Optimisation and Integration in Local Food Distribution

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Abstract

Increased interest is being shown in local, regional and traditional food and confidence in such food is high among consumers. There is also more interest in the transparency of the food supply chain. Therefore places and modes of production and traceability as aspects of food quality have gained more and more importance in the recent decades.

This necessitates the development of new knowledge of the specific logistics system to be able to identify successful approaches to improving the local food supply chain. Important questions may arise such as whether local and small-scale food producers can transport their goods more efficiently and how they can improve through cooperation and integration.

The aim of this thesis was to study how cooperation, optimisation and integration in the supply chain for local and small-scale food producers can make distribution more efficient and to estimate the environmental impact from the transports.

This work analyses, demonstrates and further develops distribution strategies for local and small-scale food producers and distributors, together with their environmental impacts. The work is based on three case studies in Sweden that have distribution systems on different scales.

The distribution system in Paper I includes logistics with local food and transport companies in and around Uppsala. In Paper II, a group of small-scale producers in Halland was integrated into a bigger retail chain using an electronic trading system. In Paper III, a distribution system for municipal units in four municipalities in Dalarna was analysed.

Data was collected by observations, questionnaires, interviews and from summaries of orders and public procurements. By mapping distribution networks, optimising routes and estimating emissions, possible improvements in the distribution system were ascertained.

There is potential for local and small-scale food producers to improve their distribution and reduce their environmental impact. Cooperation, integration and route optimisation are strategies that are suitable for producers to adopt in order to make their transports more efficient.

Keywords: transport, local food, food producers, supply chain, distribution system, environmental impact, coordination, integration, emissions

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Adieu, dit le renard. Voici mon secret. Il est très simple: on ne voit bien qu'avec le cœur. L'essentiel est invisible pour les yeux.

Le Petit Prince, Antoine de Saint-Exupéry

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to in the text by Roman numerals:

I Gebresenbet G., Nordmark I., Bosona T. & Ljungberg D. (2011). Potential for optimised food deliveries in and around Uppsala city, Sweden. *Journal of Transport Geography* 19 (6), 1456-1464.

II Nordmark I., Ljungberg D., Gebresenbet G., Bosona T. & Jüriado R. (2012). Integrated Logistics Network for the Supply Chain of Locally Produced Food, Part II: Assessment of E-Trade, Economic Benefit and Environmental Impact. *Journal of Service Science and Management*. 5 (3), 249-262.

III Bosona T., Nordmark I., Gebresenbet G. & Ljungberg D., GIS-based optimisation analysis of integrated logistics network in local food supply chain. (Submitted to Biosystems Engineering)

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The contribution made by Ingrid Nordmark to the papers included in this thesis was as follows:

I part of data analysis particularly on unloading parameters and participation in writing

II complementary data collection and analysis, main responsibility for writing

III project planning, data collection, part of data analysis and writing

List of other publications not included in this thesis:

Bosona T., Gebresenbet G., Nordmark I. & Ljungberg D. (2011). Integrated logistics network for the supply chain of locally produced food, Part I: Location and route optimization analyses. *Journal of Service Science and Management* 4(2), 174-183.

Bosona T., Gebresenbet G., Nordmark I. & Ljungberg D. (2011). Box-Scheme Based Delivery System of Locally Produced Organic Food: Evaluation of Logistics Performance. *Journal of Service Science and Management* 4 (3), 357-367.

Ljungberg, D., Gebresenbet, G., Nordmark, I., Bosona, T. G., Jüriado, R., Cardoso, M. & Redman, L. 2011. *Lokal matlogistik - Möjligheter till utveckling, effektivisering och integration med storskaliga logistikkedjor*. Internal report, Swedish University of Agricultural Science.

Abbreviations

AP	Acidification Potential
CC	collection central
CO	carbon monoxide
CO_2	carbon dioxide
DC	distribution central
EP	Eutrophication Potential
GIS	geographical information systems
GWP	Global Warming Potential
HC	hydrocarbon
HTP	Human Toxicity Potential
LCA	Life Cycle Assessment
NO_X	nitrogen oxides
PM	particulate matter
SO_2	sulphur dioxide
VRP	Vehicle Routing Problem

1 Introduction

Confidence in local food is high among consumers. The transport of local food is often thought to have a lesser environmental impacts than food that has travelled long distances. Does actual transport really meet these expectations? Can local and small-scale food producers make their transport more efficient? How can they improve through cooperation and integration?

1.1 Consumer demand for local food

There is considerable interest in local food and the desire for more 'local', 'alternative' or 'traditional/speciality' foods is well reflected in academic publications (Ilbery & Maye, 2005[1]). Consumers commonly view local food as more genuine, natural and environmentally friendly, of higher quality and better in terms of employment in the countryside and rural development (Wretling Clarin, 2010). Interest in maintaining open landscapes and protecting biodiversity are some of the other reasons why people support local and smaller-scale production.

The increased interest in local, regional, traditional and seasonal food can be explained by factors such as those presented by Hughes (2003): globalisation awakening interest in returning to what is traditional and local; an ageing population, as in the UK; concern for the environment and the large fuel use due to long transport distances; concern about the safety of global food; heavy media focus on food in shows and magazines, re-acquainting consumers with their (real or imagined) cultural heritage; it is nice to buy and since expenditures on food is a relatively small part of the family budgets (at least in

1. Illbery & Maye (2005) mention a number of themed sections and special issues published in *International Planning Studies*,4 (3), 1999; *Sociologia Ruralis*, 40 (2), 2000; 40 (4), 2000; 41 (1), 2001; 42 (4), 2002; *Journal of Rural Studies*, 19 (1), 2003; *Environment and Planning A*, 35 (3), 2003 and the *British Food Journal*, 105 (8), 2003.

wealthier parts of the world), local food can be "something special" that many can afford.

There is also a retro-trend, described by Hughes (2003), including major retailers wanting to stock unique local and regional products; a renaissance in farmer's markets; leading edge initiatives serving to reinforce the importance of local and speciality foods; offering special products is a way for restaurants and others to differ from the mainstream; a saturated global market forcing producers to seek higher value market opportunities; IT-development simplifying the connection between small-scale producers and large-scale customers; pressure from customers, lobbyists and competitors.

There is no general definition of local food (Jones, Comfort & Hillier, 2004; LivsmedelsSverige, 2012) although some organisations have definitions stating that food within a certain distance is local. An example is "Bondens egen marknad", farmers' market in Swedish with a limit of 250 km [2]. In the northern part of Sweden though (in Sweden's largest county, Norrbotten) the market is open for products from all over the county (Kask, 2012), with distances up to around 400 km accepted. Proposals on how to use the term 'local food' are being evaluated in Sweden (LivsmedelsSverige, 2012).

Recognising the difficulties in finding a strict definition covering all relevant aspects of the term, this thesis considers local food as *food produced and consumed within the same geographical region*. The definition of a region will vary and is dependent on what the inhabitants refer to as local.

1.2 Local food and sustainability

Sustainability as a term is used in many ways. One of the definitions often quoted is the Brundtland Commission's: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). It is a wide definition and nowadays the term is often referred to as the integration of social, environmental and economic responsibility (Lehtinen, 2012). This view featuring the three aspects is referred to as the triple bottom line (TBL). This term of the concept was developed during the mid-1990s and expressed the fact that companies and other organisations have created values in several dimensions but can also destroy values (Elkington, 2006).

Locally produced food is not automatically better for the environment than non-local food just because it is produced closer to the end customer (Ilbery & Maye, 2005; Wallgren, 2006) and criticism has been directed at the use of

2. Bondens egen marknad, Info, http://bondensegen.com/page.php?page=info, 2012-06-14

distance alone as a measurement of environmental impact (Coley, Howard & Winter, 2011; Johard *et al.*, 2012). Studies that compare the transport of local food with non-local food have so far not been able to determine which transportation is better in environmental terms (Wallgren, 2006; Van Hauwermeiren *et al.*, 2007).

The transparency in food produced nearby can be higher than food produced far away, which can be advantageous for locally produced food. The increased use of globalised systems for food production has increased our reliance on other nations. In Sweden (1994) over one third (35%) of food consumption needed agricultural areas abroad (Deutsch, 2004). This has an impact on distant ecosystems and as Deutsch (2004) stresses, it is important to have an understanding of these effects in order to secure food production and support these ecosystems. This should be applied no matter whether food is being produced nearby or far away.

1.2.1 Emissions from transport

Transport is a sector that uses a great deal of energy, has a major impact on the environment and is strongly dependent on fossil fuels. Almost one third of the world's energy consumption is on transport. In Sweden transport makes up approximately 23% of the country's final energy use[3] (Energimyndigheten, 2012). Most energy in the Swedish transports sector is used on road. Fossil fuels, mainly petrol and diesel, dominate and renewable fuels only make up a few per cent. The goods sector mainly uses diesel and the passenger sector mostly petrol. The use of petrol in Sweden has decreased in recent years, while diesel use on the increasing (Svensson, Kadic & Lindblom, 2012).

The energy used in the food supply system in Sweden[4] is about 34 TWh (in 2000) according to Wallgren (2006). Transport's share of total energy use in the supply chain is 14% (4.9 TWh, in 2000). The transport using private cars for shopping represents a large amount (2.0 TWh) of this energy use – an interesting phenomenon which is not however analysed in this thesis.

Transport's contribution to the total supply chain may be minor. This is often the case in meat supply chains. Foster *et al.* (2006) reports on beef supply chain where transport is 3-5% of the supply chain's global warming impact and energy consumption. In other supply chains the contribution is greater. In a

3. Energy use excluding losses in nuclear power stations, conversion and distribution losses, international transport and non-energy purposes (raw materials for the chemical industry, lubricating oils and oils used for surface treatments in the building and civil engineering sectors, etc).

4. Based on the food consumption of Swedes rather than the Swedish food production system.

bread supply chain[5] (in Sweden) transports can represent 39% of a chain's contribution to global warming, 46% of acidification and 10% of eutrophication (Foster *et al.*, 2006). In a life cycle assessment (see section 1.2.2) of peeled potatoes (in the United Kingdom), distribution to retailers used 12% of energy demand, contributed 1% to acidification potential and 15% to climate changing impact.

Even though the impact of transport in total food supply chains may be minor, food transport is essential to us. We have to plan for this and cannot expect that this transport will be entirely replaced or not needed.

The concept of eating and the need for food is so very basic and so important that the transport of food can be seen as one of the most important types of transport at all. The fact that people in general no longer grow their own food and that the food market has become more globalised contributes to making it even more essential. Given our increased awareness of the impact of human activities on our environment, we are also more aware of the need to reduce some of these activities. Emissions play an important part here and most emissions come from the transport sector.

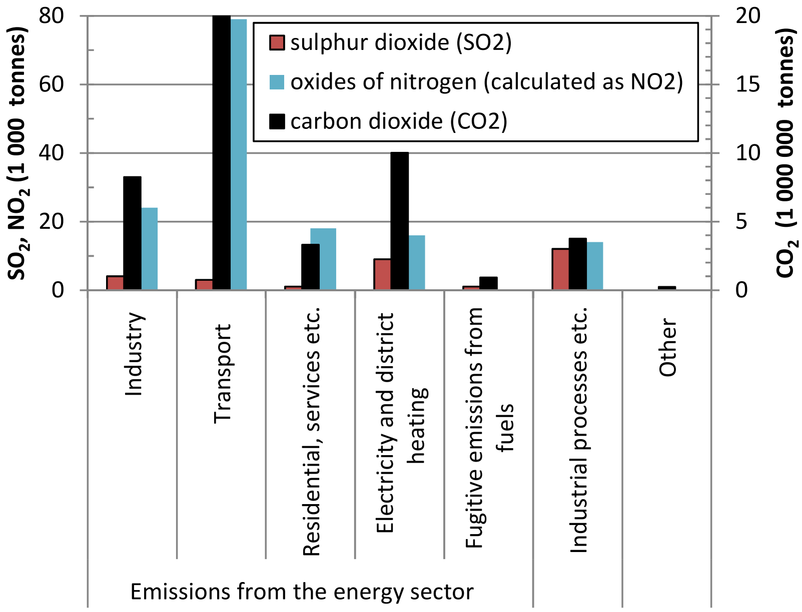

Figure 1. *Emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and oxides of nitrogen (calculated as NO_2) in Sweden 2009 (Energimyndigheten, 2012)*

5. Life cycle study of a large industry bread supply chain. The chain includes primary production agriculture, processing, milling and baking, transportation and the consumer in the home.

Of total emissions from energy use in Sweden, emissions from transport (in 2009) represented 43% of carbon dioxide (CO_2), 10% of sulphur dioxide (SO_2) and 53% of nitrogen oxides (NO_X). In the energy sector (including industry, transport, residential, services etc., electricity and district heating, fugitive emissions from fuels) transport is the largest contributor to CO_2 and NO_X, and the third largest to SO_2 (Figure 1).

Apart from the environmental aspects of transport there is also the resource aspect. We have to realise the limitations of resources, such as fossil fuels, and plan for it. Peak Oil[6] is of special concern for the transport sector since oil dependence is very high among the world's vehicle fleet.

There are many reasons for making transport more efficient and less dependent on fossil fuels as well. Global agreements in order to achieve more sustainable development have been in place for some decades, with a highlight being the UN's conference in Rio de Janeiro in 1992. The Swedish government has set a high goal for the vehicle fleet: "By 2030, Sweden should have a rolling stock, independent from fossil fuels" (Miljödepartementet, 2009).

1.2.2 Measuring environmental effects

Life cycle assessment (LCA) – a methodology used in studies of products, services or system – estimates the potential environmental impact. This methodology is standardised (in the ISO 14040 and 14044 series) and can estimate energy balance as well as emissions to air, water and the ground. Typical environmental impacts estimated by LCA are the potentials of global warming, acidification, eutrophication and human toxicity.

There are many ways of estimating global warming and its potentials. The most common, but not unchallenged (Fuglestvedt *et al.*, 2003), is the Global Warming Potential of the IPCC[7] with 100 years perspective (GWP100).

Acidification is caused by elevated amounts of protons in the ground or water *e.g.* from sulphur dioxide in fuel emissions. Eutrophication is caused by increased amounts of *e.g.* nitrates and phosphate from fertilisers in agriculture and from fuel emissions. The degree of toxicity for humans is a "degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of human exposed to the substance over a designated time period" (Institute for Environment and Sustainability, 2012).

6. "The term 'Peak Oil' refers to the maximum rate of the production of oil in any area under consideration, recognising that it is a finite natural resource, subject to depletion." Colin Campbell, About Peak Oil, http://www.peakoil.net/about-peak-oil

7. Intergovernmental Panel on Climate Change

Small parts of material called "particulate matter" (PM), usually under 10 micrometres in size, are emissions that often cause problems for the human body. Particulates are emitted from the combustion of fuel as well as from the wearing of roads and tires. Combustion emits small particulates, while wearing results in larger particulates. Particulates are a cause of increased illness and mortality and are connected to heart and lung diseases (Naturvårdsverket, 2011).

1.3 Constraints in local food supply

Consumers are increasingly concerned about food safety and quality, including food-borne illness, humane animal treatment, genetic modification and overall product safety and integrity. As a consequence, there is increased interest in the transparency of food supply chains. Places and modes of production and traceability as aspects of food quality have gained more and more importance in recent decades.

The interest in supporting farming and businesses in the countryside comes both from consumers and from society. Several municipalities in Sweden want to increase the amounts of locally produced food in municipal units, such as schools, pre-schools and homes for the elderly. In many stores local products are highlighted due to customer demand. This has aroused interest in local food production using local resources and productive inputs. Hence, local food production may represent a strategic value aspect of which farms and other small-scale food processing firms can take better advantage in their business initiatives and marketing efforts. Small-scale local producers can offer quality product (traditional recipes, artisan products) and stress the importance of product origin and transparency of the food chain as competitive factors.

For producers, several factors are important in the food supply chain such as quality, technology, logistics, information technology, the regulatory framework and consumers (Bourlakis & Weightman, 2003). Food products must be of good quality, safe, healthy and traceable (food traceability has been mandatory within the EU since 2005[8]).

Smaller food producers often experience obstacles in transport due to a lack of correctly functioning temperature management in the refrigerated transport chain and the high cost of environmentally-friendly refrigerated vehicles. This is reported on Björklund *et al.*, (2008) who also noticed that common transport solutions, simpler regulations and lower VAT and fuel costs were requested by small-scale producers in Sweden. Furthermore, as pointed out by Gebresenbet & Bosona (2012, p.127), "In local food systems, the distribution infrastructure

8. Regulation (EC) No 178/2002

is partial, fragmented and often inefficient, as in non-centralised distribution, the share of the transport cost per unit of the product is relatively high". As most producers are spread over a large geographic area they are usually far away from the consumers. On-going global urbanisation also increases the distance between customers and agricultural areas.

Today, small-scale producers deliver their produce to retailers directly, and it may take almost a day to deliver small portions of produce. These are expensive modes of delivery, both in terms of time and money. The question may then arise of finding the best and simplest delivery choice available to small-scale farmers. In Sweden the large-scale food system for food retailing has been restructured into fewer, more efficient distribution facilities and the trend towards centralisation is clear (Storhagen, Bärthel & Bark, 2008). Is it possible to make use of professional distribution systems, either on a local, regional or national scale? Table 1 summarises the societal demand for local food, its advantages, potential constraints and possible solutions.

Table 1. *Values, constraints and possible solutions associated with the local food supply chain*

Perceived values in consumer demand	Constraints for producers	Possible solutions
• Promote employment • Environment • Promote life style in countryside • Promote animal welfare • Food quality and security • Tasty food • Ecological food • Transparency • Promote regional food tradition • Tourist attraction	• High logistics costs, including management, billing and transport • Environmental impact • Seasonality /discontinuity in the marketing chain • Lack of scientific data and results from research into local food	• Develop new logistics system for local food supply - integration within local food supply system - integration with large scale supply - focus on reducing costs - focus on reducing environmental impact • Collect and document scientific data

1.4 Logistics as a tool for improving local food supply chains

What possible solutions are there for promoting more efficient transport and making economic and environmental improvements?

Logistics is a tool for bringing the right thing to the right place at the right time in the right condition. According to Council of Logistics Management, 1991 (Wood, 2012), it can be defined as:

> “the process of **planning, implementing and controlling** the efficient, effective **flow** and **storage** of **goods, services**, and related **information** from point of origin to point of consumption for the purpose of conforming to consumer requirements”

Consumer requirements have mainly focused on quality and price. However it is becoming increasingly common to include an increasing awareness of the environmental impacts from supply chains as well.

In order to reduce the impact on the environment, transport can be made more efficient. With better route planning and higher load rates, distances can be shorter and the vehicles used more efficiently.

Another part of the solution is to use more efficient engines and efficient fuels. The source of energy and the energy carrier chosen for transport can have a large impact on emissions and on our society’s sustainability. Intermodal transport, such as combining road and rail, can also reduce emissions due to an increased use of energy efficient trains and fewer miles in fossil-driven trucks.

Van Hauwermeiren *et al.* (2007, p. 45) conclude from their comparison of local versus mainstream food systems that “Local food systems can be much more sustainable by increasing their efficiency through optimising their transport and storage by diminishing the transport distance and storage time to a strict minimum and by increasing the stored and traded quantities to a full storage room and a full loaded transport mode.”

Hughes (2003) describes the ideal supply chain as short, fast, transparent and seamless: few links in the chain and close contact between company and customer. However they often appear the opposite: complex, price-driven, confrontational, disjointed and opaque. Vorst, Tromp & Zee (2009) point out that the proper design of a food supply chain not only involves improved logistics, but also the preservation of food quality and environmental sustainability. In a supply chain, it is more important to cooperate in order to create the most competitive chain than to compete for individual company profits (Christopher, 1998).

Integration, coordination and optimisation are useful when improving logistics and finding economic and environmental improvements in supply chains.

Integration in the supply chain involves:

- information integration (sharing information and knowledge among members of the supply chain, including sales forecasts, production plans, inventory status and promotion plans)
- coordination and resource sharing (realigning of decision-making and responsibility in the supply chain)
- organisational relationship linkage (communication channels between members of the supply chain, performance measurement and sharing common visions and objectives; (Bagchi & Skjott-Larsen, 2002).

The objectives of integration are to reduce administrative work, increase accuracy in information, facilitate integrated planning and support traceability. Fully integrated supply chains are popular as a concept, but there are few examples of truly integrated chains (Daffy & Fearne, 2003). Instead of developing a close connection between all firms in the supply chain, it might be more suitable to develop dyadic relationships (Daffy & Fearne, 2003). Companies in a supply chain then focus on the companies with whom they have direct contact.

Coordination of goods transport among food producers is a way of sharing workload and resources. By coordinating, producers can make their transport more efficient. Combining routes and sharing transport are examples of how producers can cooperate in a horizontal way (Figure 2). It is more common though to have vertical cooperation (with a partnership between companies at different stages, upstream or downstream, in supply chains) in the food supply chain (Daffy & Fearne, 2003).

Optimisation can be used as a tool for increased goods coordination. It is used to find more efficient logistics solutions with optimal locations and efficient routes. There are several kinds of commercial software available for route planning and optimisation. Tools for vehicle routing problems (abbreviated as VRP and first introduced by Dantzig & Ramser, 1959) can be very useful when planning the shortest time or distance and fulfilling all the demands of delivery timing and working conditions, especially for larger vehicle fleets. It is also possible to find good locations for warehouses and valuable knowledge when restructuring or evaluating a distribution system.

In order to make a system more efficient it is important to have knowledge of the system. Bloom & Hinrichs (2010, p.10) expressed it as follows: “By identifying and evaluating diverse distribution models for local and regional foods, we can better recognise and support the changes in institutions, enterprises and individuals that offer promising pathways to a more sustainable food system".

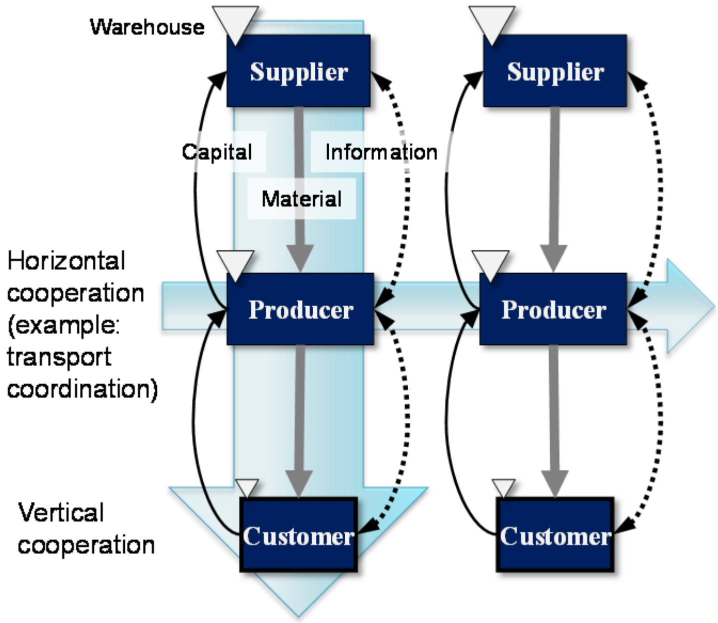

Figure 2. *Supply chains showing the flow of capital, material and information. The cooperations illustrated here are vertical, along the supply chain, and horizontal, between firms at the same stage across supply chains.*

The lack of general definition of local food is a problem when obtaining general statistics describing the producers in the sector. Therefore information is more likely to be found in case studies. Examples of studies of local food producer mapping can be found in western countries such as Great Britain (Ilbery *et al.*, 2006) and Finland (Töyli *et al.*, 2008; Lehtinen, 2012) as well as in developing countries such as Honduras (Blandon, Henson & Cranfield, 2009). There has been some mapping of small-scale producers in Sweden based on surveys (LRF, 2007; Björklund *et al.*, 2008; Wretling Clarin, 2010).

There is a need for mapping and evaluating distribution systems for local food in order to identify more efficient transport solutions and to find economic and environmental improvements in the local food supply chain. This thesis has assessed local food logistic systems at different scales, in Sweden. During three case studies, different ways of transport cooperation, route optimisation and logistics integration have been studied.

2 Objectives and structure of the work

The aim of this thesis was to study how cooperation, optimisation and integration in the supply chain for local and small-scale food producers can make their distribution more efficient and to estimate the environmental impact of the transport. This work analysed, demonstrated and further developed distribution strategies for local and small-scale food producers and distributors and analysed their environmental impacts in case studies that have distribution system of different scales. The specific objectives were to:

1. identify possibilities for coordinated goods distribution for food producers in and around a city (Paper I)
2. assess the e-trade system, the economic benefits and the environmental impact for small-scale local food producers integrated in a large scale food supply chain (Paper II)
3. evaluate the performance of integrated logistics network of a municipal local food distribution system (Paper III).

The structure of this thesis is based on the logistics performance and corresponding effects in case studies in three different regions of Sweden. The studies had distribution systems on different scales (Figure 3), ranging from a group of small-scale producers integrated with a retail chain, city logistics with local transport and food companies and to a distribution system for municipal units in four municipalities.

Paper I investigates the distribution system for 14 companies in and around the city of Uppsala and demonstrates the possibilities of developing a coordinated food distribution system. Based on field studies, interviews and a serie of seminars with stakeholders, optimisation of routes was performed. The routes from eight companies were mapped and optimised as individual routes as well as multiple routes. Emissions from the routes were estimated before and after optimisation.

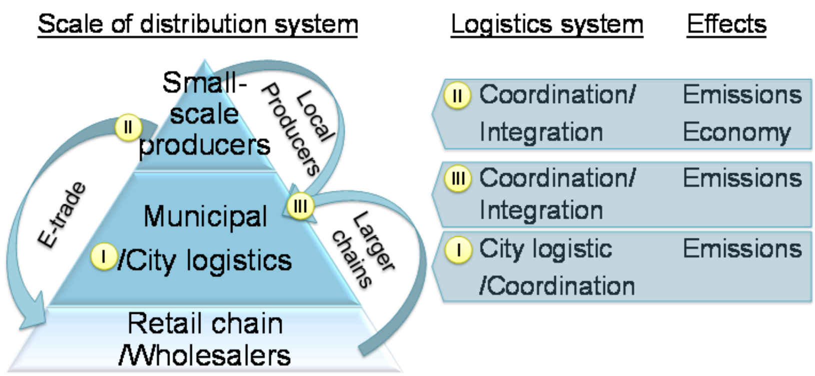

Figure 3. *Structure of the study with local producers in city logistics (Paper I), small-scale producers (Paper II) and in municipality distribution (Paper III).*

Paper II focuses on cooperation between a group of producers in Halland and the integration of their products into the distribution system of a large retail chain. The retail company wanted to integrate small-scale producers into its supply chain by including them in their physical distribution and electronic ordering system. Coordination of transport between the producers would be centred on a common collection centre (CC), before transport to the retailer's distribution centre (DC). The electronic trading system, developed specifically for the project[9], was based on cloud services, so the only equipment the producers needed was a computer with an internet connection and a printer. The electronic trading system introduced was assessed, together with the economic benefits of the new distribution system. Emissions and the potential environmental impact were estimated from an optimisation analysis with four scenarios of distribution (Bosona *et al.*, 2011).

Paper III evaluates the performance of the integrated logistics network of four municipalities in Dalarna. From the data collected a location analysis was performed in order to find the most suitable location for a distribution centre (DC). Route optimisation was done in order to compare four distribution scenarios. Emissions and the potential environmental impacts were estimated for each scenarios.

9. Developed by the software company Expert Systems, http://www.expertsystems.se/

3 Methodology

3.1 Study areas

Three case studies in Sweden are included in this thesis (Figure 4). The first case study was concentrated in and around the city of Uppsala, the second in the county of Halland, and the third in the county of Dalarna.

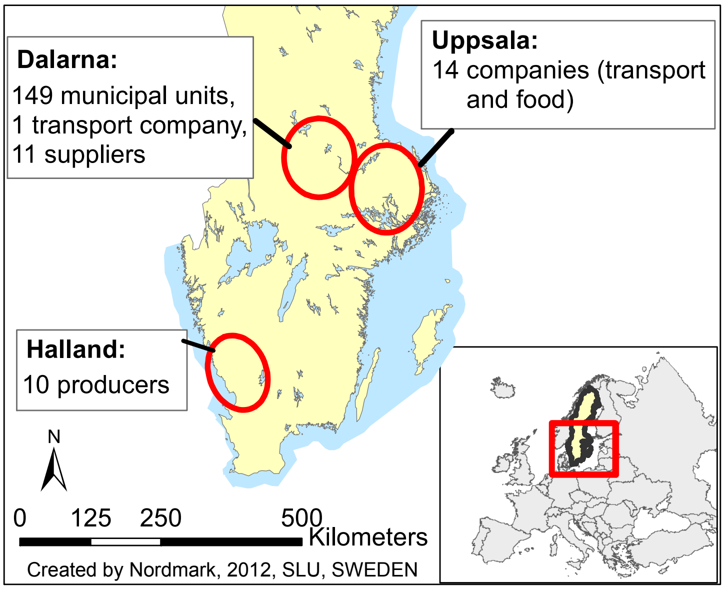

Figure 4. *Map of study areas in Sweden: Uppsala (Paper I), Halland (Paper II) and Dalarna (Paper III).*

3.2 General approach

The main approaches in the work for this thesis were related to coordination, integration and optimisation for an improvement in the logistics system (Table 2):

- possible coordination between producers and transport companies in and around a city (Paper I)
- coordination in a producer group while partly integrated in a larger retail chain (Paper II)
- coordination among municipalities wanting to integrate more local and small-scale producers into their system (Paper III)
- route optimisation (Papers I and III) and estimates of emissions generated by vehicles (Papers I to III).

The following means were used in the distribution systems to coordinate and integrate: an electronic trading system, transport coordinating using common hubs (collection/distribution centres), information sharing and engagement of third party transport companies. In Paper II, the producers' initial situations were compared with the situation of small-scale food producers in Sweden according to a limited previous study (Björklund *et al.*, 2008).

The level of cooperation and integration differed between participants in the case studies. In the case in Paper I the level of cooperation was low and in the cases in Paper II and III it was higher. While the starting points varied, the studies aimed at reaching the next step of development.

The following sections present the methodology used in the case studies: data collection, route optimisation and location analysis and an estimate of the environmental impact.

3.3 Data collection

Data collection in the study in Uppsala (Paper I) was performed by direct observations, the recording of activity times and a GPS-measuring of routes. On the routes, data for load rates, unloading time and motor idling were collected taking the following parameters into account:

1. company (postal address including telephone, fax and latitude/longitude)
2. truck performance (weight of the truck, maximum allowable load, maximum allowable volume, trucks fuel consumption)
3. time (*a*: engine warming time, *b*: transport time from transport park to terminal, *c*: loading time, *d*: transport time from terminal to shop 1 (first visit point), *e*: unloading time, *f*: transport time from shop 1 to shop 2, *g*: repeat d, e and f until shop n, *h*: transport time from shop n to the transport company's truck park)

Table 2. *Summary of case study approach and participants.*

	Uppsala (Paper I)	Halland (Paper II)	Dalarna (Paper III)
Main participants:	**municipality** (population[1] Uppsala 199 898), **8 (14) local companies** (3 transport companies, 5 bakeries, 3 meat distributors, 2 frozen food distributors, 1 flower distributor)	**10 (16) local producers** (products: fruit & vegetables, meat, egg, grain & bread, diary other), **retail chain**, **interest and business organisation**[2], **e-trade system company**	**4 municipalities** (population[1] Borlänge 49 434; Säter 10 863; Smedjebacken 10 655; Gagnef 10 076) with 149 delivery points (schools, pre-schools, homes for the elderly and persons with disabilities), **transport company**, **11 producers** (both local producers and national wholesalers)
Quantities:	n.a.	495 tonnes/year	2761 tonnes/year
Turnover:	n.a.	195 MSEK/year	n.a.
Ambitions:	Demonstrate effective and environmentally friendly distribution	Increase sales, improve logistic solutions, integrate local producers in retailer system	Evaluate system, increase number of local producers, improved logistics
Coordination/ integration:	Coordination	Coordination and integration	Coordination and integration
Main data collection (origin year):	Direct observations (38 routes), driver interviews, series of seminars (1998)	Questionnaires, interviews (2008-2009)	Interviews, archival records (2009-2010)
Route optimisation:	Route LogiX	(Route LogiX)[3]	ArcGIS
Emission estimation:	MODTRANS	Emission factors (based on ARTEMIS)	Emission factors (based on ARTEMIS)
Environmental impact:		CML, IPCC	CML, IPCC

1. SCB. Municipality population November 2011, http://www.scb.se/Pages/TableAndChart____325054.aspx, 2012-06-14.
2. Federation of Swedish Farmers
3. Route optimisation was performed in the study but is not included in this paper. For optimisation details see Bosona *et al.* (2011).

n.a. denotes 'not available'

Interviews with the vehicle drivers gave insight into how the routes were planned and the order of priority. In parallel with field measurements, a series of seminars was held with the companies involved. The results from the study as well as possibilities of future cooperation were regularly discussed in the seminars.

In the study in Halland (Paper II), data about the distribution system were collected through questionnaires and interviews. In addition, data on producer locations and delivery points, delivery frequencies, quantities and types of products and additional product distribution information were also gathered. The economic indicators collected were turnover, transport costs and IT costs.

In the study in Dalarna (Paper III) the data sources were interviews and archival records. Summaries of orders (per week or month) and public procurements gave detailed information on delivery addresses, frequencies, time windows, average and specified weight and temperature demands. Data were collected from the municipalities and the producers.

ArcGIS software[10] which is designed to handle geographical information was used to plotting the location of producers.

The choices of methods for mapping the producers depended greatly on data requirements and availability in the systems. In Dalarna delivery/purchase data could be obtained from the municipalities and producers, reducing the need to do direct observations on routes. In Halland information from the producers had to be compiled in a homogenized way. A survey with complementary interviews was found to be a suitable way of doing this. Direct observations in Uppsala gave fine primary data and it was the data collection that worked best for to mapping the system.

If similar projects were being compared, the use of different data collection methods would have been disadvantageous. However, these cases are being considered individually rather than compared. The methods used to collect data were the most suitable for each case and depended greatly on the state of the system studied.

3.4 Route optimisation and location analysis

Based on details in existing distribution systems, route optimisations were performed for:

- single routes
- combined routes based on distribution areas
- all routes in a project, established in a number of distribution scenarios.

10. ESRI, http://www.esri.com/software/arcgis/index.html, 2012-06-07

Improvements to the distribution systems were suggested in Papers I and III in order to achieve better planned distribution such as shorter driving distances and times.

3.4.1 Route LogiX, ArcGIS and location analysis

Route optimisation was performed using Route LogiX [11] (Paper I) and ArcGIS [12] (Paper III). Paper II contains results from a route analysis using Route LogiX, performed and described by Bosona *et al.* (2011). This formed a basis for the estimation of emissions (see 3.5.2). In the study by Bosona *et al.* featuring optimisation analysis of the initial situation, a location analysis suggested the most suitable location for the CC and four scenarios created to calculate improvement potentials showed a possible reduction in driving distances by 39-62%. When considering transport from the producers to the DC alone, there were improvements of 88-93% on distance travelled.

Route Logix software is a route planning system used in a number of companies, including the three largest food retail chains in Sweden [13]. The software includes vehicle routing and optimises routes by minimising driving distance and time.

ArcGIS Network Analyst tools, including the vehicle routing problem (VRP) solver, were used in Paper III. Working with the Network Analyst tools requires an existing road network. In Paper III a road network was built in order to analyse the routes, based on the road map [14] (scale: 1:100 000) produced by Lantmäteriet as part of the GSD (Geografiska Sverigedata) map series. Speed limits provided by the Swedish Transport Administration [15] were applied.

The delivery routes in Borlänge municipality, where most of the municipal units were located, were analysed in order to find improvements and to test the road network built in ArcGIS. The entire system was then simulated in four distribution scenarios (Figure 5).

A location analysis was carried out in Paper III based on the *centre-of-gravity technique*, *load-distance technique* and *location factor rating method* (Russell & Taylor, 2009). By *centre-of-gravity* a number of suitable locations were identified based on 1) producer locations and annual production together

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11 . Software from DPS (Distribution Planning Software) International, http://www.dps-int.com/products/desktop/routing-software.php?ref=topNav, 2012-06-07

12 . Software from Esri, http://www.esri.com/software/arcgis, 2012-06-07

13. DPS: *Livsmedel - referenser*, http://www.dps-int.se/Ref_livs.htm?case=1, 2012-06-07

14. Road map, http://www.lantmateriet.se/templates/LMV_Entrance.aspx?id=17406&
lang=EN, 2012-06-11

15. Trafikverket, http://www.trafikverket.se/

with delivery points and annual demand, 2) producer locations and production 3) location of delivery places and demand.

Load-distance technique was then used for the three locations mentioned and the existing distribution centre (DC) location to obtain load-distance values in tonne-kilometres. The *location factor rating method* was used to evaluate the locations from more perspectives, weighting the scores together in order to find the location with the highest scores.

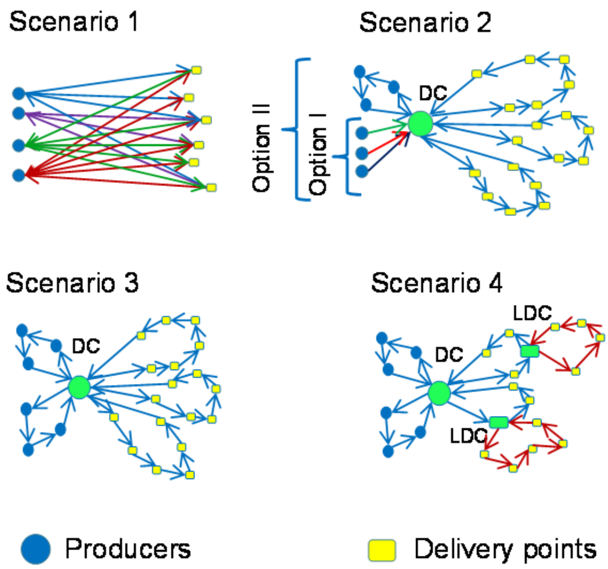

Figure 5. Scenarios in the study in Dalarna (Paper III). DC denotes distribution centre and LDC local distribution centre. Heavy trucks were assumed generally. Light trucks were assumed around the LDCs.

3.5 Estimating environmental impact

Emissions in the studies were estimated using the MODTRANS model (Gebresenbet & Oostra, 1997) in Paper I and emission factors (Trafikverket, 2009, 2010) in Papers II and III. The data collected on driving were more detailed in Paper I then in Papers II and III (see 3.1). In Papers II and III emission amounts were used to estimate the environmental impact of the distribution systems. Characterisation factors for impacts from the Ecoinvent database were applied (Swiss Centre for Life Cycle Inventories, 2010a-b).

3.5.1 MODTRANS emission model

The MODTRANS emission model was used to estimate the emissions in Paper I. The model was developed by Gebresenbet and Oostra (1997) and used speed, road slope and load for data input to compute vehicle fuel consumption. Thereafter emissions were calculated based on emission factors.

3.5.2 Emission factors

Emissions estimated in Paper I by the model MODTRANS were carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_X) and sulphur dioxide (SO_2). Emission factors in the model originated from load classes from Demker *et al.* (1994) (Table 3 and 4).

Table 3. *Emission factors, g/km (Demker et al., 1994).*

Load class	**CO_2**	**CO**	**HC**	**NO_X**	**S**
Lorry 52 tonnes	1300	3.90	1.30	25	0.70
Lorry 38 tonnes	1080	3.90	1.30	21.80	0.58
Lorry >18 tonnes	1040	5.00	1.50	18.90	0.60
Lorry 14 tonnes	750	4.50	1.50	13.60	0.41
Lorry 7 tonnes	460	2.80	1.10	5.90	0.26

Table 4. *Emission factors (g/tonnekm) (Demker et al., 1994).*

Load class	**CO_2**	**CO**	**HC**	**NOx**	**Part.**	**S**
Remote truck, 52 tonnes	76	0.23	0.08	1.50	0.10	0.041
Remote truck, 38 tonnes	83	0.30	0.10	1.70	0.13	0.045
Local truck, 14 tonnes	200	1.21	0.41	3.70	0.38	0.11

Emissions in the studies (Papers II and III) were estimated by emission factors for CO_2, CO, HC, NO_X, particulate matter (PM) and SO_2. The factors used are based on a common EU model for vehicle emissions, the ARTEMIS *Road Model*, published by the Swedish Transport Administration (Trafikverket, 2009 and 2010). Emissions factors from the Transport Administration are adapted from the common model for vehicle emissions in the EU and adapted to and tested for Swedish conditions (Sjödin *et al.*, 2009). The factors are also implemented in the NTMcalc[16] emission calculation tool.

The emission factors selected in Paper II concerned the weighted values for mixed traffic (city/countryside) in 2009 (Table 5). The passenger cars factors concerned weighted values for diesel and petrol cars, while the light and rigid trucks were all assumed to be diesel powered (Figure 6). The emissions in

16. NTM http://www.ntmcalc.se/index.html

Paper III were estimated based on emissions factors from Trafikverket (2009) (Table 6). Heavy trucks (weighted values for mixed traffic city/countryside) were considered in all scenarios (Figure 5). Light trucks were only considered in the routes from the local distribution centres (LDC) in scenario 4.

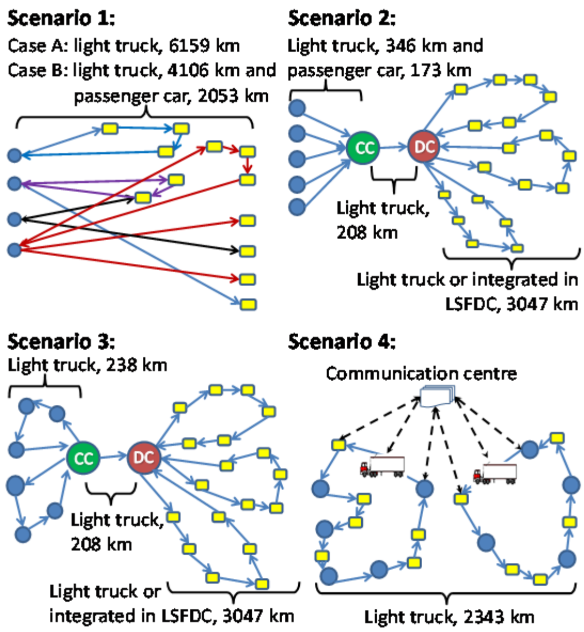

Figure 6. *Scenarios from Bosona et al. (2011) in the study in Halland (Paper II) with vehicle assumptions. CC denotes collection centre and DC denotes distribution centre. In scenario 2 and 3, the distribution between DC and the delivery points used light trucks in option I, and was integrated in the large-scale food distribution channel (LSFDC) in option II.*

Table 5. *Emission factors used in Paper II (Trafikverket, 2010)*

Weighted average, 2009	**CO_2 kg/km**	**CO g/km**	**HC g/km**	**NO_X g/km**	**PMm g/km**	**SO_2 g/km**
Passenger car (*Personbil*)	0.18	2.0	0.39	0.34	0.0053	0.0004
Light truck, diesel (*Lätt lastbil diesel*)	0.25	0.32	0.053	0.71	0.054	0.0004
Rigid truck (*Lastbil utan släp*)	0.56	0.97	0.25	5.08	0.11	0.0008

Table 6. *Emission factors used in Paper III (Trafikverket, 2009)*

Weighted average, prognosis for 2010	**CO_2 kg/km**	**CO g/km**	**HC g/km**	**NO_X g/km**	**PMm g/km**	**SO_2 g/km**
Heavy trucks (*Lastbil med släp*)	1.0	1.3	0.22	7.57	0.13	0.0015
Light trucks (*Lätt lastbil, diesel*)	0.27	0.30	0.050	0.67	0.048	0.00040

3.5.3 Potentials for environmental impact

The potential environmental impacts were estimated from the emissions by characterisation factor (Papers II-III). To provide insight into the environmental impact of the distribution systems, potentials for acidification (AP), eutrophication (EP), human toxicity (HTP) and global warming (GWP) (Table 7) were calculated from the estimated emission amounts. These factors are commonly used in life cycle assessment (LCA) methodology.

From the Ecoinvent database (v2.2, 2010 for Paper II and v2.01, 2007 for Paper III) characterisation factors for the potentials AP, EP, and HTP were selected from "CML[17] 2001" (Swiss Centre for Life Cycle Inventories, 2007, 2010a). For global warming, GWP100 from "IPCC[18] 2007" (Swiss Centre for Life Cycle Inventories, 2007, 2010b) was applied.

Table 7. *Impact categories and emission gases from the Ecoinvent database considered in Papers II and III.*

Potential impact	**Emissions**	**Unit**
Global warming potential (GWP100)*	CO_2, CO † CO_2, CO, HC, NO_X ††	kg CO_2 eq
Human toxicity potential (HTP)	NO_X, PM, SO_X	kg 1,4-DCB eq**
Acidification potential (AP)	NO_X, SO_X	kg SO_2 eq
Eutrophication potential (EP)	NO_X	kg PO_4^{-3}-eq † kg NO_X eq ††

* Potential impact over a time horizon of 100 years; ** 1,4-DCB is 1,4-dichlorobenzen ($C_6H_4Cl_2$);
† Used in Paper II; †† Used in Paper III

17. Institute of Environmental Sciences (CML), Leiden University, Netherlands
18. Intergovernmental Panel on Climate Change

4 Results

4.1 Distribution networks

This section describes the networks and cooperation between participants in the studies. There are also comments on what happened after the studies. The participants in the three studies were part of distribution systems of different scales and with different organisations (Table 2).

4.1.1 Paper I

Paper I describes the attempt to create new distribution solutions in and around Uppsala by involving the participants (in regular seminars), and analysing and discussing the results. The distribution took place within a radius of approximately 100 km from Uppsala. Eight companies participated in field studies and 38 routes were observed in all. Routes were planned by drivers and mainly in order of priority: shops, restaurants and schools or nurseries. Queuing at delivery points and lower load rates were more common observed in urban areas than in rural areas. Several routes had similar delivery points and covered similar areas to the routes used by the other companies.

In the seminars, participants expressed satisfaction with the results of the optimisation analysis (section 4.2.1) and interest in continuing the process. After the seminars the engagement decreased. However, a project on city logistics in Uppsala's city centre followed in 1999-2001 (Ljungberg, Gebresenbet & Eriksson, 2002; Ljungberg & Gebresenbet, 2004) where possibilities to coordinate private companies' deliveries to city centre were pursued. Furthermore the municipality arranged municipal transports (non-food goods) in the ways discussed in the seminars. The Uppsala municipality "Sustainable goods transports" started in 2008 (Åhlman, 2009).

4.1.2 Paper II

The producers were concentrated in the county of Halland, with nearly all the main customers in the same or adjacent counties. The producers offered a wide range of products: fruit and vegetables, meat, egg, grain and bread, diary and other products. The producers mainly handled the transport themselves and through transport companies. The load rate when shipments left the producers in Halland was over 50% in most cases. The ambition among the producers was primarily to increase sales and improve the logistic solution.

Compared with a national study (Björklund *et al.*, 2008), the Halland producers were more independent and had higher turnover. On the other hand, the average yearly quantities and transport costs (as a per centage of total costs) were a little bit lower among the Halland producers.

The use of the electronic trading system resulted in direct savings of 15-20 SEK per invoice (working time savings not included). License costs (6300 SEK/year) would be free the first year. The cost of IT support was added from first year.

Initial transport costs (based on questionnaire answers from four producers) were 268 SEK per hour. With the new system, costs for collection (80 SEK/occasion), fees for transporting boxes (54 SEK), pallets (232 SEK) or freezer boxes (414 SEK) would arise. Costs for packaging and warehousing in a future system were not determined during the pilot project, nor were the costs for using the specially designed return boxes.

The producers tried the system with the electronic trading place and the distribution system. Although it worked, it never became more than a trial. The producers found using the electronic trading place complicated, the retail chain lost some of its interest and the producer network developed differently.

The producers wanted to expand to a larger market, and were in contact with customers outside the county and even outside Sweden. In their case they act more as food producers from a certain region when distances to customers increase, rather than as local food producers.

In the system currently in place, equipment (such as scales and packaging machines) for value-adding activities is available for producers at the collection centre (CC). The company managing the CC acts as a central point handling customers ordering and invoicing. All distribution is managed via customers' wholesalers.

4.1.3 Paper III

In the Dalarna study (Paper III) a coordinated distribution network was in place at the beginning of the study. Eleven producers delivered food to the municipalities' common DC located in Borlänge. The total delivered quantities per year were around 2761 tonnes. The producers were located 7-415 km from the DC. The four municipalities in cooperation were using a local transport company and its DC for food transports to 149 municipal units in all. The majority of units, around 60%, were located in Borlänge municipality. The units often received food deliveries 1-2 times per week. Deliveries took place Monday-Friday in Borlänge, Monday and Wednesday-Friday in Gagnef and on Tuesdays and Thursdays only in Säter and Smedjebacken.

Some deliveries could be made before the children were in school. In these cases, the drivers had access to storage rooms and there was no need for staff to be there to receive the goods. This practice improved traffic around schools and resulted in fewer interruptions for the staff.

The municipalities in Dalarna have made efforts to increase the number of local producers in their network. Here the local food was mainly food from the same county. The municipalities are continuing to work on simplification so that smaller producers can bid in the tendering process, *e.g.* by providing procurements for smaller amounts. Two nearby municipalities have expressed interest in joining the cooperation at some point in the future.

4.2 Routes and optimisation analyses

4.2.1 Paper I

The 38 routes in Paper I were optimised as single routes and as multiple routes. The driving distances and times were reduced by 10% in average on individual routes. When comparing the observed routes with optimisation results, six routes of the 38 routes studied were already planned optimally. Motor idling occurred on 66% of the routes, in some cases due to queues at delivery points and without idling being required (section 4.3.1).

The optimisation for individual routes showed potentials for reducing the distances with 6% in total for company A, 25% for company B, 7% for companies C and D, 16% for E, 12% for G and under 2% for company F and H, presented in more details in Table 3 in Paper I. The maximum distance reduction on a single route was 34%, and the maximum time reduction was 40%. A total optimisation of all routes reduced the distances by 35% (1408 km) and the number of routes by 58%.

Several routes with overlapping service areas were identified and possibilities examined for coordinating of routes. Combining 2-3 routes in certain areas resulted in possible reductions in transport distances of 25-46% and time by 23-42% (Table 8).

Table 8. *Summary of possible co-ordination of distribution in rural areas*

No. of original routes combined	Region in relation to Uppsala city	Transport distance [km] before co-ordination	Transport distance [km] after coordination (reduction, %)	Transport time [hr:min] before co-ordination	Transport time [hr:min] after coordination (reduction, %)
2	NW	481	274 (43)	09:24	6:00 (36)
3	NE	765	413 (46)	14:11	8:13 (42)
2	SW	378	284 (25)	08:19	6:24 (23)
2	SE	255	145 (43)	07:37	5:38 (26)
2	N	637	395 (38)	12:02	8:18 (31)
2	E & N	538	393 (27)	11:12	7:50 (30)

There were good opportunities for combining routes for similar goods, *e.g.* bread from different suppliers, without any structural changes in the system. The producers were located near each other geographically and had customers in similar areas. On some routes there was considerable queuing and trucks were even following one other from delivery point to delivery point.

The load rates were found to be higher in the companies that distributed in rural areas rather than in urban areas (Figure 7). There were correlations between unloading time and weight, volume and number of packages at many companies, but not all (Table 9).

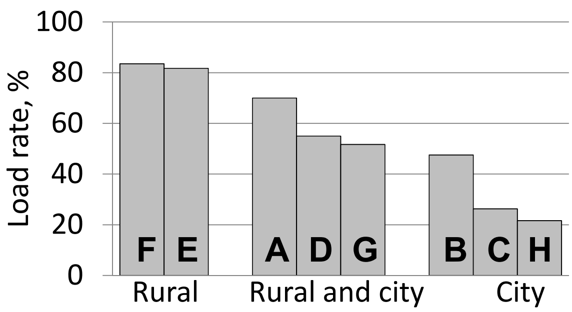

Figure 7. *Load rates on routes of companies A-H.*

Table 9. *Summary of unloading times and correlations with three load variables.*

Company (no. of delivery stop)	Unloading time mean [min:sec]	minimum [min:sec]	maximum [min:sec]	Correlation coefficients between unloading time and no. of packages	volume	Weight
A (99)	07:51	01:05	34:04	0.458	0.590	0.613
B (61)	03:35	00:27	19:42	0.549	n.s.	0.559
C (93)	01:40	00:20	04:55	0.575	0.634	0.591
D (42)	07:04	01:08	33:18	0.575	0.475	n.s.
F (19)	06:23	01:51	16:54	0.538	0.628	n.s.
G (29)	06:41	01:44	22:22	n.s.	0.457	0.545
H (12)	07:08	03:04	11:12	n.s.	n.s.	n.s.

n.s. denotes that the correlation is not significant

4.2.2 Paper III

In Paper III, route optimisation was first performed on 12 routes in Borlänge for distribution from the DC to the municipal units, based on the delivery orders of actual routes. Optimisation of individual routes resulted in reduced transport distances of 0-48%. For three routes (numbers 1, 9 and 10 - Figure 8) only small improvements in distance reduction (0-6%, corresponding to 0-2 km) were found.

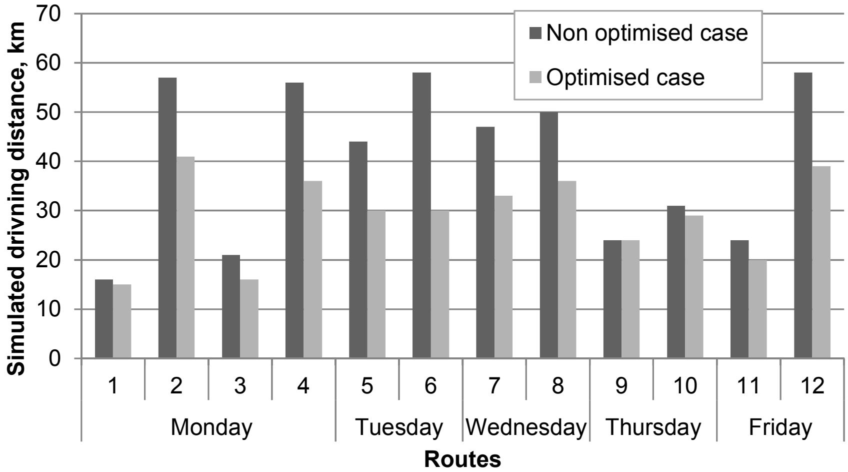

Figure 8. *Simulated driving distances for routes in Borlänge.*

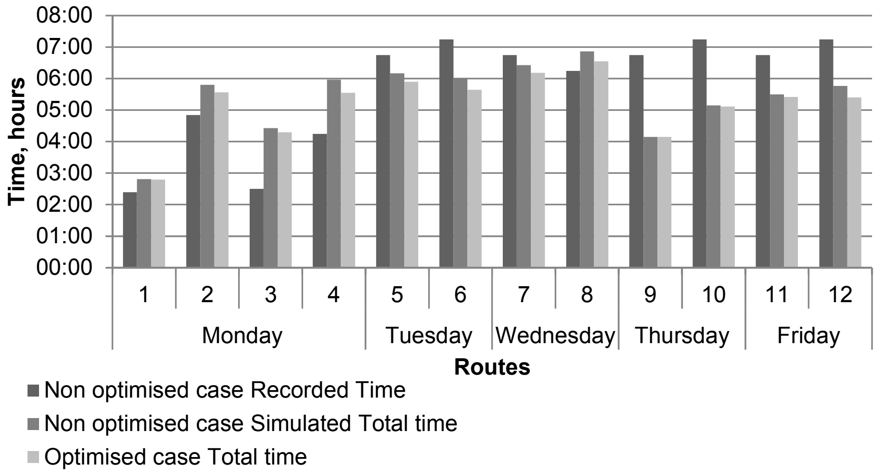

Figure 9. *Simulated driving time for routes in Borlänge.*

The distances and travel times were reduced on average by 28%. The total time, taking service times[19] into account, was reduced by 4% on average. On most of the routes (8 out of 12) the differences between reported and simulated times for the non-optimised case were less than or equal to 20%. However, on some routes (numbers 3, 4, 9 and 10 - Figure 9) derived from the simulated results based on the delivery lists, the driving times specified in the given timetables were up to between one and two and a half hours longer or shorter.

The entire delivery system was analysed by optimisation according to four scenarios (Figure 5), based on the amount of food ordered from the producers to the municipal units in the four municipalities. In scenario 1, which was used as a reference, all producers were assumed to undertake their own transport for 25 routes, 334 visits, 7627 km and taking 228 hours. Compared with scenario 1, the distances in scenario 2 (option 1 and 2), scenario 3 and 4 were reduced by 64, 68, 74 and 74% respectively. The time improvements were 54, 60, 63 and 58% respectively, the number of routes were reduced by 36, 44, 64 and 40% respectively (to 9-16 routes) and the number of visits more than halved (to 158 visits).

There were delivery time windows, set by the municipal units, in the existing system. All deliveries were scheduled during the day (6:00-18:00) and the most popular time window was 6:00-8:00. In the analysis delivery time windows were made more flexible during the day, allowing delivery any time

19. Service times in the simulated routes consisted of 30 minutes loading time for each route, 15 minutes per delivery stop for unloading and handing over the goods, and 1 hour and 30 minutes for resting and extra time.

between 6:00 and 18:00. The flexible delivery time windows reduced the driving distance by 62% (from 1457 to 552 km) and the time by 23% (from 78 to 60 hours).

Location analyses were done to identify the most suitable location for a DC for a local distribution system. The centre-of-gravity technique generated three new possible locations based on data of i) producers and delivery points, ii) producers and iii) delivery points (Figure 10). In further analyses, using the load-distance technique and location factor rating method, the existing location was identified as the preferable of the three candidates.

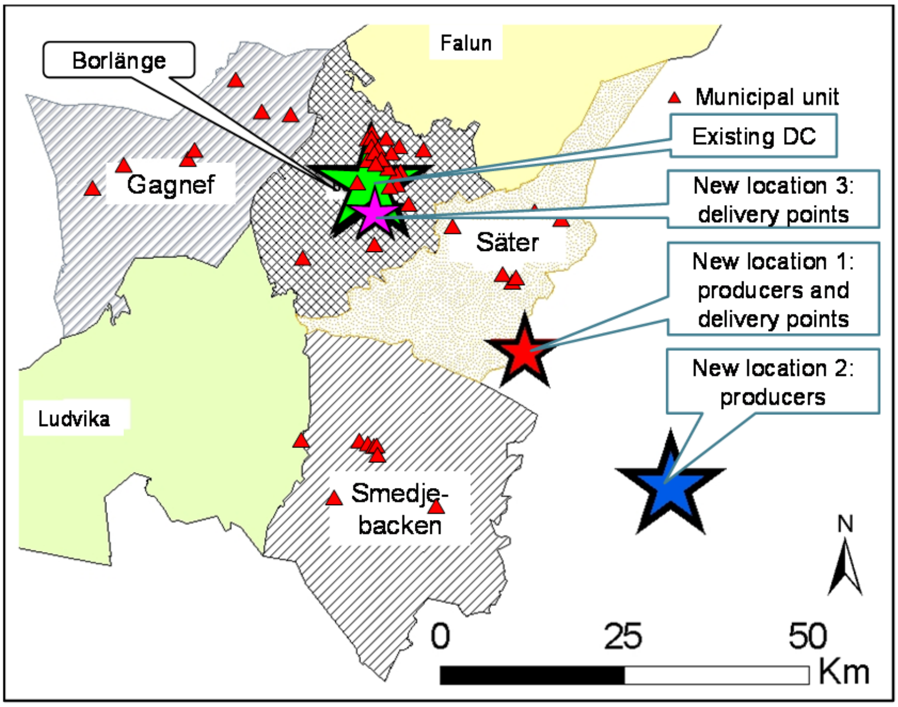

Figure 10. Results of centre of gravity technique. The locations are based on data of producers and/or delivery points.

4.3 Estimating the effects on the environment

4.3.1 Paper I

When all routes were optimised together, the emissions were 48% lower than before optimisation. All emissions were calculated using the MODTRANS model based on route observations. In the total optimisation, emissions decreased by 48-50% (Table 10).

On several of the routes (66%) motor idling occurred during unloading. In some cases motor idling at delivery points can be required to control the temperature in the loading zone. However, this was not required on many of the routes that had a higher percentage of motor idling time.

Queuing, common at some delivery points in the city centre, and motor idling contributed to increased emissions. An example with two companies (A, mainly delivering in rural areas, and C, mainly in town) showed that company C had higher emissions per kilometre even though its vehicles' fuel consumption was lower than company A's. Motor idling was more common in company C.

Table 10. *Summary of emissions in kg for the companies and for total route optimisation.*

Company	**CO**	**CO_2**	**NO_X**	**HC**	**SO_2**
A	1.51	489.1	9.78	1.13	0.007
B	0.25	79.46	1.59	0.19	0.0009
C	0.70	226.7	4.54	0.53	0.003
D	0.14	45.83	0.92	0.11	0.0007
E	0.57	186.4	3.73	0.43	0.003
F	0.21	67.99	1.36	0.16	0.0009
G	0.32	104.9	2.10	0.24	0.002
H	0.28	89.18	1.78	0.21	0.002
Total	3.98	1290	25.8	3.00	0.02
Total after opt.	2.07	671	13.4	1.56	0.01

4.3.2 Paper II

While the distance reductions for scenarios 2, 3 and 4 were 39, 43 and 62% respectively (option II in scenarios 2 and 3 led to reduction of 88 and 93% respectively) in the route optimisation (Bosona *et al.*, 2011), emission reductions (except for NO_X) were 5-86% and 16-92% lower than in scenario 1, case A and B. Scenario 3 option II had the lowest emissions (66-86% and 79%-92% lower than in case A and B) excluding NO_X, and scenario 4 had the lowest NO_X emissions (62% and 54% lower than in case A and B). The low NO_X values in scenario 4 made this the one with the lowest potential for environmental impact for AP, EP and HTP, while the lowest GWP potential was achieved in scenario 3 option II (Figure 11).

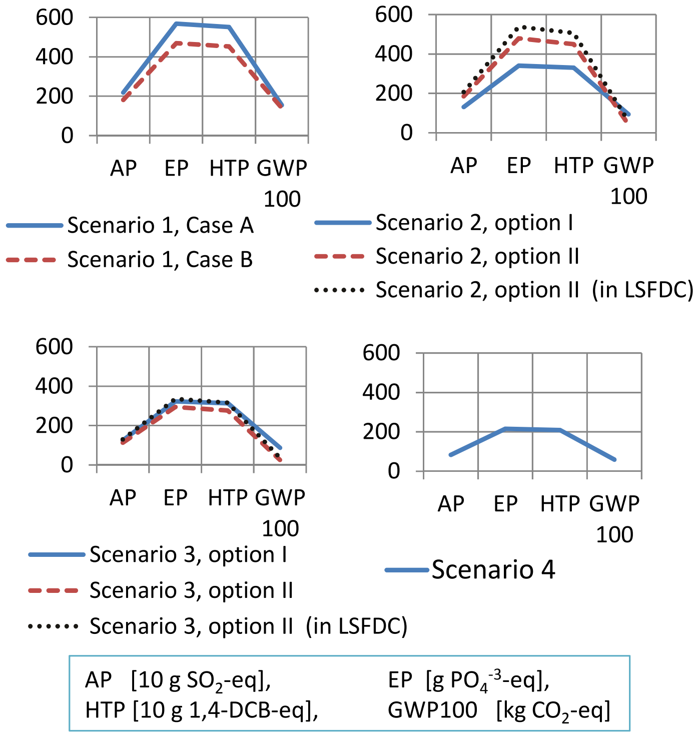

Figure 11. *Overview of estimated environmental impacts, Paper II. LSFDC is the abbreviation for Large-Scale Food Distribution Channel.*

4.3.3 Paper III

In Paper III the impact assessment was performed for the four scenarios for the purpose of comparison. The environmental impacts decreased with 64, 68, 73-74 and 75% for scenario 2 (option I), scenario 2 (option II), 3 and 4 compared with scenario 1 (Figure 12).

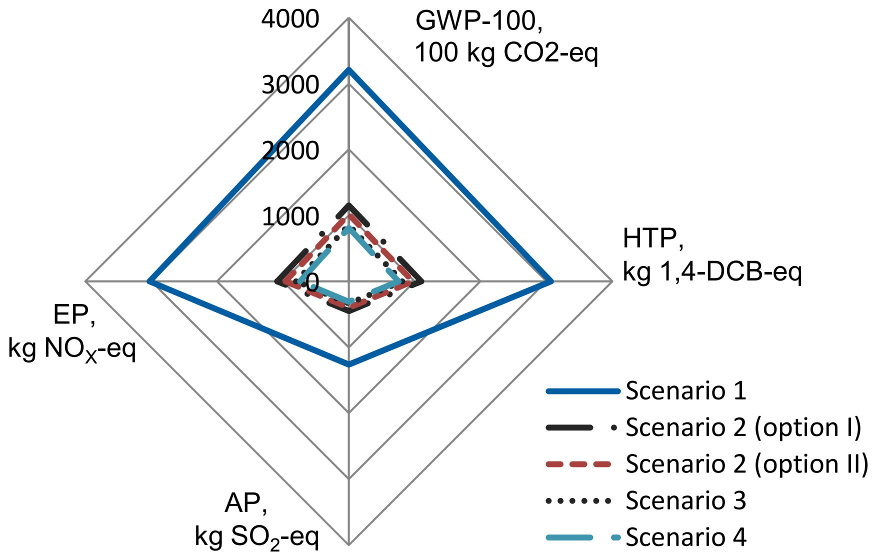

Figure 12. *Overview of the estimated environmental impacts of different distribution scenarios, Paper III.*

5 Discussion

This thesis analyses distribution systems for food from local and small-scale producers. The different scales of the systems studied have enabled a broader view to be obtained of the situation for local food producers in Sweden. Relatively few studies so far have examined this sector and there is limited data available. Since the situation for producers operating on a small and/or local scale can vary considerably due to parameters such as location, competition and hardiness zone, it was found useful to study differing systems rather than comparing several very similar systems.

The question of whether local food producers can meet the high expectations of consumers may require a general definition or definitions of local food (Jones, Comfort & Hillier, 2004; LivsmedelsSverige, 2012) and may not have a clear answer yet. However, local food is food produced and consumed within a region. Although the size of regions can differ since there is a lack of general definition, many consumers have a feeling for what local food means to them.

Referring to the case in Halland, their food can be seen as ‘local food’ when it is sold in Halland and adjacent counties, but when sold in another part of Sweden or abroad it is rather to be considered as ‘regional food’.

Just because the food is produced close to you does not mean that it is automatically better. This has been noticed by Wallgren (2006), Ilbery and Maye (2005) and others. However traceability and emotional connections are likely to be greater when you buy from nearby producers. Transparency in production can also be higher if you know the area of production and the producers. This can be used as an advantage for local food when competing with food produced in systems on a global scale. However there is still room for improvement in transparency concerning the environmental impact and pricing for local food.

The case studies in this thesis have revealed that there is potential for local small scale food producers to improve their distribution. Cooperation, integration and route optimisation are suitable strategies for producers to make their transports more efficient and reduce their environmental impact.

5.1 Collecting data

Route planning and optimisation may be powerful tools, but they can only be used if the distribution systems can be described sufficiently well. It was often difficult to obtain information about the complete system, e.g. when the transports contained more products than those covered in the study or the companies responsible for the transport were not willing to share information. This seems to be due to reasons such as limited resources for finding the requested data, lack of interest and a desire to protect their and other customers' interests. Transport systems are inherently location specific and driven by demand. Depending on the organisation of the distribution system, different data collection methods need to be used.

This work of identifying and evaluating different distribution systems enabled us to recognise and support changes more effectively towards a more sustainable food system, which is well formulated by Bloom and Hinrichs (2010, p 10).

Advantages of the data collection in Paper I were mainly the detailed results available from the route observations. Primary data collection together with interviews and seminars allowed a good insight into the distribution system, even though several companies were included in the study.

Secondary data were collected in the studies in Halland and Dalarna (Paper II and III). In Paper II there were no gathered data available initially, so questionnaires and interviews were used. This can be performed at a distance, but includes additional difficulties in understanding the reliability of the data. The summary of orders and public procurements in the Dalarna study (Paper III) gave detailed information on addresses and the amounts ordered. Although detailed route information from the transport company was hard to access, the summary from the municipalities together with interviews with producers allowed a fairly good understanding of the distribution system. A great advantage with the municipalities' data was that it covered all their units. This would have been difficult to record manually since it is a time-consuming data collection method.

The data from the municipalities compared with the route simulations in Paper III gave different results in driving time in some cases. It was unclear whether this was due to the road model, the assumptions, the data material or something else. This is one problem when using customer/producer-specified data instead of recording the data yourself.

5.2 Cooperation, integration and competition

Cooperation between producers is a way of creating a more competitive supply chain which, according to Christopher (1998), is more important to the supply chain than competing for individual company profits. It can be difficult to realise when cooperation is beneficial and where common goals can be achieved.

Increased centralisation among larger retail chains can make it harder for smaller producers to benefit from and become integrated into these chains. The case studies in this thesis, however, show that it is possible. Nonetheless, more suitable distribution channels for these producers can be found on a local and regional scale *e.g.* wholesalers, municipalities and local markets.

The case studies showed that there was potential for making distribution more efficient. The results from the studies were encouraging and identified several improvements, but subsequently the projects developed in different directions.

With the Uppsala study (Paper I), it was concluded that the possibilities of cooperation on a local scale were very good. Combining routes could reduce the distances of these routes with up to 46% and optimisation of all routes indicated possibility to reduce the number of routes with 58% and the transport distance up to 35%. The participating companies did not complete the proposed horizontal cooperation. One reason for this was the difficulty of agreeing on the signage on vehicles. This signage was seen as an important marketing channel and the agreement on new signage was associated with negotiations and additional costs. Competition may have prevented the companies from seeing the benefits of cooperation. They might have needed more proof of positive effects from the cooperation. It may have been that the companies did not see each other as that closely connected, and focused instead on developing stronger vertical relations along their own supply chains. They may also have needed more help after the project to build up and develop their cooperation further. The study led to further studies and a pilot demonstration of city logistics (Ljungberg, Gebresenbet & Eriksson, 2002; Ljungberg & Gebresenbet, 2004). More recently the municipal coordination of non-food goods has been initiated (Åhlman, 2009).

In the Halland study (Paper II) the producers became integrated into the national distribution system of a large-scale retail chain. However, after the demonstration they preferred working in a local network with one central actor operating with wholesalers' national distribution systems. This company now manages customer relations and establishes contact with producers. The fact that they are several producers working together is advantageous since they can offer customers more products.

The integration of local food producers into a larger food supply chain worked on a technical level. The e-trade system made this possible with improved contact between producers and retailers, but did not reduce the administrative workload for producers. Interest from the retail chain declined and the producers struggled with the internet-based trading place.

Retail chains and municipalities have noticed consumers' interest in local food. Locally produced food can, for example serve as premium products in shops or increase the traceability and, hopefully, the quality of food served in the municipality. The municipalities in the Dalarna study (Paper III) want to have a high number of local producers for their municipal units and have been working to ease the procurement process for smaller producers.

At the same time the municipalities have to follow the Swedish regulation for procurement[20] which states that the place of origin cannot be specified. One way of attracting local producers, who are often small-scale and with seasonal production, could be to allow the producers to bid on smaller quantities or during part of the year.

By taking control of the distribution, the municipalities shifted from using national distribution systems to having a more local and transparent distribution system. Although still in place, the system is not as local as they hoped. The municipalities still want to increase the number of local producers in their system, and have therefore created some conditions to facilitate the integration of smaller producers.

5.3 Route analysis and optimisation

In the studies in this thesis, the optimisation of routes proved to be a useful method for identifying, improving and evaluating distribution systems. Potential savings were identified when optimising individual and multiple routes. Multiple routes having the greatest potential require both cooperation and integration. Transport distances, time and the number of routes could be reduced with optimisation.

Simulations and demonstration trials of coordinated transport led to fewer delivery stops which may result in less queuing, with its associated costs, and less motor idling, with its associated emissions. Furthermore safety can increase with fewer stops required *e.g.* at schools.

The use of third party logistic services can have many advantages for the small producers, allowing them to concentrate on their area of competence. The producers in Paper II dropped their own transport fleet because they found

20. Lag (2007:1091) om offentlig upphandling (SFS 2007:1091) [Swedish Public Procurement Act]. Stockholm: Socialdepartementet. http://rixlex.riksdagen.se [2012-09-13]

the use of wholesalers' transport to be a better solution, reducing the need of vehicles of their own and providing opportunities for expanding their distribution area.

In the Uppsala study (Paper I) the routes were planned manually. Several routes were observed where the vehicles were following each other to the delivery points, this caused queuing at the delivery points. It was recommended that the companies cooperate with one other, based on the possibilities identified of combining multiple routes in the optimisation analysis.

The relation between unloading time and the amount of goods unloaded was analysed for the routes in Paper I and there were large variations in unloading times (Table 9). From this analysis, significant correlations were identified. Still, a large part of the variations could not be explained by these correlations and for some routes, the correlations were very weak or insignificant. Although not many comparable published studies have been found, these results are well in line with e.g. Ljungberg & Gebresenbet (2004) and Allen *et al.* (2000). Fewer stops due to route optimisation could reduce the variation in unloading time.

In general it is still difficult to predict the unloading time since there are several other factors influencing it. Examples of what can cause delays when reaching the delivery area are the design of the delivery areas, whether receiving personnel are required and equipment available for unloading. Route optimisation can improve things considerably by reducing driving time, but to have unloading areas that are well suited to the purpose can also shorten the time required and facilitate unloading.

Better knowledge of how different factors influence the unloading time would increase the possibilities to predict delivery times. This would improve the reliability of the planning model and possibly increase the acceptance for the proposed delivery time windows. The current research can contribute to this knowledge but more research is needed in the area.

There is also uncertainty in the prediction of travel times. As indicated in Figure 9, this uncertainty may be of similar magnitude as the potential savings, when analysing individual routes. Therefore, the proposed solutions should always be manually assesses or evaluated. However, when multiple routes have been optimised, the magnitude of potential savings has been so large that the uncertainty in predictions for individual routes can almost be neglected.

The scenarios in the optimisation analyses were designed to be able to compare solutions within a study. The focus was on comparing scenarios within the studies, rather than comparing the studies.

In Paper III the second scenario, option II, was most similar to the real situation in Dalarna and this would imply that a change to scenarios 3 or 4 could reduce the distances by 16-17%. Scenario 3 takes 7% less time than scenario 2, option II, while scenario 4 takes 5% longer due to extra unloading and loading time at LDCs.

Changes in delivery time windows can have a large impact and offer more efficient distribution. Although delivery time windows are often set for good reasons (*e.g.* when someone is available to receive the goods), their impact on the results is so great that they should always be challenged. In fact there may be alternative solutions. In the case in Dalarna (Paper III) it was confirmed that significant improvements can be gained by amending the delivery time window and this can be achieved since there is high level of trust between the partners in the distribution network.

When suggesting changes in delivery times, it is not necessary to have flexible delivery times throughout the day to achieve more efficient distribution. However when re-planning a system, it is wise to consider the reasons for the current time windows. Considering more delivery during non-office times (evenings/nights/ early mornings) can also be possible in some distribution systems.

The current DC was well situated according to the location analysis. It should be recognised that a location analysis based on an existing system, such as the one in Paper III, is valid as long as the system is not changed. The most suitable location can change when the system expands or alters in other ways. For the situation in Dalarna, Borlänge is the municipality with the highest number of deliveries and with only small changes in the system it is likely that the location will continue to be a suitable site. Since two neighbouring municipalities, Ludvika and Falun, are interested in joining the system, it is possible that the system will change within a few years. In that case Borlänge will still be in the middle of the system and will probably remain a good site for a DC.

5.4 Environmental impact

The estimated amounts of emissions are closely connected to driving distances. The fuel used results in differences in the proportions of substances. The environmental impact has been visualised for different scenarios (in Papers II and III) as profiles. By choosing several impact categories, the analyses have adopted the broader perspective used in LCA rather than a one-sided focus, *e.g.* on global warming. On the other hand, no further steps have been taken to aggregate the impacts by using a weight index. Weight indices for the aggregation of impacts are based on subjective values and should only be used in special cases since they make the results rather one-dimensional (Rydh, Lindahl & Tingström, 2002).

The use of smaller vehicles during parts of the routes, as suggested in Paper III, scenario 4, can result in longer driving times and increased handling costs, but it does reduce the use of heavy trucks. Other than having a smaller environmental impact, the use of smaller vehicles can have positive effects on the traffic situation in densely urbanised areas. Near schools and other locations with children, traffic safety is especially important. Decreasing congestion and cleaner air are important issues in many city centres.

There are many ways of optimising distribution systems but of central importance is using the vehicles as efficiently as possible in order to reduce "empty miles" with a low or zero load rate. It is also a matter of using the "right" vehicle for the right purpose. This must be done in ways that keep the efficiency of the system in focus and without a unilateral focus on load rates. In Paper II load rates were lowest in the urban areas, indicating potential for coordination.

The unnecessary motor idling that occurred on some routes led to unnecessary environmental pollution and a waste of fuel, resulting in unnecessary costs (and, if it was due to queuing, a sign of inefficient planning). By estimating environmental impacts, other aspects of a distribution system are examined. When comparing the results, it is important to have similar conditions between the systems. In these cases the goal has been to compare the impacts from scenarios within the studies rather than between studies. All estimates of vehicle emissions in this thesis are simply estimates, since no actual measurements of emissions were taken in the studies.

Estimates of emissions from transport are moving towards greater standardisation. In Europe a standardised methodology for the calculation and declaration of energy consumption and GHG emissions in transport services should be ready this year[21]. The development of the European ARTEMIS emission model facilitates a more common way of estimating other emissions and its adaptation to Swedish conditions (Sjödin *et al.*, 2009; Trafikverket, 2009, 2010) is of great use to national researchers.

It can be easier to estimate the environmental impact of short food distribution chains rather than longer (and global) chains. This is of advantage to local food if producers want to show consumers the impact of their transport more transparently. Regardless of the distance to production areas, our concern

21. CEN/TC 320 - WI 00320025, "Methodology for calculation, declaration and reporting on energy consumption and GHG emissions in transport services (goods and passengers transport)". http://www.cen.eu/cen/Services/EHD/Sectors/Pages/Servicessector.aspx [2012-09-07]

for food production and ecosystems has to remain on both a local and a global scale (Deutsch, 2004).

5.5 Developing logistics solutions for local food

Efficient logistics is a tool for improved quality and service, with minimised use of resources. By developing their logistics local food producers can decrease their logistics costs and environmental impact. The case studies analysed in this thesis demonstrated several possible improvements (*e.g.* coordination between companies, single and multiple route optimisation, integration into existing distribution systems and changes in delivery time windows).

Collecting and analysing geographical data is getting technically easier with increased availability of GPS-equipment and electronic maps. For a very small producer with few occasions for transport or delivery points, it might be enough to use simpler routing solutions such as free internet map services or a hand-held or car-mounted GPS with built-in maps. The companies handling larger material flows have in many cases bought advanced route planning and scheduling software such as DPS's Route Logix[22] to manage the logistics. For companies between these two categories, the use of route optimisation can greatly improve logistical performance. The choice of tools and level of utilisation is a matter of finding the balance between investment required and profits.

A balance is also to be found concerning how resources are utilised in general; *i.e.* if less or more time and money should be spent on production, refinement of products, logistics planning, or learning and implementation of new systems. For example, while a new electronic trading system may have advantages when comparing the direct costs, the time spent for learning the new system may change the balance.

In order to improve and develop the logistics of local food it is important to make the best of the available resources and take advantage of cooperation possibilities. Producers can cooperate and coordinate transport. They can also integrate their supply chain with larger logistics management and physical distribution systems. A logistics analysis can be a starting point for a producer when choosing between distribution channels to find the most profitable distribution solution. It is important for local producers to be flexible and open to different kinds of cooperative possibilities, since the prerequisites for cooperation can vary.

22. Software from DPS (Distribution Planning Software) International, http://www.dps-int.com/products/desktop/routing-software.php?ref=topNav, 2012-06-07

6 Conclusions

The main conclusions from the current thesis work are that coordination, optimisation and integration can improve logistics for local and small-scale producers in terms of cost, environmental impact and labour.

Great possibilities were identified for coordinating goods distribution for food producers in and around a city (Paper I):

- individual routes could be reduced by up to 34% in terms of distance and 40% in terms of time
- coordinating and optimising multiple routes could reduce the total number of routes by 58% and total route distance by 35%
- emissions were 48% lower after the total optimisation than before.

Small-scale producers with different kinds of products could coordinate and integrate their supply chains with a large scale retailer's logistics management and physical distribution system (Paper II):

- utilising an e-trade system small scale local food producers could integrate with a large scale food supply chain. Economic benefits could be gained if the system was well adapted to the producers
- coordinated and integrated transports reduced the environmental impact of the distribution: scenarios with coordinated collection and integrated distribution had 66-92% lower emissions than scenarios where all producers did their own deliveries.

The integrated logistics network of a local food distribution system in municipalities could be efficient (Paper III):

- route optimisation analyses indicated significant improvements: 64-74% and 54-63% shorter distances and total time respectively when transport scenarios with an integrated logistics network were

compared to a scenario where every producer/wholesaler distributes their own products
- a reduction in emissions of 68-75% when transport scenarios with an integrated logistics network were compared to a scenario where every producer/wholesaler distributed their own products.

The methods used in these studies to evaluate the performance of food distribution systems can be applied to the distribution systems of other goods as well.

6.1 Recommendations and further research

Based on the analyses undertaken, several areas requiring improvements were identified:

- coordination among companies with similar food products, distributing in the same region, requiring no further vehicle development
- coordination among companies with different kind of food products, distributing in the same region, might require vehicles with different temperature-insulated containers or other climate control solutions
- IT system for producers should be well adapted to the users
- consideration of delivery time windows could be necessary in a distribution system.

In order to address these issues raised in this thesis, further research into local food distribution needs to consider:

- continuous investigations of possibilities to improve the logistics strategies for small scale and local food producers
- development of research methodologies for small scale and local producers
- energy and environment analyses, in relation to transport, including alternative fuels.

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