever transportation managers and TSPs provide relevant insights. Appendices B-K of this report provide background information of the interviews. In Chapter 4, the literature provides the academic angle on optimising routing networks. We review theories and appoint appropriate optimisation strategies. Chapter 5 demonstrates a savings application in Excel, developed specifically to optimise the routing network of Unilever. This model generates savings proposals and validates them with relevant key performance indicators. Moreover, it measures the impact of constraints and environmental factors on these savings. Chapter 6 presents three concrete optimisation proposals for specified networks in Europe. Chapter 7 draws conclusions particularly concerning the, with a suitable optimisation strategy generated, cost savings and carbon footprint reductions. Concluding, Chapter 8 puts recommendations for further research.

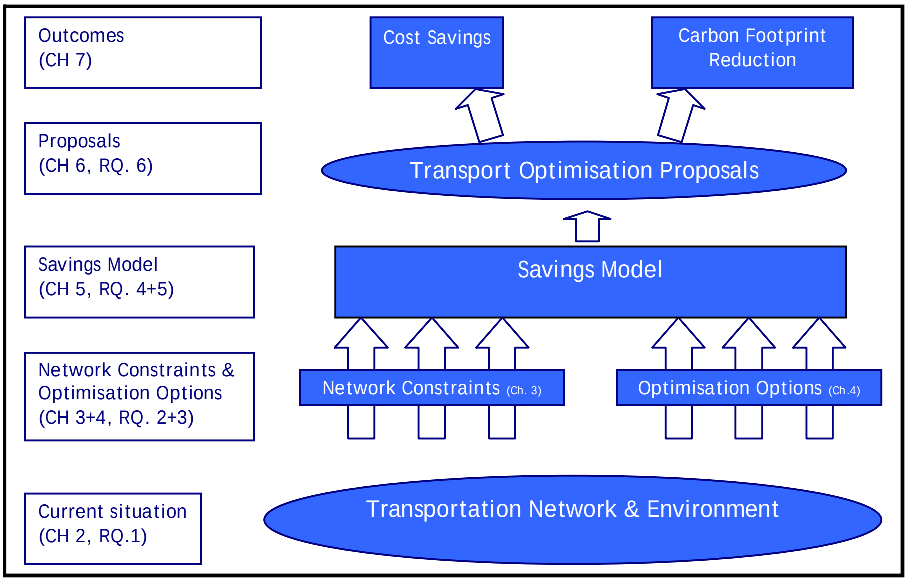

Figure 1.1 Methodology of the research

2. Unilever European Routing network

To consider the current situation of the Unilever routing network, it is relevant to look at both the internal and the external environment. First, Sections 2.1 and 2.2 focus on the internal part, describing the scope of this research, providing insight in the layout of the routing network. Section 2.3 discusses the external environment in which Unilever acts and how major developments affect the network. Concluding, Section 2.4 elaborates on the gap between the current and desired routing network.

2.1 Research Scope

The routing network that is the subject of this research, is a complex network that involves over 9,000 transportation movements per year. Figure 2.1 provides an overview of the supply chain and the transportation steps within this supply chain.

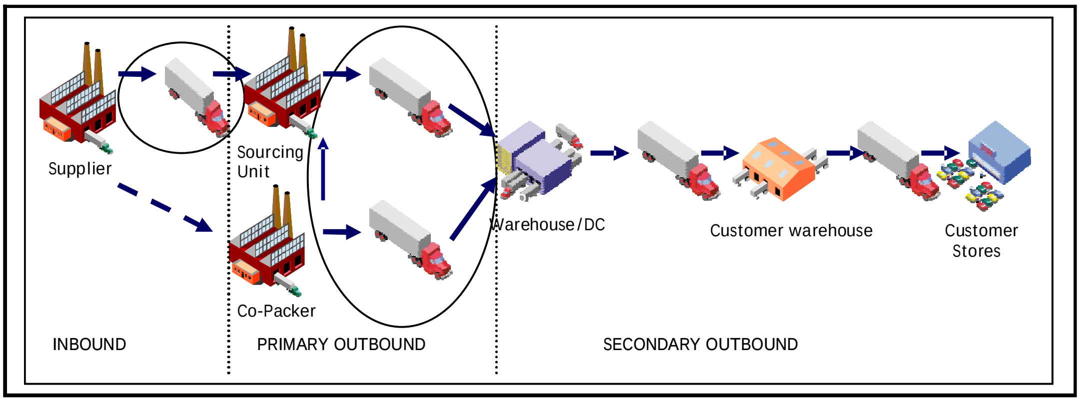

Figure 2.1 Supply Chain

Focusing on transport in the supply chain, the first step is inbound transport, which concerns transportation between the supplier of raw and package materials towards a sourcing unit of Unilever. The next step of transportation is between the sourcing units and warehouses, where finished products are transported. Finished products are transported towards warehouses in the countries, where the products are temporarily stored. Besides the sourcing units, there is also a significant amount of factories that produce Unilever products and transport finished products to the warehouses, i.e. co-packers. This report has a focus on cross-border transport, i.e. transport from one country to another, which concerns the majority of the inbound and primary outbound freight. The final two transportation steps in the supply chain concern the transport towards customer warehouses and customer stores. This is secondary outbound freight and is not considered in the scope of this research, as the majority of the transport takes place within the same country.

2.2 The current network

This section elaborrates on the current location and routing network of Unilever in Europe. The location network concerns sourcing units and warehouses. There are two main sources of data. The first source is the European Logistics Booklet [ELB] that is created by the USCC and contains data of locations for each European country separately. The second source is the Everest Database [EDB] that contains detailed information of the transportation lanes of inbound and primary outbound transport. This database is updated quarterly.

Location Network: Sourcing Units

Figure 2.2 shows the 77 European SUs. The yellow nodes are the Foods SUs, the blue nodes represent the Ice Cream and Frozen Foods (ICF) SUs, and the orange nodes are the Home- and Personal Care (HPC) SUs.

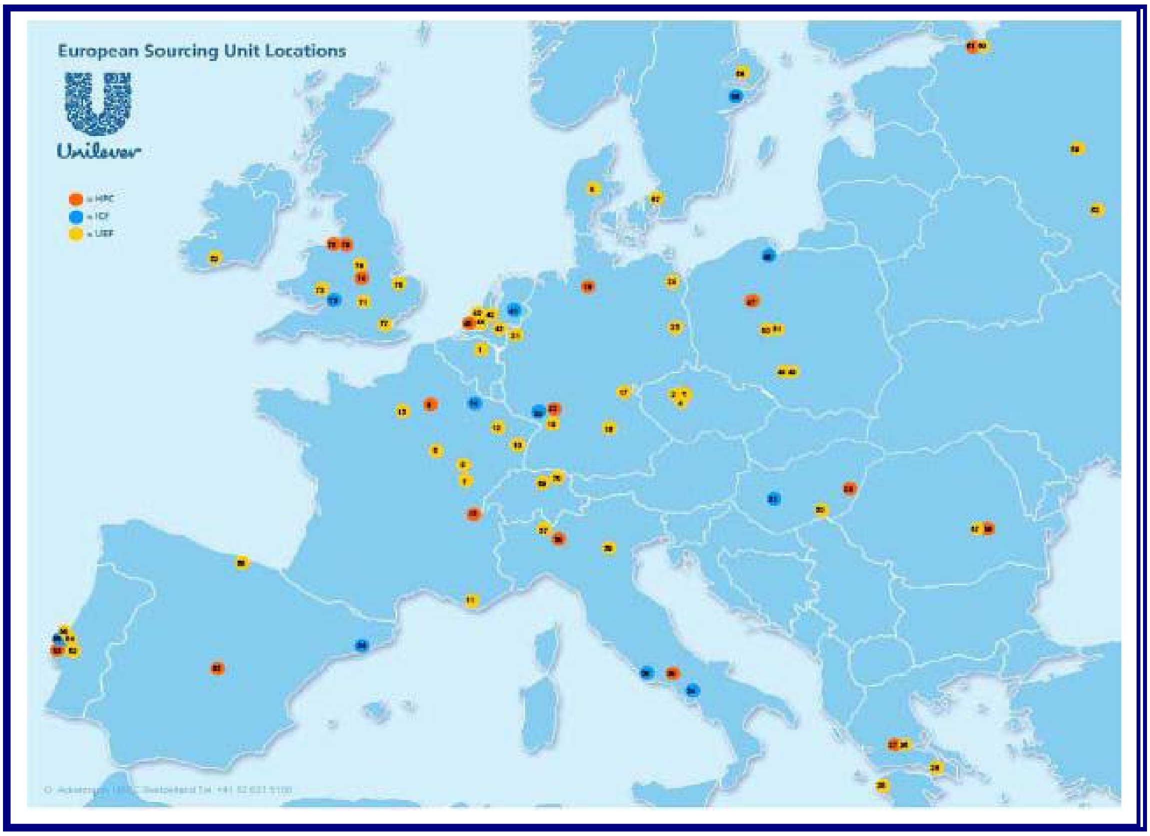

Figure 2.2 European Sourcing Units [ELB]

Table 2.1 lists the countries that are involved in the European SU network and the number of SUs per country.

		77 Sourcing Units
HPC	ICF	Foods
17	10	50
		69 Locations
		21 European countries
Austria (0)	Greece (4)	Portugal (5)
Belgium (1)	Hungary (3)	Romania (2)
Czech Republic (3)	Ireland (1)	Russia (4)
Denmark (1)	Italy (6)	Spain (3)
Finland (0)	Netherlands (6)	Sweden (3)
France (10)	Norway (0)	Switzerland (1)
Germany (9)	Poland (6)	United Kingdom (9)

Table 2.1 European Sourcing Units [ELB]

The reason why there are 8 more SUs than locations is that there are 5 locations that have more than one SU. Furthermore, Austria, Finland, and Norway do not have a SU, implicating that there is no inbound transport in these countries. Primary transport towards DCs in these countries is comparable to other countries.

Location Network: Warehouses

Besides the sourcing units, warehouses are the second kind of locations that we consider. There are two kinds of warehouses: *National Distribution Centres* (NDC) and regional warehouses. NDCs are operationally managed by the Marketing and Sales Organisations (MSOs) and store finished goods that are sent at a later stage to the customer secondary warehouses. In general, every country has a separate NDC for the different three business groups. Optimising the warehousing network is one of the major projects of the USCC, aiming at reducing the number of (expensive) NDCs. One solution method is storing products of different business groups together in one NDC. The Unilever network has 100 NDCs and about 270 regional warehouses. The latter is a collection name for multiple kinds of warehouses, such as storage places for inbound material, storage of finished goods near the SUs, co-packer warehouses, and external buffers.

Routing Network

The defined scope of inbound and primary outbound freight concerns over 9,000 transportation lanes. A *lane* is a route between two locations in the supply chain on which a certain amount of products are transported. We use this term frequently throughout this report. Figure 2.3 gives background on the lanes in Europe. Note that the numbers frequently change due to changes in the network (e.g., consolidation of warehouses or moving production capacity amongst sourcing units).

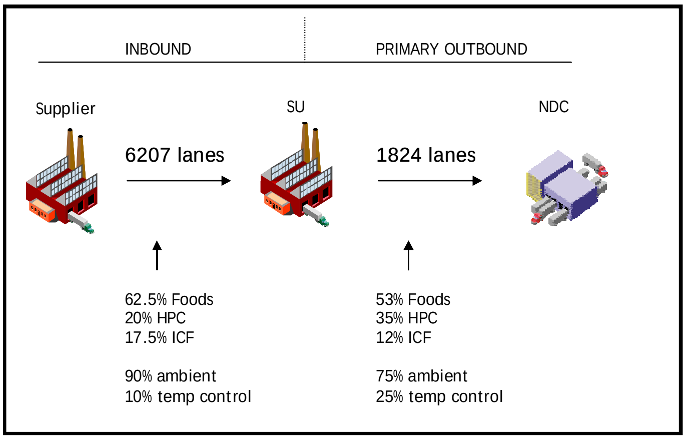

Figure 2.3 European inbound and primary outbound lanes [EDB]

As the figure demonstrates, there are substantial more inbound lanes on a yearly basis. The main reason behind is that SUs are delivered in correspondance with their production schedules. Therefore, transport is arranged more frequently with trucks that are only partially loaded. Remarkable are the difference between inbound and primary outbound freight, in terms of percentages. Foods and ICF both require relatively more inbound transport than outbound. The large number of ingredients that food products contain, might be a reason for this. HPC products do not require many different raw and package materials to manufacture the product. Also, a substantial amount of ingredients for the ICF products arrive in a ‘normal’ temperature, i.e. ambient, while the end product is frozen or chilled.

2.3 External Environment

Besides having clear in mind how Unilever’s routing network is internally organised, it is also important to understand the environment it acts in. This section discusses the relevant characteristics of the transportation market nowadays and in what way it affects Unilevers routing network.

2.4.1 Transportation Market Characteristics

The transportation market is a dynamic market with various stakeholders and influencing factors. This section systematically elaborates on the most important characteristics.

Fragmented transportation market

There is a large number of active small players in the transportation market, since it is rather simple to start a transportation company. Investing in a truck and licenses are the only action to take when starting a transportation company. This makes the transportation market very fragmented: 82% of the total European road freight capacity is provided by transport providers with less than 10 drive units. The average number of trucks of an internationally operating road freight company is 3 to 5 [LKW, 2007]. Freight forwarders take advantage, since these larger players in the market set contracts with the small companies, sell transport to the customers, and take a substantial margin on it [LKW, 2007].

Increasing costs per km

There are 3 main elements that form the costs for transport: fuel, wages, and capital. Fuel costs depend on the oil price on the market, which fluctuates, but gradually rises overtime. The wages are increasing. A large part of the truck drivers are from Eastern Europe, where economy and wages gradually go up. The capital element are the costs of investing in, e.g., trucks. This element of the transportation costs stays relatively equal [LKW, 2007].

European differences

Within Europe there are various differences regarding legislation and infrastructure amongst the countries. Taxes, weight limitations, loading procedures, and rail tracks are examples which make it difficult to have optimal flows within Europe. Harmonisation of legislation amongst countries is desired [LKW, 2007].

Next to these 3 general comments regarding the transportation market, Figure 2.4 shows how other factors lead to either an increase in demand for transport or a decrease in capacity of transport possibilities.

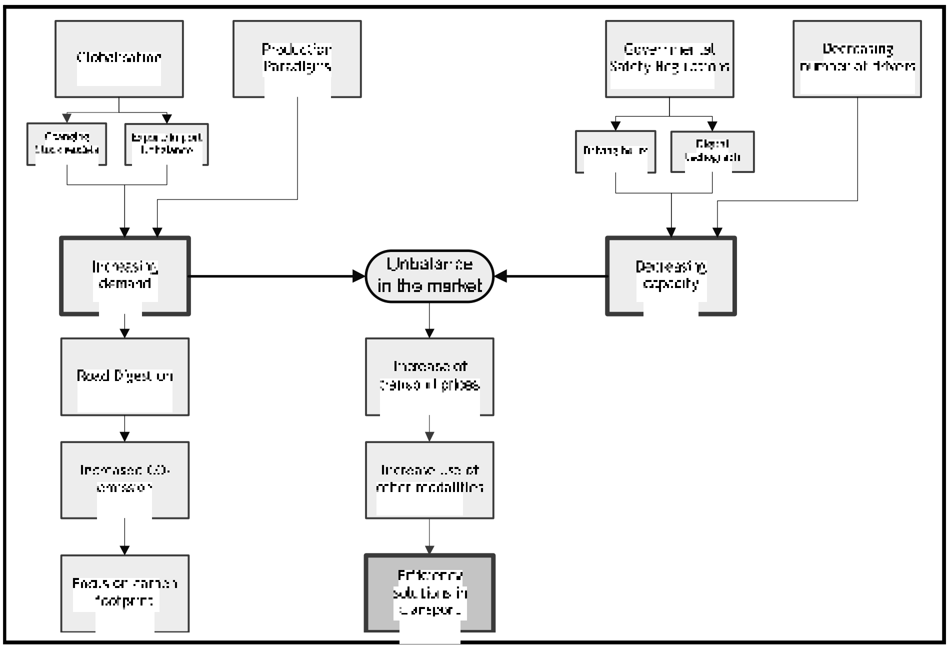

Figure 2.4 Transportation Environment

2.4.2 Increasing demand

Looking at the left hand side of Figure 2.4, this section first discusses the reasons for an increasing demand for transportation, i.e., globalisation and production paradigms. Then, we touch upon the consequences of the increasing demand, i.e., road digestion, increased CO_2 emission, and a required focus on the carbon footprint.

Globalisation

Global sourcing, production, and consumers enlarge the scope of both producers and transport providers. There are two important results of the introduction of free trade zones, which are the changing stock model and the unbalance.

- Changing stock models

The emergence of free trade zones and the opening of borders have their effect on stock model strategies of companies; it is no longer necessary to have distribution centres in each country. This results in fewer warehouses and transportation over longer distances [Crainic, Laporte, 1997].

- Import/Export Unbalance

Another effect of the free trade of goods within the European countries is the movement of production towards Eastern European countries, as labour costs are significant lower in this part of Europe. This leads to transport over longer distance, and to an unbalance of transport amongst regions [LKW, 2007]. We will discuss the balance of a region in more detail in Chapter 6 of this report.

Production Paradigms

Just in Time production and delivery, quality-control in the entire supply chain, and customer demand driven supply chains result in severe requirements regarding transportation. The transportation industry needs to decrease total delivery time (be there fast) and increase service reliability (be there within specified limits and be consistent in performance) [Crainic, Laporte, 1997].

Road Digestion

The increase in demand for transportation leads to an increase in road traffic. As the road network does not increase accordingly, capacity is not meeting demand, which results in more road digestion [Crainic, Laporte, 1997].

Increased $C0_2$-Emission

Research of universities and institutes found out that the transportation sector is one of the main polluters on the environment. Road vehicles are substantially more energy efficient and environmental friendly than years ago, but still the CO_2 emission of trucks increased in the past years. The transportation sector is responsible for 44% of the total CO_2 emission from fossil fuels [Aronsson, 2006].

Focus on carbon footprint

Carbon footprint is a measurement of the impact that human and corporate activities have on the environment. The amount of greenhouse gas production is measured in units of carbon dioxide [@ Carbon footprint, 2007]. Reducing the carbon footprint represents a company's responsibility to reduce their CO_2 emission, while maintaining the same performance levels.

2.4.3 Decreasing Capacity

This section elaborates on the factors that lead to a decreasing capacity for transportation. We touch upon the boxes on the right hand side of Figure 2.4.

Governmental Safety Regulations

Since April, 2007, the E.U. has changed the driver regulations drastically [LKW, 2007]. This has a major impact on the planning and operational procedures of transportation, since drivers cannot traverse the same distance in the same time period any longer, which has a large impact on daily operations:

- Driver hours

The E.U. regulation imposed more stringent regulations with respect to drivers, e.g. a 15% decrease in working time per week and an increasing number of rest days. These regulations lead to an increase in prices and time for transport. [LKW, 2007].

- Digital tachometer

Another new regulation obliges that each truck has a digital system that registers the number the working hours of the drivers by tracking every movement of the truck. When the restricted working time is exceeded, either the TSP or the user of the transport service gets a fee [LKW, 2007].

Decreasing number of truck drivers

In the past, being a truck driver was mainly in Eastern Europe a highly appreciated job. Freedom and international experience were the main reasons for people to choose this job. Nowadays there is a trend that shows a lack of truck drivers. Apparently, the irregular shifts and low wages that make the job unattractive let people choose another sector to work in.

2.4.4 The consequences of unbalance in the transportation market

The increase of transportation demand and at the same time a decrease in capacity results in an unbalance in the transportation market. This has 3 major consequences for Unilever's routing network:

- Increase of transport prices

The reason for the increase of transport prices is twofold, according to Figure 2.4. As discussed, the increasing costs per kilometre result in higher prices to be paid by the customer. Also, there is the market mechanism of supply and demand. Since demand is higher than supply, prices go up.

- Increased use of other modalities

The increasing road digestion and the focus on carbon footprint force companies to consider other modalities in transport. Options are rail, sea, and air transport, of which rail transport is in Europe mostly used, although the average speed is substantially lower than trucks (± 18 km/h) [LKW, 2007].

- Need for efficiency solutions in transport

The factors, discussed above, lead to a desire for efficiency solutions for transport. Efficiencies lead to a decrease in freight price per unit and a decrease in the quantity of transportation movements.

The three consequences are important factors from the external environment that affects the Unilever transportation business and contribute to a strong desire to optimally organise the network.

2.4 The desired network

The routing network is managed by a diverse set of organs and people. Up to now, the business groups, HPC, ICF, and Foods, work independently from each other in the area of delivery. Also, within each business group, the inbound freight and primary outbound freight are arranged separately. Due to the fragmentation of managing transport, the responsibilities are fragmented too. For inbound transport, the majority of the lanes are arranged by the supplier. The structure of responsibilities in primary outbound transport differs amongst the three business groups. Having several parties responsible for transport, there is no transparency what lanes exist outside a managers own area of responsibility. Therefore, inefficiencies occur on a regular basis. More than once, trucks drive empty, or unnecessarily partly full. Currently, other parties take advantage of these inefficiencies, e.g., the suppliers and transport providers. Project Everest creates a central organisation that has a clear overview of all transport that takes place in Europe. Once the complete network is transparant and responsibilities are centralised, there is a major opportunity to optimise the network.

The next chapter steps in detail in the characteristics of the Unilever network, which provides insights in the factors that need consideration if searching for efficiency solutions.

3. Routing Network Constraints

As every routing network is different, it is critical to elaborate in detail on its specifications. This chapter discusses the constraints of the routing network of Unilever in Europe. Section 3.1 starts with an introduction, explaining how to distinguish different constraints and order them in a systematic way. Sections 3.2 to 3.5 explain the constraints in detail. The majority of the information in this chapter is based on interviews with experts inside and outside Unilever. To obtain a complete and clear overview of the relevant constraints, we have explicitly searched for key persons in the network to verify their view. The meetings with transport managers in Italy, Germany, and Switzerland provided a good insight in the supply and delivery locations. A discussion with a transport provider and workshops with several MSO delegates gave a better idea on the constraints of the products that are transported. Appendices B to K give the outcomes of the interviews in detail.

3.1 Introduction

Looking at the variety of constraints that are related to a routing network, there is a clear split: The constraint either concerns the locations or the products. In both areas there is again a split between fixed and variable constraints. Fixed constraints are hard to change and need to be taken for granted. It is out of the scope of this research to eliminate or change these constraints. On the contrary, variable constraints are areas of attention when optimising a routing network. These constraints could be subject to change. Figure 3.1 gives the four constraint areas and Sections 3.2 to 3.5 elaborate on the areas separately.

	Fixed	Variable
Location	• Country Legislation • Productive Time • Loading equipments	• Slot Management • Production Schedules • Stock model
Freight	• Hazardous • Shipping Format • Frequency • Temperature Control • Shelf life • Distance	• Truck Requirements • Modality • Transit time • Order Lead Time

Figure 3.1 Overview of constraints

3.2 Fixed Location Constraints

This section elaborates on the fixed constraints at locations in the routing network.

Country Legislation

An important legislation, which differs amongst the countries in Europe, is the restriction regarding driving and loading at night. This restriction limits the efficiency of transportation. Certain countries have a ban on night driving, e.g., Switzerland, implicating that trucks need to be at their destination before 11 P.M. or otherwise have to rest at parking places along the road (see Appendix D). Transportation planners need to consider this consciously and send trucks in time. Loading and unloading at night prohibitions exist due to the noise pollution it causes in the area. In practice, truck drivers are waiting in front of a ramp to be unloaded until 6 A.M. For SUs that produce 24/7, there is a point of concern in storing finished goods during the night.

> Example: Country Legislation
>
> The Knorr factory was built in the rural area around the city Heilbronn, Germany. By that time it was far enough from the city not to disturb any inhabitants. However, during the years the city has grown and moved its borders, which results that nowadays the SU of Heilbronn is located in the city area. Due to noise pollution, there is a prohibition for the SU to (un)load trucks in the night (see Appendix F).

Productive Time

There are various characteristics of a location that determine its productive time and flexibility; these characteristics are related to the physical lay-out of the warehouse. The number of docks and (fork) lift trucks, and the space of the site determine the speed of the (un)loading activity. (Un)loading takes in general 30-40 minutes (see Appendix D), which cannot be decreased significantly, even if more resources are available.

> Example: Productive Time
>
> In the chilled warehouse of Thayngen, (un)loading is smooth and fast. However, the pallets are placed on a temporary space. It takes more than one hour to bring them to the right place in the warehouse, since there is only one automated lift truck available that stores the pallets in the warehouse. The next trucks have to wait until the temporary space is free again, before they can be unloaded, which results in long waiting times (see appendix D).

Loading equipments

Locations could have special requirements for the loading process of trucks. Sometimes, there are special docks at the location, or the trucks need to be unloaded from the side instead of from the back. This constraint might require specific trucks to transport products to that specific location.

3.3 Variable Location Constraints

This section touches upon the variable location constraints.

Slot Management

Regarding the loading and unloading activity of trucks, slot management is important to consider. Regarding slot management there are three options:

- o Hourly slots: carriers make a reservation in the warehouse agenda for one hour slot in which they will be (un)loaded.
- o AM-PM slots: warehouses agree with carriers to arrive either in the morning or in the afternoon, without a specific hourly slot.
- o Daily slots: there is only an agreement concerning the day that carriers come, without a specific timeslot.

Slot management is also indicated with 'time windows' and is a major factor in the assignment of vehicles to lanes and creating tours. Warehouses prefer to use tight time windows, so that they can perfectly manage the resources in the warehouse (e.g., personnel, fork lift trucks, spaces) and can equally divide the workload during the day. However, truck driver prefer wide time windows, since it is hard to predict the exact arrival time, particularly for more than one day trips. If a driver misses his slot, he has to wait, until the warehouse has a new slot available. The strictness differs per location, but sooner or later every truck will be (un)loaded, i.e. a truck will never leave the location without having delivered or picked up its load. This means that locations of Unilever handle soft time windows.

Production Schedules

The production schedules of the sourcing units are calculated with care. With the supply of raw and package materials, on the one hand, and the demand for finished goods, on the other hand, a SU requires a precise schedule of when to make which products. A detailed schedule of transportation requirements is related to this. It is hard to change these schedules from one day to another.

Stock Model

Sourcing units and warehouses handle stock models to have a good balance between stock keeping costs and transportation costs. Changes in supply and deliver moments, due to optimisations in the routing network, might conflict with this stock model.

3.4 Fixed Freight Constraints

Besides location constraints, also the characteristics of the *freight*, the products to be transported, are necessary to consider when optimising transport. Due to the variety of products in Unilever's portfolio, this routing network has a relatively large number of freight constraints. This section discusses the fixed constraints.

Hazardous

Hazardous goods are products that have a certain danger to transport. There are specific rules to apply when transporting hazardous goods, which are described in the European agreement concerning the international carriage of dangerous goods by road [@ ADR, 2007]. In practice, ADR concerns presence of specific documents in the vehicle, packaging and labelling of the products, prescriptions for vehicle equipment, and a specific certificate for the driver.

Shipping Format

The shipping format describes the form in which products are shipped, which depends on the type of product. Silos (for bulk material) and pallets are examples of shipping formats. Furthermore, a truck can carry a legally specified maximum weight and volume, see Table 4.1. In a regular truck fit 33 pallets or 25 ton, which is indicated as a *full truckload* (FTL) [ECR, 2000].

	Truck capacity	Available for freight
Weight	40 ton	25 ton
Volume	78 m^3	64 m^3

Table 4.1 Weight and Volume space in a truck [ECR, 2000]

In terms of combining certain goods, there are rules defined what products may be combined and what products must be kept separated. An internal research within found out what rules and limitations to consider, regarding the combinations of products of the Foods and HPC business groups in warehousing and transport [Project Cavern, 2007]. Two basic rules for transport are defined:

- The HPC and Foods products are transported on separate pallets
- No laundry products are transported in the mixed HPC-Foods loads

Appendix N elaborates on the outcomes of this project in more detail.

Frequency

The frequency of a lane indicates how many loads are transported on that lane per year. This is an important characteristic of a lane to know when optimising the network. Clearly, it is far more profitable to combine lanes that have a high frequency than lanes that only take place on a rarely basis. For seasonal products, e.g., ice cream, the total number of loads per year is not sufficient to know. The allocation to the 4 seasons of the year, and the maximum number of loads per week, is relevant information too.

Temperature control

Certain products need temperature control during their transport (e.g., ICF products and also HPC products in winter). Temperature controlled trucks can be used for both ambient and chilled transport: Either the system is set at a certain temperature, depending on the type of goods, or it is switched off. Standard ambient trucks do not have the possibility to transport chilled freight. The price of a temperature controlled truck is higher, partly depending on the temperature outside; the more the cooling system is working, the more fuel is used, the more expensive the price per kilometre in a temperature controlled truck. A temperature controlled truck costs on average 10% more than an ambient truck of which 5% is fixed and 5% is temperature dependent (see Appendix J).

Shelf life

The product life cycle is another characteristic of freight. The majority of the products in Unilever's portfolio are food, which have a limited shelf life. The shorter the shelf life of a product, the less flexible it is to combine the load with other products. A delay, e.g. due to combining lanes, might result in obsolescence costs.

Distance

The distance is the length of a lane between supply and delivery location, measured in kilometres.

3.5 Variable Freight Constraints

This section touches upon the variable freight constraints.

Truck requirements

If products allow 'double stacking', meaning that a pallet is placed on top of another pallet, it is more profitable to transport these products in a truck that can transport this. If the weight of the products is low, about 50 pallets fit in one truck instead of the regular 33. However, not every product allows double stacking, e.g., deodorants would explode and certain packages are not strong enough to carry this weight. Besides double stacking, certain products have other truck requirements. E.g., glass jars must be loaded from the side, instead of the back side of the truck.

Transit Time

Transit time is the time interval during which freight is transported from supply – to delivery location (one way) and is related to distance and modality. The same distance might take the double time and could be twice as cheap if part of the transport takes place on a boat instead of a truck. The required transit time is of major importance for carriers to determine their prices. If they know the delivery date far enough in advance, carriers choose a cheap modality to transport the products, which accordingly leads to a lower price for Unilever to pay.

Modality

As said, the modality of transport influences in great extent the transit time of transport. The common modalities are road, rail, sea, and air. Note that every modality requires a truck for (part of) the route. Freight needs to be transported from the supply location to the train, boat or plane docking station and accordingly from a docking station to the delivery location. Road transport is the most flexible transport mode. The time windows of the other modalities are hard, i.e. they handle a strict departure time, even if the truck with goods has not arrived.

Order Lead time

With respect to the optimisation of transportation lanes, the lead time expresses the number of days a location requests transport in advance. This time span determines the possibilities to combine transport and to potentially choose the modality. The shorter the order lead time is, the less flexible the freight is for carriers and the more expensive the transport is for Unilever. The flexibility on this parameter differs per product type and the seasonality. It also depends on promotional activities (see appendix J).

3.6 Impact of constraints on decision making levels

This chapter has provided insight in the different constraints and requirements that locations and freight have regarding transport. When optimising a routing network, the relevance of the constraints differ, depending on the decision making level, i.e. the strategic, tactical, and operational level [Daft, 2000], see Appendix M. Figure 3.2 is an extension of Figure 3.1, taking this dimension into account and this section discusses the relevant constraints per level of decision making.

Strategic constraints

The contraints in Figure 3.2 with a blue color, i.e. the production schedule and stock model of locations, are strategic constraints. When optimising an entire logistics network, these constraints are of great importance, e.g. when determining the trade-off between transportation and warehousing costs. For the daily operations and for the medium term, these constraints are rather fixed.

Tactical constraints

The constraints with a red color in Figure 3.2 are the tactical constraints. A optimisation opportunity on tactical level could be identifying beneficial lane combinations. Fixed tactical characteristics of the products are important to consider when assessing lane combinations. Furthermore, variable tactical constraints require, in contrast with strategic constraints, less strategic debate to change. For example, switching from road to rail could be a tactical decision.

Operational constraints

The contraints of Figure 3.2 that have a green color are the contraints that affect the operational level of decision making, i.e., country legislation, productive time, loading equipments, and slot management of a location, and truck requirements, shelf life, and order lead time of the product. The operational level of decision transfers tactical plans into daily execution. These constraints need to be considered for every transportation movement that takes place.

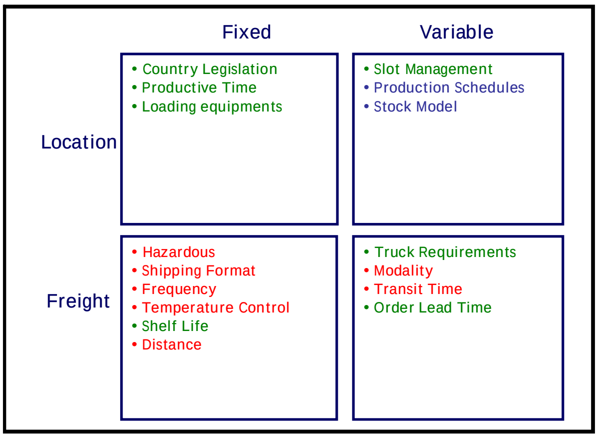

Figure 3.2 Constraints categorised per decision making level

3.7 Conclusions

This remainder of this research focuses on the tactical level of decision making. The constraints in red in Figure 3.2 are therefore relevant to take further into consideration, i.e. the hazardousness, the shipping format, the frequency, temperature control, distance, modality, and transit time of a product. The reasons for focusing on the tactical level are twofold: On the one hand, optimising on tactical level generates an overview of the potential optimisations areas. This ensures that optimising on operational level, thereafter, occurs at the places where it delivers the highest savings. A focus on operational level would be too quick, looking at the current stage of efficiency in the routing network. Furthermore, optimising the network on strategic level needs involvement of other departments in the USCC too. Since this research focuses on identifying optimisation opportunities in the routing network specifically, the strategic area of decision making is out of scope.

4. Routing network Optimisation Options

This chapter elaborates on the options that existing literature provides to optimise routing networks on tactical level. Figure 4.1 visualises the structure of the remainder of this chapter. Starting from the bottom of the figure, Section 4.2 describes three major routing problems. Section 4.3 explains the difference between heuristic and exact algorithms. Continuing, Section 4.4 discusses construction algorithms and Section 4.5 elaborates on improvement algorithms, both important groups of heuristic algorithms. A heuristic algorithm is frequently consists of a construction and an improvement algorithm. Both Sections 4.4 and 4.5 also describe which of the discussed algorithms are applicable for the Unilever routing network and the reasons behind this.

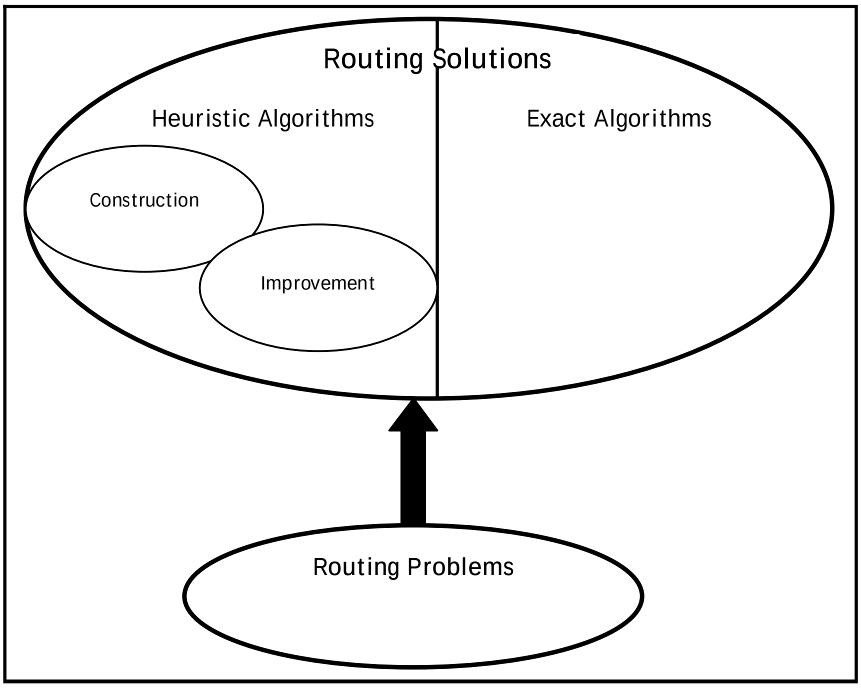

Figure 4.1 Framework for Chapter 4

4.1 Routing Problems

The literature distinghuishes three main routing problems: the Travelling Salesman Problem, the Vehicle Routing Problem, and the Pickup and Delivery problem. Every routing problem has its own algorithms to solve the problem, which we discuss at a later stage in this report.

Travelling Salesman Problem (TSP)

The TSP is the basic routing problem on which other routing problems are built. A salesman is required to visit a set of cities at least once, starting and ending at a central depot. Capacity does not play a role. The objective is to find a tour that minimises the total distance [Gendreau et al., 1996].

Vehicle Routing Problem (VRP)

The VRP can be described as the problem of creating optimal delivery (or collection) routes from one or several depots to a number of geographically scattered cities. The routes originate and terminate at one depot. The difference with the TSP is that capacity restricts the problem. Where in a TSP one man visits all the cities regardless of the number of cities, in a VRP the number of required trucks depends on the demand of the cities, since trucks have a limited capacity. Unless otherwise specified, all vehicles are identical and have the same capacity. There exists a variety of VRP that include side constraints. The most common side constraints are vehicle-specific capacity restrictions, total time restrictions, and time windows of locations [Laporte, 1992].

Pickup and Delivery Problem (PDP)

The PDP is a generalisation of the VRP and is concerned with the construction of optimal routes to satisfy transportation requests, each requiring both pickup and delivery. In this problem, each transportation request has a specific origin and destination instead of one depot [Dumas et al., 1991].

4.2 Exact and Heuristic algorithms

As Figure 4.1 indicates, there are two different types of algorithms to solve routing problems: Exact and heuristic algorithms. This section explains the differences between these two classes of algorithms.

Exact Algorithms

Exact algorithms yield an exact solution for a problem in a finite number of steps. In mathematics there is a strict division between easy and hard problems. For a hard problem, it holds that the time to solve the problem increases exponentially with the size of the problem. Therefore, exact algorithms are appropriate to use for either *easy* or *small* hard problems. Dynamic Programming and Branch and Bound are two examples of exact algorithms. The algorithms both implicitly enumerate every solution and select an optimal solution.

Heuristic Algorithms

Heuristic algorithms, i.e. heuristics, are algorithms that aim to find good solutions, but do not guarantee to find an optimal solution. In contrast with exact algorithms, heuristics are often faster and capable of obtaining optimum or near-optimum solutions to much *larger* problems in a reasonable amount of time [Gilette, Miller, 1971]. In this report we discuss various heuristics and their characteristics. The next sections step into detail in two types of heuristics: Construction and improvement heuristics.

4.3 Construction of Tours

This section first reviews six construction heuristics and evaluates after that their relevance for the Unilever network.

4.4.1 Construction Algorithms

Construction heuristics start with an empty route and insert new cities so that a tour is created [Van der Heijden, Van der Wegen, 2004]. Every algorithm has a different rule that specifies which city to insert at what place in the tour.

Nearest Neighbour for TSP

This heuristic constructs a tour by inserting repeatedly the nearest city at the end of the route. The vehicle starts at the depot and drives to the nearest city, visiting every city exactly once and ending again at the depot. A tour is formed at the end of the algorithm, when all city are visited. The tour could become far from optimal when the distance from the last added city to the depot is far [Van der Heijden, Van der Wegen, 2004].

Nearest/Farthest Insertion for TSP

In contrast with Nearest Neighbour, this algorithm constructs a tour from the depot to one city and extends this tour every iteration with one city. Nearest insertion includes the nearest city at the position in the schedule of the tour such that the increase in total costs of the tour is minimal. Farthest insertion inserts the city with the largest distance [Van der Heijden, Van der Wegen, 2004].

Cluster-first, Route-second for VRP

This algorithm draws all the cities in a two-dimensional field. With a (forward or backward) sweep, a line is drawn from the depot to a certain city and from this city on the demand of the nearest city is added up until vehicle capacity is reached. This forms the first city cluster, which is entirely served by one vehicle. This process iterates until all cities are assigned to a cluster. The algorithm constructs tours within the clusters with e.g. Nearest Neighbour [Van der Heijden, Van der Wegen, 2004].

Route-First, Cluster-Second for VRP

This algorithm first forms a 'giant tour', i.e., a travelling salesman tour, from the depot around all the cities and back to the depot, without taking truck capacity into account [Beasley, 1983]. This tour can be formed with e.g. Nearest Neighbour or Nearest/Farthest Insertion. Then, the aim is to optimally partition this tour into a set of feasible vehicle routes. The algorithm fills a cost path matrix, calculating the costs of all feasible city combinations. The solution with the least costs, that includes all cities, partitions the giant tour best into feasible routes [Beasley, 1983].

Savings algorithm for VRP and PDP

The savings algorithm of Clarke and Wright [Clarke, Wright, 1964] is widely used for solving routing problems. The algorithm tries to allocate loads to trucks in such a manner that all the cities are assigned and the total mileage covered is minimal. The basic idea of the savings algorithm is to start visiting every city in a separate tour and to generate savings by combining cities in one tour. The upper part of Figure 4.2 demonstrates the savings algorithm where two single routes are combined. The savings come from erasing the empty miles from city *i* back to the depot (c_{i0}) and from the depot to city *j* (c_{0j}). The costs of empty miles from city *i* to city *j* (c_{ij})need to be considered instead. The lower part of Figure 4.2 demonstrates the same principle: Routes with more than one city could be further combined. The algorithm ranks the savings in non-increasing order in a savings list. After that, it starts on top of the savings list and checks whether the proposed tour is feasible. If so, the two routes are combined and form a tour [Laporte et al., 2000]. The former routes are erased from the available set and the newly established tour is included.

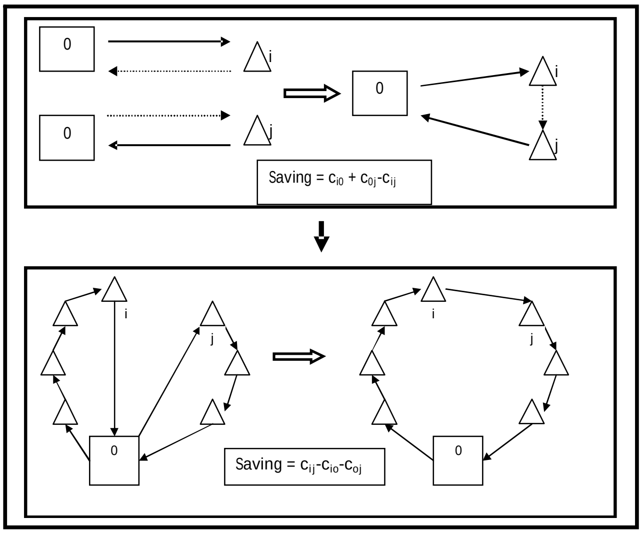

Figure 4.2 Savings algorithm

Backhauling algorithm of Jordan and Burns for VRP and PDP

Jordan and Burns [Jordan, Burns, 1984] created a model that calculates the best combination of cities for backhauling. Truck backhauling aims at reducing empty truck-miles by having drivers taking loads back to their home terminal [Jordan, 1987]. The objective of the algorithm of Jordan and Burns is to minimise empty truck-miles, subject to each city only being matched with, at most, one other city. The algorithm iteratively picks the city pairs that increase the backhaul savings most and erases these cities from the set. The algorithm stops when only negative savings are found. At the end of the procedure, all cities that remain in the set are served by non-backhauling trucks [Jordan, Burns, 1984]. Figure 4.3 demonstrates how the backhaul savings are calculated. In this example, the driver departs from its home depot *m* and drives to city *i* (1). Instead of going back to its home depot *m*, the driver goes to depot *n* (2) and picks up the load to deliver at city *j* (3). Finally, the driver goes back to its home depot *m* (4). With this backhaul loop, the driver saved once the distance from *i* to *m* and once the distance from *j* to *n*. The extra costs of driving from *i* to *n* and from *j* to *m* need to be considered instead.

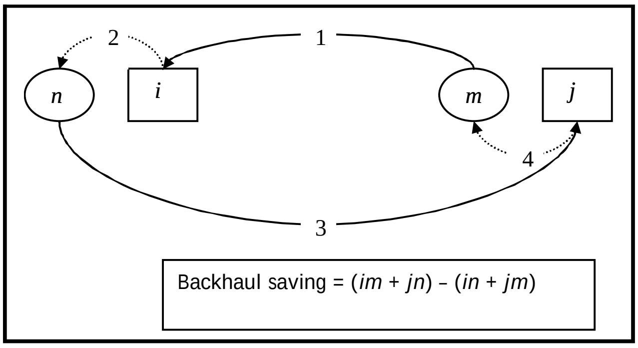

Figure 4.3 Savings Backhaul loop

4.4.2 Application for Unilever network

Table 4.1 summarises the discussed heuristics and displays to what extent they take the Unilever constraints into consideration. Unilever aims to maximise the cost savings, by means of combining city visits. The required functionality for the routing network of Unilever is therefore to *combine* cities that are currently visited separately. In Unilever terminology, cities are defined differently. A ‘transportation lane’ is the transport that takes place between the supply location (depot) and delivery location (city). Where in the literature a ‘tour’ is defined as a visit to various cities, in Unilever terms a ‘tour’ consists of multiple transportation lanes. This section discusses the usefulness of the discussed heuristics in Unilever terminology.

Nearest Neighbour and Nearest/Farthest Insertion are algorithms to optimally *schedule* transportation lanes in one tour, rather than combining different transportation lanes. The algorithms do not take any of the Unilever constraints into consideration. Therefore, these algorithms are least suitable to apply to the Unilever network.

Cluster First– Route Second and Route First- Cluster Second are applicable to solve Vehicle Routing Problems (VRP) and take the capacity constraint into account, which is relevant for the Unilever network. However, also these algorithms focus on the sequence of transportation lanes in one tour, rather than analysing the best lane combinations. Also, the heuristics consider one depot from where all locations are supplied. This is not the situation in Unilever's network, which makes the algorithms not easily applicable for this network.

The Savings Algorithm and the Backhauling Algorithm of Jordan and Burns are both applicable to solve VRP and Pickup and Delivery Problems (PDP) and supports Unilever's mean (functionality) to reach its goal: To create beneficial lane combinations. Furthermore, both algorithms take some capacity and costs (here: distance) if the routes into account. These two heuristics form the best basis to build a Unilever-specific algorithm, where also the maximum duration of a tour, the temperature control, and the frequency of the lanes will be taken into account.

Heuristic	Route problem	Objective	Unilever					
			Functionality	Constraints				
	TSP/PDP/VRP	Minimise truck-miles	Create beneficial lane combinations	Capacity of truck	Lane price/ Distance	Max. Tour Duration	Temp. control	Frequency of lane
Nearest Neighbour	TSP	X						
Nearest/ Farthest Insertion	TSP	X						
Cluster First- Route Second	VRP	X		X				
Route First – Cluster Second	VRP	X		X				
Savings Algorithm	VRP, PDP	X	X	X	X			
Backhauling of Jordan and Burns	VRP, PDP	X	X	X	X	X		

Table 4.1 Overview of construction heuristics

4.4 Improvement of tours

Besides construction heuristics, improvement heuristics are a second group of heuristic algorithms. This section reviews two improvement heuristics and evaluates their relevance for the Unilever network.

4.5.1 Algorithms

Improvement algorithms start with a basic feasible solution, which potentially is the solution of a construction algorithm. Improvement algorithms aim to improve the feasible solution, until no better solution can be found [Van der Heijden, Van der Wegen, 2004].

2-Opt algorithm for TSP

This algorithm considers a basic feasible solution and aims to improve the created tour by swapping 2 (2-opt) or more (k-opt) cities within a tour. When a swap generates a better solution, this algorithm continues with the new tour. After that, the algorithm seeks for improvements by swapping cities between tours. At the moment that no better schedule within the tour is found, the algorithm stops [Van der Heijden, Van der Wegen, 2004].

Set Partitioning algorithm for VRP

The Set Partitioning algorithm is a heuristic that has both a construction and an improvement phase. To introduce the underlying methodology, consider the example illustrated in Figure 4.4. From the depot, a single delivery is made to each of the cities (circles). The numbers on the arcs represent the travel distance from one city to another. Assume that a driver can visit at most two cities in one tour. The objective is to visit all cities with a minimum travelled distance [Cullen et al., 1981]. Each column in Table 4.2 represents a route. The task is to select a set of columns such that every row, i.e. customer, is represented exactly once and the sum of the costs is the smallest possible.

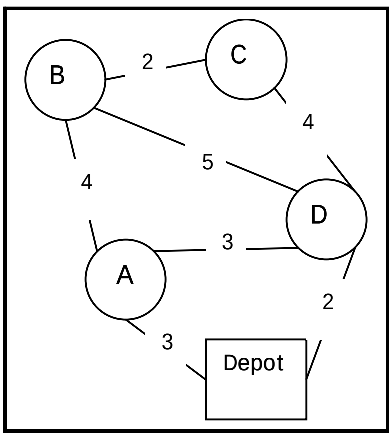

Figure 4.4 Distribution Network

Route	1	2	3	4	5	6	7	8	9	10	
Costs	6	14	12	4	14	15	8	15	14	12	
A	1	0	0	0	1	1	1	0	0	0	
B	0	1	0	0	1	0	0	1	1	0	
C	0	0	1	0	0	1	0	1	0	1	
D	0	0	0	1	0	0	1	0	1	1	
Savings	0	0	0	0	6	3	2	11	4	4	Route 8 = 1
	0	-	-	0	-8	-9	2	-	-10	-8	Route 7 = 1

Table 4.2 Set Partitioning Column Generation

Cullen et al. presented a heuristic to solve this problem. It calculates the potential savings of a route, which is the difference between the price of a combined route and the sum of the prices of the included individual routes. Table 4.2 demonstrates the potential savings in the 'savings row'. The algorithm picks the column with the largest potential savings, i.e. route 8. It erases the routes that consist of the chosen route combination and calculates the potential savings again. Route 7 then delivers the largest savings. Combining cities B and C (route 8) and cities in A and D (route 7) delivers a total saving of 13 (= 11+2) for the network in comparison with the basic situation of delivering each city separately. Route 7 and Route 8 are together called 'Partition 1', which is the basic feasible solution of this problem. This is the construction phase of the algorithm. We prefer to call the routes 7 and 8 *tours*, since they concern more than one route.

Besides generating a basic feasible solution, Cullen et al. also generate an improvement step in the algorithm, aiming to improve the initial partition. The fundamental idea underlying the improvement step of the heuristic is the concept of 'row pricing' [Cullen et al., 1981]. The prices in the second row of Table 4.2 are the feasible row prices of partition 1, which are the initial prices according to Figure 4.4. Once the algorithm has delivered a feasible solution, it recalculates the row prices, in order to generate a potential 'Partition 2' (an improved solution). In the example of Figure 4.4, the algorithm calculates new row prices for the routes in tour 7 and tour 8. A weighted formula allocates the column costs (i.e. the costs of tour 7 and 8) in proportion to the cost of serving the cities in the tour. Appendix O elaborates on this formula in detail. With the newly obtained row prices, the algorithm starts again. If partition 2 generates a better solution, i.e. larger savings, the algorithm continues with calculating the new row prices for partition 3. If only negative savings are generated, the algorithm stops and the last established partition is the solution.

4.5.2 Application for Unilever network

Table 4.3 summarises the discussed heuristics, 2-opt and Set Partitioning, and displays to what extent they take the Unilever constraints into consideration. The table illustrates that the Set Partitioning algorithm seems to be better applicable for the Unilever network.

2-Opt improves TSP construction algorithms. To use 2-opt in the Unilever network, we only consider one part of the algorithm as described in the literature: 2-opt originally first swaps the schedule of visiting cities *within* a tour, and accordingly *between* tours. For the Unilever network we only profit from executing the second step, since tours exist of at most 2 cities.

The construction phase of the Set Partitioning algorithm is comparable with the Savings Algorithm [Clarke, Wright, 1964] and the Backhauling algorithm of Jordan and Burns [Jordan, Burns, 1987] as described in Section 4.4. The algorithm allows to determine a maximum number of lanes to combine in a tour and includes the lane and tour prices in the calculations. In the Unilever network, these prices highly depend on the combination structures and are therefore important to consider. Chapter 5 elaborates in detail on how the cost structures of lanes and tours are built.

We will apply both the discussed algorithms in the Unilever Savings Application. According to Table 4.3, the temperature control and the frequency of the lanes are not considered in both algorithms. However, with the functionalities of the Set Partitioning algorithm, we are able to transform this algorithm into a Unilever-specific algorithm that considers all constraints. The next chapter describes how this specific algorithm is created.

Heuristic	Route problem	Objective	Unilever						
			Functionality	Constraints					
	TSP/PDP/VRP	Minimise distance	Create beneficial lane combinations	Capacity of truck	Lane price/ Distance	Max. Tour Duration	Temp. control	Frequency of lane
2-Opt	TSP	X	x					
Set Partitioning	VRP	X	X	X	X	X		

Table 4.3 Overview of improvement heuristics

5. Unilever Savings Application

This chapter presents the Unilever savings application, designed to optimise the European routing network of Unilever. As discussed earlier in this report, project Everest aims to create transparency of this network. Transparency leads to the ability to design an efficient routing network. Accordingly, efficient vehicle routing can lead to a reduction in the number of trucks to provide the required service. This research delivers a solution for Unilever to efficiently design its routing network. Section 5.1 describes which specific lanes in the routing network we focus on and to what extent we take the tactical constraints of Chapter 3 into account. Section 5.2 discusses the mathematical formulation of the routing problem and Section 5.3 proposes both an exact and a heuristic algorithm to solve this problem.

5.1 Problem Description

To design an efficient routing network, backhauling and consolidation are two optimisation options for the tactical level of decision making. Backhauling is an optimisation strategy for a network of *full truckload* lanes (FTL). Truck backhauling reduces empty vehicle movements by having drivers haul loads on trips back to their home terminal [Jordan, Burns, 1984]. Consolidation is applicable on *less than truckload* lanes (LTL), since this strategy aim to fill trucks to near capacity and to minimize the total distance in visiting all cities [Clarke, Wright, 1964]. The focus of the research presented here is on FTL. Therefore, the primary goal is to obtain cost savings through minimising the empty vehicle movements. The reasons for focusing on FTL are twofold:

- Reliable dataset

Since a pan-European tender for full truckloads took place in Q4, 2007, there is a reliable dataset available to research backhaul opportunities. This tender data is up to date and represents real market prices for the transportation lanes. The available dataset of less than truckloads, i.e. the Everest database [EDB], is less accurate and not up-to-date.

- Majority of network is FTL

The total routing network of Unilever contains over 9,000 transportation lanes. The majority of the lanes are full truckloads. Except for a number of inbound shipments, i.e. from supplier to sourcing unit, almost all freight is transported in full truckloads, since sourcing units and warehouses are able to have an 'internal consolidation'. Locations combine different products in one truck that have the same destination in order to use the full capacity of a truck.

Having our focus on FTL, and therefore on backhauling, clarified, the remainder of this section elaborates on what kind of backhauling opportunities exist for the routing network.

When a truck has delivered a load, it could return empty to its home location. Alternatively, it could go to another location to pick up a load and deliver it near the home location. Figure 5.1 demonstrates four different examples of backhauling. Starting with the top left figure: This figure shows the simplest and most beneficial variant of backhauling where no empty vehicle movements are included. The upper right figure shows a 'triangulation', where a truck transports a load from A to B, drives empty from B to C, and picks up a load for location A. The bottom left figure requires two empty vehicle movements. The bottom right figure shows a backhauling loop with more than two lanes and could be further enlarged.

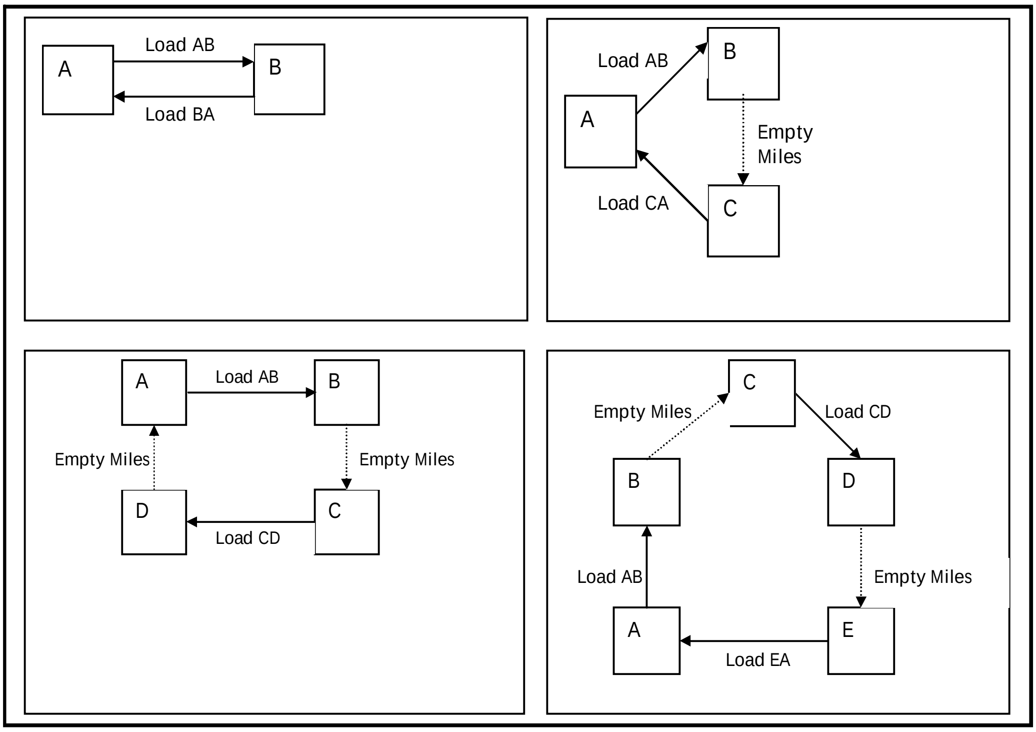

Figure 5.1 Four variants of Backhauling

The remainder of this report considers the following terminology:

- *Backhaul loop*: A tour consisting of at most two lanes, executed by one vehicle.
- *Lane*: A route between a supply and delivery location on which transportation takes place.
- *Load*: An actual transportation movement; the frequency of a lane is the number of loads per year.
- *Specified Routing Network*: a specific group of FTL transportation lanes within the Unilever European cross border routing network.

As discussed in Chapter 3, there are seven constraints to consider when optimising a routing network on tactical level. For the savings application we will consider these constraints as follows:

Distance

The distance has a direct impact on the costs, since transport service providers calculate lane prices based on formulas with a distance factor in it. Also, we can use the distance to calculate the prices per km for different lanes and backhaul loops.

Transit Time

The transit time is important to consider with respect to the maximum length of a backhaul loop. If a driver needs to be back home after a specific number of days, the sum of transit times of the lanes and the empty miles, if any, defines whether that backhaul loop is feasible or not.

Modality

The savings application only focuses on *road transport*. Other modalities (e.g. rail, sea) are excluded. The reasons for considering only road transport are twofold: On the one hand, approximately 90% of the transportation lanes of Unilever are carried out by road, which makes research to optimising the road network more relevant than any other modality. On the other hand, as discussed, the time windows of rail, sea, and air transport are stricter than for road transport. The schedules are not flexible and therefore slot management is more important to consider. This is a constraint on operational level, since it highly determines the day-to-day schedules at locations, which is not the focus of this research.

Hazardous

A fourth constraint is whether the product is hazardous or not. This constraint is of minor importance for backhauling, since products are not combined in one truck. Only cleaning activities after the truck has transported hazardous products, if required, affects the situation. We do not include this cleaning aspect in our problem description.

Shipping format

In this research we will consider *pallets* and *big bags* as shipping formats, i.e. the formats that fit in a regular truck. Since transport with silo trucks is a minority in the total transportation network of Unilever, and these trucks also have specific cleaning requirements, we do not consider silo transport in this research.

Frequency

The frequency of a lane is the number of loads that is transported on a lane on a yearly basis. If the frequencies of lanes are not considered when forming backhaul loops, the backhaul loop with the lowest total empty miles is always the most beneficial one to choose. However, if the frequency of the lanes are considered in the calculations, this could lead to different solutions. Let us illustrate this with an example. Consider Figure 5.2. Situation 1 combines Load AB with Load BC and Situation 2 combines Load AB with Load BD. The distances and frequencies of the loads are indicated in brackets. If we do not consider frequency, the calculations of the saved empty miles are as follows:

- Situation 1:
  - Without backhauling, the number of *empty miles*: 5 km (Load AB) + 10 km (Load BC) = 15 km,
  - With backhauling, the number of *saved* empty miles: 15 km – 3 km (Empty miles CA) = *12 km.*
- Situation 2:
  - Without backhauling, the number of empty miles: 5 km (Load AB) + 12 km (Load BD)= 17 km,
  - With backhauling, the number of saved empty miles: 17 km – 8 km (Empty miles DA) = *9 km.*

From this perspective, Situation 1 is more profitable, since this lane combination delivers the largest savings. If we also consider the frequencies of the loads, the situation changes. The lane with the lowest frequency determines the number of times a backhaul loop could be executed. This is the number of *joint loads*. The calculations with frequencies are as follows:

- Situation 1: Since Load AB occurs 20 times and Load BC 10 times, the number of joint loads is 10. The savings of this situation: 10 * 12 km = *120 km*,
- Situation 2: Since Load AB occurs 20 times and load BD 25 times, the number of joint loads is 20. The savings of this situation: 20 * 9 km = *180 km*.

From this perspective, Situation 2 is more profitable, since the total amount of saved kilometers on a yearly basis is larger. This example illustrates the importance of taking the frequencies, if known, into account.

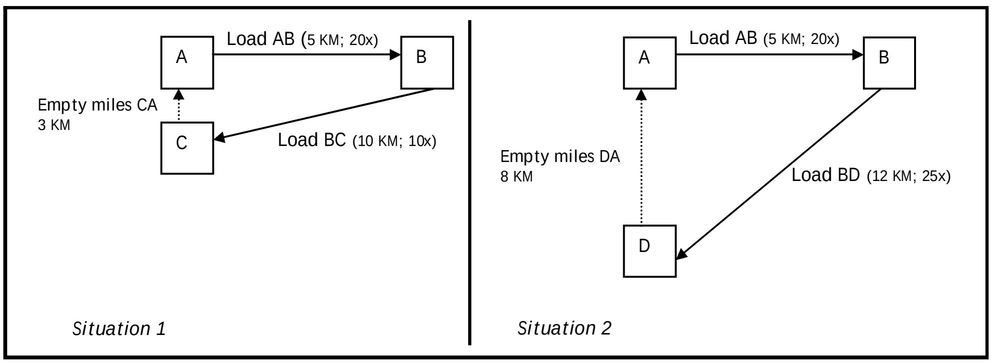

Figure 5.2 Example on frequency constraint

Temperature Control

For the routing network of Unilever, lane prices for the single lanes and for the backhaul loops are not fixed, but differ per specific situation, depending on the temperature control requirements of the lanes. The *lane price* is the market price of transporting one load from the supply to the delivery location (one way). To give an example: Let lane 1 and lane 2 be ambient lanes (i.e. no temperature control required during transport) and lane 3 a temperature controlled lane. A backhaul loop consisting of lane 1 and lane 2 is rather easy to calculate, since both the lanes require a regular truck. The lane prices remain unchanged. But, if lane 1 is combined with lane 3, the situation is different. As lane 3 requires a temperature controlled truck, also lane 1 will be transported in this truck. Since the costs of driving in this type of truck is more expensive, the lane price of lane 1 needs to be multiplied with a surcharge factor. This example illustrates that a lane price potentially changes, depending on the temperature requirements of the other lane in the backhaul loop.

Summarising, the tactical savings application that will be formulated in the next section, takes the following constraints into account: Distance, transit time, frequency, temperature control, and the lane price and is restricted to road transport of non- hazardous products in pallets and bigbags.

5.2 Mathematical formulation

The objective of the savings application is to determine the maximum cost savings for a specified routing network of full truckload lanes, by means of creating backhaul loops.

The underlying assumptions of our model are:

- The problem is static: Full lane information is known.
- All lanes have the volume of a standard full truckload; 33 pallets or 25 tons.
- Every lane is two-ended, i.e. the supply location is different from the delivery location.
- There are sufficient trucks available (both with and without temperature control system).
- Loads are city-specific; a city cannot receive a load from another, perhaps closer, location.
- There is no preference of which lane in a backhaul loop to serve first.

The problem can be described as follows: A routing network contains a region *1* and region *2*. There is a set L of transportation lanes l. Set L consists of type 1 and type 2 lanes. Type 1 lanes depart from a supply location in region *1* and drive to a delivery location in region *2*. Vice versa, type 2 lanes depart from a supply location in region *2* and drive to a delivery location in region *1*. Each lane l has a length D_l, which is the distance from supply to delivery location (one way), measured in kilometres. Each lane l also has a transit time TR_l, which is the time it takes to bring freight from supply to delivery location (one way), measured in days. The frequency of lane l is indicated with F_l and expresses the number of loads that take place on the lane on yearly basis. The temperature control requirement of lane l is indicated with a parameter with the value 0 or 1; TC_l is 1 if freight on lane l requires a temperature controlled truck and 0 otherwise. Each lane l has a lane price, LP_l, which is the price to pay to get a load transported from its supply to its delivery location, without a backload. S_{ij} denotes the cost savings obtained by serving lane i and lane j together in a backhaul loop. The binary decision variable X_{ij} is 1 if lane i and lane j are served together in a backhaul loop and 0 otherwise. A backhaul loop always consists of one type 1 lane and one type 2 lane.

The objective is to maximise the total cost savings of the routing network, i.e. the sum of the cost savings of the backhaul loops that will be implemented:

$$MAX \sum_{i,j.L} S_{ij} X_{ij}$$

Figure 5.3 gives a flow diagram on how the cost savings of a backhaul loop are calculated. In order to clarify the calculations, we will elaborate on each step separately.

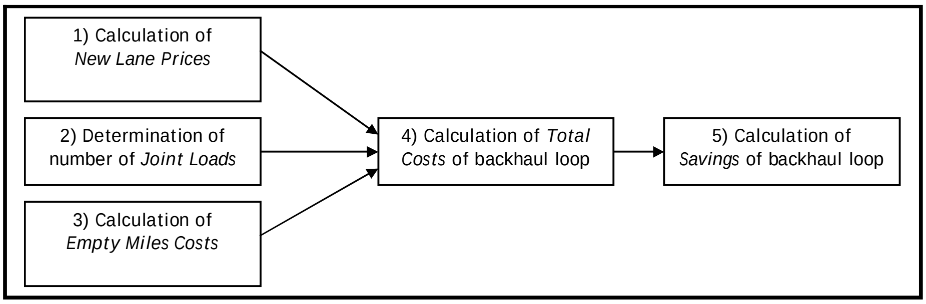

Figure 5.3 Flow diagram of calculating cost savings of a backhaul loop

1) Calculation of New Lane Prices

When a lane is combined in a backhaul loop, there are two factors that potentially change the lane price:

- Discount

Depending on the import-export balance of a region, a carrier is willing to give a discount (D) on the lane prices if he can serve the lanes in a backhaul loop. If a region has substantial more import than export (e.g. United Kingdom), a carrier is eager to get a backload out of this region, since it is hard to arrange one himself. In this situation, the carrier will give a discount on the lane prices. On the contrary, if a region has a substantial more export than import (e.g. the Netherlands), a carrier can easily arrange a load out of this region himself (and get a high margin on both separate lanes). In this case, he will not give a discount. Since the import-export balance highly differs per region, the discount differs accordingly.

o Temperature control surcharge

As discussed, if lanes are combined in a backhaul loop, the lane price is potentially multiplied with a temperature control surcharge factor. For a backhaul loop of lane *i* and lane *j*, holds that the lane price of lane *i* is multiplied by a surcharge factor (*SC*), if lane *i* is ambient (TC_i=0) and lane *j* is temperature controlled (TC_j=1). The same surcharge applies to lane *j* if the situation is vice versa: If lane *j* is an ambient lane and lane *i* is temperature controlled.

2) Determination of number of Joint Loads

As discussed, a lane takes place a number of times per year, i.e. the frequency. If lane *i* and lane *j* are transported in a backhaul loop, this loop only occurs if both the lanes have a load to be transported. The number of joint loads (JL_{ij}) is therefore the minimum of the frequencies of the involved lanes:

$$JL_{ij} = min\ (F_i,\ F_j)$$

The remainder of the loads of the lane with the largest frequency is satisfied in a non-backhauling truck. These loads will not be further considered as option to combine with another lane, since this goes beyond the practical situation.

3) Calculation of Empty Miles Costs

Figure 5.4 demonstrates the empty miles between the supply locations (SL) and delivery locations (DL) of which we aim to calculate the costs. Since two regions might have different fuel prices and other cost factors, we calculate the costs of the empty miles in region *1* and in region *2* separately. Depending on the type of backhauling loop, see Figure 5.1, we have zero, one, or two empty miles distances.

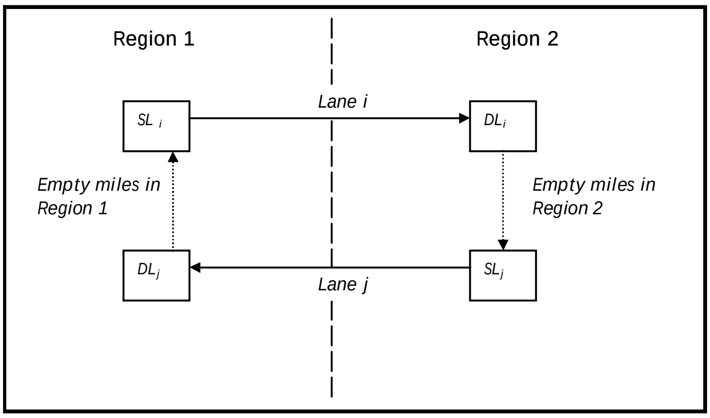

Figure 5.4 Empty miles regions in a backhaul loop

The costs of empty miles consist of two elements. We will illustrate how to determine the costs of empty miles of region 1:

- *Distance related costs* depend on the distance between the delivery location of lane j and the supply location of lane i (E_{ij1}). A region-specific fixed cost per kilometer (Ekm_1) is multiplied by this number of kilometres.
- *Time related costs* depend on the time it takes to drive the empty miles. A region-specific fixed cost per hour ($Ehour_1$) is multiplied by the number of hours it takes to drive the empty miles. This depends on the average speed of a driver in a region (S_1). Also, there is a fixed number of hours included for the waiting time (WT) at the locations in the region.

The costs of empty miles of region *1* for the backhaul loop of lane i and lane j ($TotalECosts_{ij1}$) are:

$$TotalECosts_{ij1} = E_{ij1}Ekm_1 + ((E_{ij1} / S_1) + WT) * Ehour_1 \qquad i, j \in L$$

The costs of the empty miles of region 2 are calculated similarly. The costs of empty miles are based on ambient truck prices. Similar as for the lane price, also the costs of empty miles could be multiplied by the surcharge factor, depending on the temperature control requirements of the lanes. If both the lanes i and j in a backhaul loop are ambient, no extra costs are charged. In any other case, the costs of empty miles are multiplied by the surcharge factor.

4) Calculation of total costs of backhaul loop

The total costs of a backhaul loop on yearly basis (TCB_{ij}) are the sum of three elements:

- The total costs of empty miles multiplied by the number of joint loads
- The sum of the new lane prices of the involved lanes multiplied by the number of joint loads
- The original lane price of the lane with the highest frequency multiplied by the number of loads served in a separate truck

5) Calculation of savings of backhaul loop

The yearly savings of a backhaul loop are the difference between the yearly costs of serving the lanes in separate trucks, i.e. the lane price multiplied by the frequency, and the yearly costs of serving the lanes in a backhaul loop:

$$S_{ij} \quad LP_iF_i + LP_jF_j \quad TCB_{ij} \qquad i, j \in L$$

The next section elaborates on an exact and a heuristic algorithm that determine what backhaul loops to execute in a network and which lanes to serve in separate trucks.

5.3 Solution methods

In this section we first present an exact algorithm to solve the problem for a small routing network. After that, we will present a heuristic algorithm to find solutions for large routing networks.

5.4.1 Exact algorithm

The exact algorithm that we use in the savings application explicitly enumerates all possible backhaul loop combinations for a specified routing network: First, it calculates the savings of all potential backhaul loops in the network. After that, it calculates the total savings for the network for each combination of backhaul loops. For example: Consider a network of two type *1* lanes and two type *2* lanes. Figure 5.5 demonstrates the backhaul loop combinations for this network.

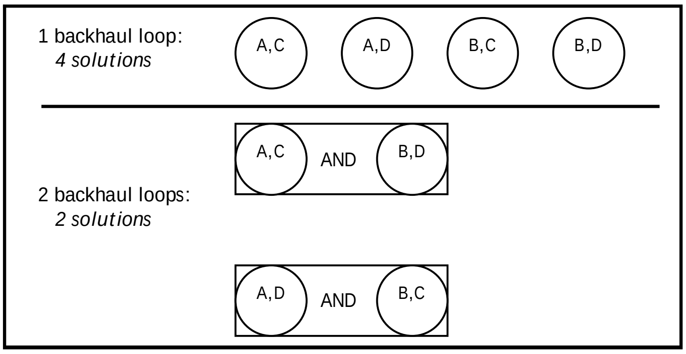

Figure 5.5 Solutions for a two by two lanes network

The circles represent the backhaul loops in the network. The first letter (A or B) in a circle is the type *1* lane and the second letter (C or D) is the type *2* lane that together are combined in a backhaul loop. The different options for this network, for which the exact algorithm calculates the savings, are:

- All the lanes are served in separate trucks, resulting in no savings (= 1 option),
- As the upper part of Figure 5.5 indicates: Two lanes are combined in a backhaul loop and the other two lanes are served in a separate truck (= 4 options),
- All lanes are served in a backhaul loop; i.e. there are two beneficial backhaul loops. The options are shown in the lower part of Figure 5.5 (= 2 options).

The example of a two by two network has 7 options, where for a network with three lanes of both types, there are 34 potential backhaul loop combinations. For a four by four network, this number is 209. To give an impression on how the number of backhaul loop combinations increases exponentially with the size of the network: A ten by ten network delivers over 30 million combinations. It takes substantial computer calculation time to calculate an exact solution for networks of this size. Therefore, we present a heuristic to generate solutions for large routing networks in the next section.

5.4.2 Heuristic algorithm

As explained in Chapter 4, to solve the routing problem with a heuristic, two phases could be considered: A *construction* algorithm to obtain a basic feasible solution and an *improvement* algorithm that tries to improve this basic solution. This section first elaborates on the construction algorithm of the savings application and then on the two improvement algorithms that the savings application executes.

Construction Algorithm

As discussed in Chapter 4, both the Savings Algorithm of Clarke and Wright [Clarke, Wright, 1964] and the Backhauling Algorithm of Jordan and Burns [Jordan, Burns, 1985] are useful to generate a basic feasible solution for a routing network. Therefore, the developed algorithm for the savings application contains elements of both these algorithms. Figure 5.6 illustrates the iteration process of the construction algorithm. In the initial situation, each lane is served in a separate truck. Then, for each type 1 lane the cost-savings and kilometre savings of a backhaul loop with all type 2 lanes are sequentially calculated. The algorithm picks per type 1 lane, depending on the priority rule, the backhaul loop that generates either the largest *cost* savings or the largest *kilometre* savings. When for eacht type 1 lane the best loop with a type 2 lane is determined, the algorithm picks, again based on a priority rule, out of these backhaul loops the one that either delivers the *most* or the *least* savings. The lanes corresponding with the solution are erased from set L. This process is repeated until either all type 1 lanes are combined in a backhaul loop or only negative savings are found. At the end of the algorithm, there is a list of backhaul loops with a maximum amount of the number of type 1 lanes.

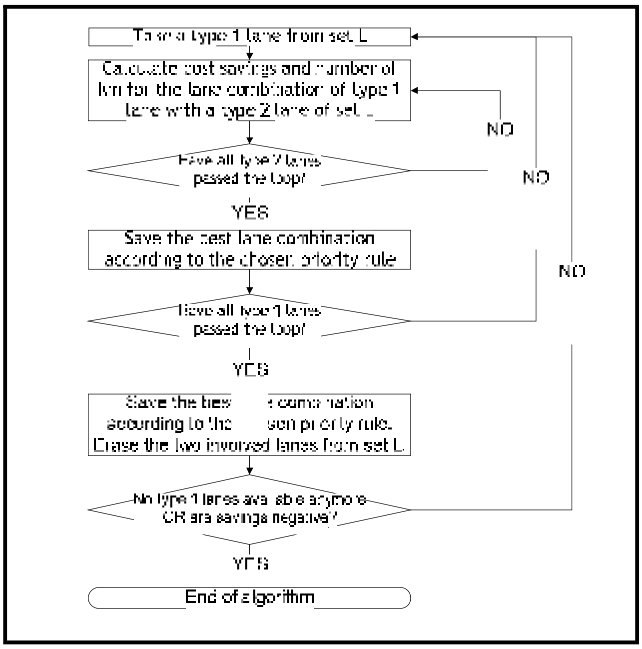

Figure 5.6 Flow diagram of heuristic algorithm

Improvement Algorithms

After the construction phase, two different improvement algorithms are executed: 2-Opt and the set partitioning algorithm. To illustrate the customised 2-opt algorithm with an example: Consider the backhaul loops in Figure 5.7. In this solution, 2-opt swaps lane A with lane C and calculates the savings of the newly obtained backhaul loops of lanes C & B and lanes A & D. If the sum of the savings of these backhaul loops is larger than the original savings, the algorithm changes the solution. The heuristic tests the swaps between every backhaul loop combination in the basic solution. It also analyses the potential benefits of swapping the type *2* lanes that are served in a separate truck in the basic feasible solution.

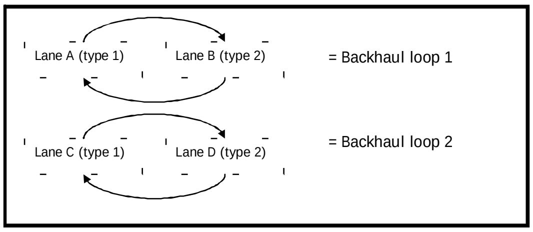

Figure 5.7 2-Opt

Besides 2-opt, the model also executes the set partitioning algorithm to find an improvement in the basic solution. As explained in Section 4.3, the algorithm determines new lane prices for the lanes that are served in a backhaul loop. After that, the construction algorithm is executed again to find out whether a solution with more savings could be found in this network with modified lane prices.

The next chapter transforms the discussed savings application into a concrete application in Excel. The application generates proposals for concrete specified networks within the European routing network. The different algorithms are executed in the application, which results in a proposal. A proposal contains a list of which lanes to combine in a backhaul loop and which to serve in a separate truck. Also, it summarises how the network looks like in terms of generated cost and kilometre savings.

6. Conclusions

The contributions of this research to the Everest team of the USCC are twofold: On the one hand, it provides a good understanding on the *constraints* of the European cross-border routing network. On the other hand, it delivers a *tactical savings application* that calculates potential cost- and kilometre savings for specified groups of full truckload (FTL) transportation lanes within this routing network.

An in-depth analysis of the European transportation market shows that demand for truck transport increases, while at the same time available truck capacity is shrinking. Together with the facts that costs for transport sincerely rise and that companies feel a growing responsibility for their carbon footprint reduction, it is essential to find optimisation opportunities to use the available truck capacity at full potential. To obtain reliable optimisation solutions, full transparency and centralised responsibility of the transportation lanes in Europe is required. Currently, transparency is lacking and responsibility is fragmented. The Everest team creates a central transport organisation with full transparency and centralised responsibility. This report gives proposals to optimise the network once full transparency is established.

To be able to identify relevant optimisation opportunities for the Unilever routing network, it is evident to know the constraints of the routing network and to understand their impact on potential savings. Due to the variety of business groups within Unilever, there is a large number of constraints that require a detailed look. There is a split between location- and freight constraints. *Location* constraints consider the requirements of locations in the network, i.e. sourcing units, warehouses, and distribution centres. *Freight* constraints concern the characteristics of the products to be transported. This research points out that the impact of constraints is not the same for different levels of decision making. On strategic level, the stock model and production schedule of locations play an important role, e.g. when determining the trade-off between warehousing- and transportation costs. On the contrary, slot management and order lead time are constraints to consider when optimising a day-to-day routing schedule, which concerns the operational level of decision making. The following lane characteristics are necessary to look at when optimising a routing network on tactical level: The frequency, temperature control, lane price, distance, and transit time of transportation lanes.

Two optimisation opportunities to use available truck capacity efficiently are c*onsolidation*, which ensures that truck space is optimally used through consolidating LTL lanes, and *backhauling*. Backhauling strives for minimisation of empty driving of trucks through serving FTL lanes in a backhaul loop. A backhaul loop is a combination of 2 lanes that are sequentially served with the same truck. The savings application presented in this research, is focused on backhauling and searches for beneficial backhaul loops within a specified network of lanes. For small networks, i.e. up to 5 backhaul loops in a network, the model calculates all potential solutions exactly, which delivers an optimal solution of backhaul loops for a network, with corresponding cost- and kilometre savings. Due to the large calculation time that the exact algorithm requires, a heuristic is used to generate solutions for larger networks. The savings algorithm of Clarke and Wright and the backhauling algorithm of Jordan and Burns are the two heuristics on which the heuristic of the savings application is based. Besides generating a basic feasible solution, the model also tries to improve this solution with the 2-opt and set partitioning algorithms. Two factors that highly influence the savings are the import- export balance of a region and the choice to focus on open- or closed backhaul loops:

- The import-export *balance* of a region expresses the volume that is transported into and out of a region. It influences the chance to find a backload for a carrier and accordingly the discount a carrier offers to drive a backhaul loop. Also, the guarantee for a carrier to find an own backload out of a region depends on the balance. This guarantee rate influences the impact backhauling has on the carbon footprint reduction.
- The choice for *open*- or *closed* backhaul loops determines whether a truck needs to return to its start location or not. Solutions with open loops show substantial higher savings, since the empty miles of one region are not considered. For open backhaul loops, the model determines in which region it is more profitable to start the trip, i.e.which empty miles to include in the trip.

The savings application is designed in a user-friendly way, which enables the Everest team to calculate savings for other specified routing networks in Europe too.

7. Recommendations

We appoint 3 recommendations that are directly related to the research area:

- The savings application proposes beneficial backhaul loops, based on lane information and environmental factors. We would like to emphasise that only in consultation with the involved locations and synchronisation of pickup and delivery slots, the backhaul loops could be implemented on operational level. Moreover, once a feasible backhaul loop is agreed with the involved locations, one needs to find a suitable transport provider that can accomplish this loop against a certain discount. We recommend not to underestimate the efforts required on operational level to implement the proposed backhaul loops.
- A second recommendation concerns the decision to implement open- or closed backhaul loops. The results of the savings application point out that savings for networks with open backhaul loops are substantial higher. Therefore, we recommend to design transport in that way that these loops could be executed. One option might be to rent a truck and driver for a fixed time period and optimally schedule a route for that period. In this situation, a carrier is not obliged to return to its start location but is free to start the next backhaul loop. Different KPIs, such as the price/km with and without backhauling, are useful to develop a solid pricing model for this way of managing transport.
- A third recommendation is to develop a model that also calculates routes with more than 2 involved transportation lanes, of which the maximum number of lanes depends on the allowed duration of a trip. In all likelihood, a backhaul loop with more than 2 lanes delivers larger savings.

Further research

We would also like to shortly zoom in on three topics that are relevant to further research. First, this research focused on road transport, since it concerns the majority of the transportation lanes of Unilever's routing network. However, since mainly *rail transport* increasingly gains popularity within Europe, it is relevant to research the backhauling possibilities within this modality. Swop bodies, i.e. containers that could be both placed on a trailer and a train, could be useful for combining rail and road transport. A second recommendation is to determine the savings potential of *consolidation* too. Although LTL lanes are a minority in the European routing network, the savings of optimally using truck capacity could be large. Before a study to the savings potential of consolidation of LTL lanes could take place, first a reliable dataset needs to be obtained. A European freight tender could serve as a tool to obtain a benchmark of actual market prices for these lanes. Related to this research on LTL lanes, also a research on the benefits of placing *hubs* is an important area to further research. Substantial literature is available on this topic and it requires input from both the transportation and warehousing side of logistics. A third area of attention is *real time scheduling* of trucks, which is a subject that belongs to the day-to-day operations. Connecting real time information of where trucks are to where demand for transport is, might lead to further savings in a dynamic routing network.

Glossary

3PL:	Third Party Logistics; another company that provides a service.
4PL:	Fourth Party Logistics; Example: DHL arranges transport by having contracts with several smaller transportation companies.
ADR:	the French abbreviation for 'Accord Européen relatif au transport international des marchandises dangereuses par route'. In English: 'The European Agreement concerning International Carriage of Dangerous goods by road'.
Ambient:	transport without temperature control.
Backhaul loop:	A tour consisting of at most two lanes, executed by one vehicle.
CMR:	Convention on the contract for the international carriage of goods by road.
Cross- border:	Transport lanes of which supply and delivery location are in different countries.
Empty miles:	The kilometres that a truck drives without a load.
FG:	Finished Goods, products that are transported from SU to warehouse.
FMCG:	Fast Moving Consumer Goods; the branch Unilever belongs to.
FF:	Freight Forwarder; a transport provider without own assets.
(Freight) Lane:	Route between two locations in the supply chain on which a certain amount of freight is transported.
FTL:	Full Truckload; a truck is loaded with 33 pallets or 20 tons raw material.
HPC:	Home- and Personal Care; business group of Unilever
ICF:	Ice Cream and Frozen foods; business group of Unilever
Joint Loads:	The number of loads that two lanes in a backhaul loop have in common.
Lane Price:	The actual market price that Unilever has to pay for transport on a lane.
Load:	An actual transportation movement; the frequency of a lane is the number of loads per year.
Load rate:	Transport price per truck, including wages etc.
LTL:	Less than Truckload; a truck is only partially loaded.
MSO:	Marketing Sales Organisation
NDC:	National Distribution Centre
Priority Rule:	a rule that defines which new location should be inserted in a tour, e.g., the nearest neighbour.
SU:	Sourcing Unit
Transit time:	No. of days the transport takes from A to B.
TSP:	Transport Service Provider
Unbalance:	the difference between the number of lanes that enter and leave a country.
USCC:	Unilever Supply Chain Company
UTPO:	Unilever Transportation Planning Organization

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Appendices

Table of Contents

A. Corrugated cardboard transport lanes

This document summarizes the general findings of the short research on corrugated transport, done by Simone Verhoeven. It gives an overview of the ways of working of several sourcing units, an updated version of the costs compared with the international transport formula and some immediate areas of attention, where inefficiencies seems to occur.

Sourcing Unit constraints

In a questionnaire the SUs answered several questions regarding stockholding possibilities, order lead time towards suppliers and flexibility in receiving freight: opening hours and days, slot management etc. The excel sheet shows the outcomes of these questions in an overview (SU characteristics.xls). Next to that, the other excel sheet (corrugated transport cost analysis.xls) shows an updated version of the transport costs compared with the formula internationally used (1.03X+100). Besides focusing on potential savings in Euros, it is also worth it to consider the lanes that show a huge discrepancy with the calculated costs with respect in percentage.

General findings

Transport prices differ a lot in different countries in Europe, therefore it is not representative to use the international transport formula (1.03X+100) for domestic transport. Mainly driver wages and fuelling costs differ in large extent amongst the countries. Every potential saving should be checked with a local transport manager, as they have better understanding of the local transport market. SUs are obviously used to their ways of working and aim to stick on that (resistance to change). Old contracts with suppliers should be reconsidered, as the agreements and numbers might be outdated.

Immediate recommendations for further research:

Caivano: supplier SADA delivers ± 20 trucks a week, which all have 16 pallets. Both supplier and SU are able to switch to FTL, just due to contracts made in the past, they are used to this. Caivano has stock holding possibilities. Immediate action possible!

Nyirbator: supplier Dunapack (Alliabox) charges a high transport price, although constraints at SU are good. Reasons might be: weekend delivery, emergency delivery (LTL trucks) and lack of sufficient stockholding at SU.

St. Vulbas: supplier Alliabox is located at 300 m distance, but charges a very high price per truck. There is daily delivery of 10 pallets, because there is no stockholding possibility at St. Vulbas.

Buxtehude: supplier THIMM charges extremely high prices from both their factories to all (satellite) factories of Buxtehude. Renegotiation of contracts is recommended.

B. Set Partitioning Algorithm

The goal is to minimize costs of the total network. It is formulated as follows:

$$\min \sum_{j=1}^{n} c_j x_j \qquad (1)$$

Such that:

$$\sum_{j=1}^{n} a_{ij} x_j = 1 \qquad \forall i - 1,2,\ldots,m$$

$$x_j \in \{0,1\} \qquad \forall j = 1,2,\ldots,m$$

Where:

c_j = the cost of tour j

x_j = the decision whether tour j will take place

a_{ij} = indicate whether tour i is performed in tour j (1) or otherwise (0)

If one calculates with different partitions (different feasible solutions) each iteration the prices of the routes are adapted. To determine the best combinations of trips, the following calculation is made:

$$\sum_{i=1}^{m} p_i^1 a_{ij} - c_j \qquad (2)$$

The costs of the single lanes that are combined in a tour summed up minus the roundtrip price are calculated and the tour representing the biggest saving is picked. The lanes involved in this tour are erased from the set of lanes and the second best saving is chosen next. This iteration is repeated until either all lanes in the set are combined or only zero or negative savings appear.

The next step of the algorithm is to recalculate the prices of the lanes that are in the combined tours. Example: lanes 1 and 2 are in Partition 1 chosen to be together in a tour. c_1 is the original route price of lane 1 and c_2 the price of route 2. $c_{combined}$ is the total cost of serving lane 1 and lane 2 in a backhaul loop. Assume that lane 1 costs 2,500E and lane 2 costs 1,000E each and the backhaul loop costs 3,000E. The new price of route 1 for calculating Partition 2 is:

$$p_1^2 - \frac{c_1 c_{combined}}{c_1 + c_2} \qquad (3)$$

In this formula the new lane prices for lane 1 and lane 2 become:

p_1=2,500*3,000/3,500=2,143E

p_2=1,000*3,000/3,500=857E

To double check this formula: the sum of both the new lane prices is 3,000E, which is the price of the backhaul loop. With these new prices the algorithm is executed again, to verify if there exist backhaul loop prices that are more profitable than the once appointed in partition 1.