Effective Transport Systems in Food and Agricultural Supply Chains

for Improved Economy, Environment and Quality

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Abstract

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Transport is a key link in the food and agricultural supply chain, providing essential services to the society. However, it is at the same time a major contributor to the negative environmental effects of goods transport as a whole, and this necessitates efforts to improve the economic as well as environmental efficiency. It was assumed that a detailed study of the most important material flows and transport operations, from a regional viewpoint, with the application of appropriate tools of logistics and supply chain management, could promote the sector on national and international levels.

The strategic objective of the current thesis was to promote effective transport systems in food and agricultural supply chains, for improved economy, environment and quality. In four case studies, a range of data collection methods (including key informant interviews, surveys, direct observations, measurements) were employed to investigate the possibilities to improve logistics performance using route optimisation, coordinated transport and integrated logistics methods.

It was found that constraints associated with environmental effects and effective utilisation of transport resources were significant. Loading rates were high (around 95%) in transport of primary products, whereas small, frequent deliveries and low (less than 50%) load rates characterised distribution of consumer products. Queues before delivery extended delivery operations in retail distribution and animal transport, resulting in stress on animals.

Several possibilities for transport coordination were identified, including coordination of grain collection with delivery of agricultural supplies, coordinated meat and dairy distribution, and coordinated delivery to city centre retailers. In the latter case, a demonstration trial illustrated that the number of deliveries to retailers could be reduced by 40%. With route optimisation, time savings of 16-24% were possible when optimising multiple routes. Farm drying and storage of grain could benefit the whole supply chain by reducing transport demand and seasonal concentration and enhancing transport coordination. Although this practice should be rewarded in an integrated supply chain, a modelling study indicated that wet grain delivery during the harvest season was the most beneficial for the supplier.

Keywords: supply chain management, agricultural transport, animal transport, city logistics, route optimisation, linear programming, delivery strategy

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To Malin & Linnea

“ **optimise**

…

verb; act as an optimist and take a sunny view of the world ”

(http://www.onelook.com/?loc=bm2&w=optimise; 10-Oct-2006)

Contents

Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Gebresenbet, G. & Ljungberg, D. 2001. Coordination and route optimization of agricultural goods transport to attenuate environmental impact. *Journal of Agricultural Engineering Research* 80(4), 329-342.

II. Ljungberg, D. & Gebresenbet, G. 2004. Mapping out the potential for coordinated goods distribution in city centres: The case of Uppsala. *International Journal of Transport Management* 2(3-4), 161-172.

III. Ljungberg, D. & Gebresenbet, G. 2006. Logistics chain of animal transport and abattoir operations. (Submitted to Biosystems Engineering).

IV. Ljungberg, D., Gebresenbet, G. & Ortiz, C. 2006. Optimisation tool for analysis of grain delivery strategy. (Manuscript).

Papers I and II are reproduced by permission of the journals concerned.

1 Introduction

1.1 Background

Goods transport within, to and from the agricultural sector is a significant component of goods transport as a whole, both on national and international levels. For example, Rogers and Davies (1990) noted that grain (188 million tonnes) and fertilisers (145 million tonnes) comprise 13% and 8% of the international sea-borne bulk trade, respectively. In Sweden, transport of agriculture and food products constitute about 12% of the goods volume, 17% of the goods value and 20% of the transport work (tonne-km) of total road transport (SIKA, 2006*a*; SIKA, 2006*b*). As an illustration of the economic significance of transport cost in the agricultural sector, the total cost of grain transport in Sweden may be estimated at SEK 281 million, representing about 6% of the producer price and EU direct payment (in comparison, the net revenue from grain production was estimated to 3-13% depending on farm size). The information is based on a freight tariff for grain transport (Svenska Lantmännen, 2005*b*) and agricultural economic survey (Swedish Board of Agriculture, 2006).

The accessibility to transport services is a prerequisite for trade and economic growth, for any kind of goods product. In the food and agricultural supply chain, reliable and effective transport systems supplying food to consumers in concentrated city centres as well as dispersed rural areas, are essential and need to accommodate the different requirements related to hygienic conditions, temperature, product quality and animal welfare.

Moreover, transport activity is one of the major contributors to environmental degradation and resource depletion in the western economy. The transport sector is responsible for 21% of the total greenhouse gas (GHG) emissions of the EU (15 member states) and for 87% of the increase in GHG emissions since 1990 (EEA, 2005). In Sweden, road goods transport has increased by 22% since 1994 (SIKA, 2005) and constitutes a significant share of road traffic. In a study in the county of Stockholm (SIKA, 2001) it was reported that goods vehicles represented 11.6% of the total road traffic performance in vehicle-km. The external cost of transport, considering accidents, air pollution and climate change (but not infrastructure, congestion and noise) has been estimated at 7% of the EU's GDP and for road freight transport (heavy duty goods vehicles), corresponding marginal costs were estimated at €0.26-0.92/vehicle-km (EEA, 2005).

Considering its extent and significance, transport related to the agriculture and food chain deserves attention from two perspectives;

- → as a key link in the food chain, providing cost-effective services and maintaining quality, including animal welfare
- → as a major contributor to the environmental effects of goods transport as a whole.

Undoubtedly, there is good reason for efforts to improve the economic as well as environmental efficiency of transport activities. Even more beneficial would be if transport could be minimised without compromising the service requirement. An approach to the analysis and improvement of transport efficiency is therefore to extend the view and study the transport system as part of a logistics system rather than as an isolated phenomenon. The most effective logistics solution to a problem may well be to minimise the need for transport. Considering this, an underlying assumption for the current work was that studying logistics for the agricultural and food chain is a relevant and effective approach to address important problem areas for supply chain performance and for a sustainable environment.

1.2 Logistics

The concept of logistics has essentially evolved through the development of optimisation methods and heuristics for the planning of military operations forming the area of operations research methodology, over physical distribution planning into a multi-disciplinary subject involving mathematics, programming, engineering, physical planning, economics, social sciences and more. Much of the development in the field of logistics takes place in business environments rather than in the academic environments and concepts and definitions are in continuous development.

However, a general definition has described logistics 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 customer requirements*" (http://www.clm1.org/mission.html, 12-Feb-1998). In essence, the same concept was referred to by Gecowets (1979) as the "*five rights of distribution: the right product at the right place at the right time in the right condition for the right cost*". The same author argued that coordination and continuing exchange of information between the functions involved in distribution in a company, was the key for physical distribution management.

The concept of supply chain management extended the perspective beyond the internal operations of a company; supply chain management (SCM) is *"…the integration of key business processes from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders"* (http://scm-institute.org/premise.htm; 9-Oct-2006), while "*Logistics Management is that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements*" (CSCMP, 2005). Another distinction of SCM from the prior terms of materials management and physical distribution management is the notion of complexity, volatility, and operational velocity (Hall & Braithwaite, 2001). As it may be argued (Christopher, 1998) that real supply chains are complex and better described as networks, and that management should be guided by customer demand rather than supplies, *demand network management* could have been a better term to use. The network idea might be gaining interest (*e.g.* Mattsson, 2003; Kotzab & Teller, 2003; Shen, 2006), and demand management is used for the activities of forecasting, managing and communicating demand data in the supply chain (Taylor & Fearne, 2006), but SCM has become the global term, used in line with the definitions above, in management and research communities.

Hall and Braithwaite (2001) described the development of lean logistics for improving supply chain performance. Aiming to eliminate waste (categorised as inventory and overproduction, transportation and motion, defects, waiting and inappropriate processing) from the processes, the principle of just-in-time (JIT) was globally adopted as a strategy where frequent and timely deliveries enable reduced inventory in the production system.

Stating that "*the real competition is not company against company but rather supply chain against supply chain*", Christopher (1998) stressed that the companies involved in a supply chain need to cooperate in order to create the most competitive supply chain possible, rather than compete for individual company profits. In the supply chain perspective, the requirement for company-internal coordination and continuing exchange of information (as requested by Gecowets above) is extended to inter-organisational coordination and exchange of information, in order to maximise the profitability of the supply chain. Consequently, finding the ways and structures for collaboration has emerged as a key topic within SCM. This is frequently referred to by the term 'integration'; the task of coordinating physical, economic and information flows (Figure 1) in collaboration between organisations in order to create a competitive supply chain.

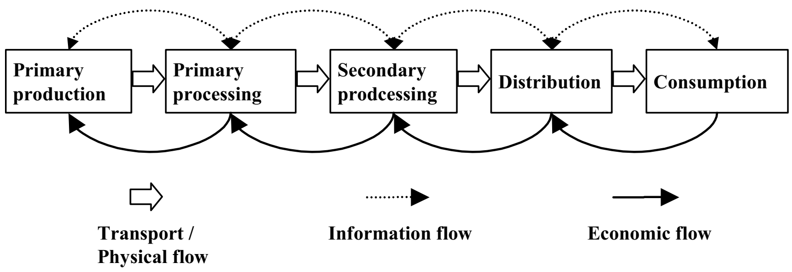

Figure 1. Physical, economic and information flow in a supply chain

Extensive research has been carried out in the field of supply chain integration in various industries. Folkerts and Koehorst (1997) argued that this integration will result in "*greater accuracy, speed and flexibility in response to consumer demands*" which could not be achieved by individual companies. Li *et al* (2005), Gavirneni (2006) and Chu & Lee (2006) used operations research methods to model the effects of information sharing in the supply chain. However, according to Bonet and Paché (2005), logistical relationships still tend to lead to competition within the supply chain. A typology for supply chain collaboration was suggested by Holweg *et al* (2005). The authors discussed the applicability of different strategies (traditional supply chain, information exchange, vendor managed inventory, synchronised supply chain) in different settings, arguing that the strategy of information exchange could be the most appropriate in many cases. The investments (in trust and commitment as well as in monetary terms) of vendor managed inventory and synchronized supply chains may be too high in relation to the expected outcome. Studying 300 US companies, Das *et al* (2006) found that there is an optimal level of supply chain integration, where over-investment is avoided.

1.3 Effective transport systems

In freight transport, the principle of JIT acts as a driving force for smaller and more frequent deliveries, contributing to increasing transport work for constant goods volumes and increasing modal share of road transport. Furthermore, JIT influences the increasing utilisation of light goods vehicles, as stressed by Browne *et al* (2004). However, it may be argued that to some extent, the current tendency is contra productive; in their efforts to eliminate waste in their internal processes, actors contribute to increased transport intensity and congestion, negatively affecting the performance of the transport system as a whole (in addition to the external effects on traffic safety, environment, *etc.*). McKinnon (2001) cited the statement of the European Logistics Association: *"Members of an integrated supply chain should collaborate to maximize vehicle load factors, minimize empty running, achieve an optimal allocation of freight between modes, and standardize on handling systems that make effective use of vehicle and warehouse capacity"*. In fact, responding to this statement may also require collaborative approaches across supply chains in order to improve transport efficiency.

There is a wide range of possibilities to define the efficiency of transport and effective utilisation of vehicle capacity does not only depend on the load rate, measured at a single point of the route; load rate variation during the route and empty-running should also be regarded. In general, a combination of indicators may be required. As a complement, an 'effective load rate' (weighted average over the whole trip) was proposed by Tarkowski *et al* (1995), which could reflect also the utilisation of back-hauling and integration of collection and distribution during the route.

A framework model discussed by Samuelsson & Tilanus (1997), defined an overall theoretical efficiency based on time, distance, speed and capacity efficiency components. Ideally, the vehicle should be in movement 24 hours a day, on the closest route between destinations, carrying the maximum amount of goods possible (considering the multi-level efficiency of loading the goods, including vehicle design and packaging). Furthermore, as pointed out by the authors, the efficiency could be defined not only in economic terms but also, for example in terms of environmental performance.

Although the model illustrates the complexity involved, it may not be possible to find a single indicator to define transport efficiency in a practical and transparent way. Furthermore, transport efficiency is a component of a larger system, where many factors, such as infrastructure, facility location, product design and the generation of physical flows influence the total efficiency. More appropriate could be to use a number of indicators. Another approach to measuring transport capacity utilisation would be to compare observed system to a reference system based on optimisation.

1.3.1 Route optimisation

Route optimisation refers to the optimisation of single or multiple vehicles movement between call points in a network, often involving the task of finding the optimal sequence of call points (known as the travelling salesman problem) and taking into account the vehicle load capacity and time windows for pick-up and delivery locations.

Commercial software is available to handle the problems noted above and in addition, location analysis based on road network travel time, vehicle tracking and integration in enterprise resource planning systems, where an important feature of the route generation is to provide transport costing data. The calculation is based on simplifying heuristics, which reduce calculation time at the expense of optimality in the solutions. Extensive publications of research in this area indicate potential for improvement in calculation time as well as optimality. A review of literature related to vehicle routing problem was presented by Giaglis *et al* (2004).

Vehicle routing and scheduling systems are closely connected to intelligent transport systems (Ockwell, 1999; Cendré *et al,* 1999), where technologies for geographic positioning, wireless communication and vehicle routing may be integrated for the improvement of vehicle operations. In their review, Giaglis *et al* (2004) found that the improvements in performance and availability of wireless communication technology create possibilities for dynamic vehicle routing and scheduling, which could handle deviations from the planned routes due to unforeseen events.

In contrast to the extensive publications on optimisation models and heuristics, however, the effect of implementation of route optimisation systems (as presented by Gebresenbet, 1999) in real problems has received less attention.

1.3.2 Transport coordination

To identify the possibilities for transport coordination, it is essential to map out directions and characteristics of material flows. Coordination of transport operations may be implemented along two lines:

- → back-hauling and
- → combined loading.

Back-hauling refers to the utilisation of loading capacity on empty return trips for movement of one product in each direction. Sometimes, a detour is required to collect goods for the return trip.

Combined loading refers to the utilisation of loading capacity for goods movement in the same direction. Combined loading could be organised by means of goods terminals and/or collection/distribution routes. Thus, back-hauling reduces the empty haulage and combined loading increases the load rate. Furthermore, transport concepts where back-hauling and combined loading are integrated are possible. Various optimisation tools, as discussed above, provide powerful tools for strategic and operative planning of coordinated transport operations.

For back-hauling as well as combined loading, the coordination could be constrained by: laws and regulations for goods handling (*e.g.* food products, animals); type of goods (*e.g.* palletized, bulk); technical (*e.g.* loading equipment, temperature); competition; and reluctance to change.

1.4 City logistics

In the food and agricultural supply chain, as a consequence of urbanisation, a large and increasing proportion of the distribution of consumer products takes place in cities. Furthermore, as reported by Allen *et al* (2000), food deliveries are among the most frequent to city centre retail shops. Goods distribution in crowded city centres is increasingly recognised as an important problem. However, the phenomenon is not new. Many city centres of today would fit well into the description made by Horwood (1958), of the city of Philadelphia, US: "*The great number of trucks delivering only a few pieces each, and the space they occupy on the streets as well as at loading docks, gives rise to a serious consideration of the need for some system to reduce deliveries of one or two pieces. Conceivably this could be a consolidation scheme.*"

Urban goods transport systems have been studied since 1950's (although not nearly with the same effort as has been put into systems for passenger transport), for the purpose of improving the traffic conditions in congested city centres in the US (Demetsky, 1974; McDermott & Robeson, 1974; Smith & Douglass, 1982), and Australia (Taylor & Ogden, 1999). In Europe and Japan, combined loading was promoted in the concept of 'city logistics' (Janssen & Oldenberger, 1991; Ruske, 1994; Taniguchi *et al*, 1995), defined as "*the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy*" (Taniguchi *et al* 1999). Methods to optimise the coordinated distribution were presented by e.g. Nemoto (1997), Taniguchi & van der Heijden (2000) and Sheu (2006) and it is assumed that the coordinated transport operation will result in efficiency improvements. However, there is also a strong emphasis on reducing the negative economic, environmental and social impacts of urban transport. In Sweden, studies of urban goods distribution were presented by Taflin *et al* (1982), Pettersson (1999) and Backman *et al* (2001).

Although congestion, which is one of the main reasons for city logistics initiatives, tends to increase with the size of cities, the problem may be relevant also for a city like Uppsala (138 000 inhabitants). The air quality standards in the city centre of Uppsala have not been met during recent years (LVF, 2006). When studying the logistics systems for the food and agricultural supply chain in the Uppsala region, deliveries in the city centre should therefore be of major concern.

1.5 Logistics for the food and agricultural supply chain

In the food and agricultural supply chain, it appears that more research has been attracted to the supply chain aspect (emphasising the demand side), than to logistics and transport systems in the agricultural system (supply side). Optimisation models with application to the collection of biomass have been presented by several authors, including Cundiff *et al* (1996), de Mol *et al* (1997), Higgins (2006) and Lopez Milan *et al* (2006). Broek *et al* (2006) addressed the optimal location of abattoirs. Prentice (2000) and Vachal & Reichert (2000) discussed containerisation of grain and the potential of adding value to the product and strengthening its linkage to production methods and region of origin by preserving the identity of shipments.

Recently, supply chain integration has received increasing interest in the food chain and the field of value chain analysis has expanded. Folkerts and Koehorst (1997) described the food supply chain as "*a set of interdependent companies that work closely together to manage the flow of goods and services along the value-added chain of agricultural and food products, in order to realize superior customer value at the lowest possible costs*", and used the term '*chain reversal'* to emphasise the need for customer orientation, rather than supplier orientation, throughout the chain. Minegishi and Thiel (2000) modelled system dynamics in a poultry supply chain. Several authors (Kotzab & Teller, 2003; Taylor, 2005; Taylor & Fearne, 2006) discussed the challenges of applying lean logistics in food and agricultural supply chains, proposing that more collaboration, information sharing and joint planning for the supply chain to work effectively. Prater *el al* (2005) reviewed the use of radio frequency identification (RFID) in supply chains of the grocery industry.

Although important achievements have been made regarding how to better understand, and collaborate in, the supply chain, transport-related research in the field is more limited. Moreover, most of the research referred to above was economically, rather than environmentally motivated. Whereas in many ways, the most economic logistics solutions also may be resource efficient from an environmental point of view (e.g. minimisation of transport cost), other economically motivated tendencies, such as JIT (as discussed above) and structural rationalisations (centralisation of facilities) may result in increasing transport activity. It is therefore of interest to emphasise the transport system not only as part of a supply chain (economically motivated), but also with a concern for its external costs for the environment (environmentally motivated).

The differences between countries and regions associated to *e.g.* geographic and climatic conditions and the structures of production, industrial processing and markets motivate that studies were made in a regional perspective.

Transport research in the food and agricultural supply chain related to Swedish conditions has been quite limited. The investigation made by Svensson and Ottosson (1982), on the possibilities for coordination of goods transport in agriculture, and the report of Abrahamsson (1992) on the distribution of agricultural supplies, were among a few examples.

1.5.1 Characteristics of agricultural transport in a regional perspective

To discuss transport and logistics systems for food and agricultural supply chains, some characteristics of the material flows should be considered. In the current work, special emphasis was made on application to the Uppsala region, Sweden. It is assumed that a detailed study on the most important material flows and transport operations in the food and agricultural supply chain, from a regional point of view, with the application of appropriate tools of logistics and supply chain management, could promote the sector on national and international levels.

The production of grain, milk and meat, in Uppsala region and in Sweden as whole, is summarised in Table 1.

Table 1. Type of farms and production in Sweden and Uppsala county (Statistics Sweden, 1999)

	Type of farming in Uppsala county and Sweden, %				Agricultural production in Uppsala county and Sweden, tonnes×10[3]			
	Crop production	Animal husbandry	Integrated production	Small-sized holdings	Grain	Milk	Meat	Eggs
Uppsala region	35	28	14	23	335	90	17[a]	3[b]
Sweden	17	38	7	38	5 618	3 300	570	106

[a]Slaughtered weight of animals from Uppsala county, estimated by Ingstedt (2000) to 50% of the total slaughter in Uppsala (34 000 tonnes/year); [b]Forhammar et al. (1995)

Figure 2 illustrates the material flow in the agricultural and food supply chains, with a focus on agricultural produce, agricultural means of production, related processed products and by-products. Means of production, such as seed, commercial fertiliser, plant protection, supplies to fodder factory, reach the farms via processing industries and trading organisations. Grain, milk, live & slaughter animals leave the farms as agricultural produce. Processing industries refine these into processed products, such as flour, malt, fodder, dairy products and meat. By-products at the farm level (*e.g.* natural fertiliser and straw) are transported within and between farms. By-products at the industrial level (including bran, whey, and by-products from malt production) are to a large extent re-distributed to farms, directly from the processing industries, via fodder factories or via the trade channels for agricultural supplies. Figure 3 illustrates the specialisation of farms and the material flow generated between farms (in practice, many farms are combinations of the types in the schematic description).

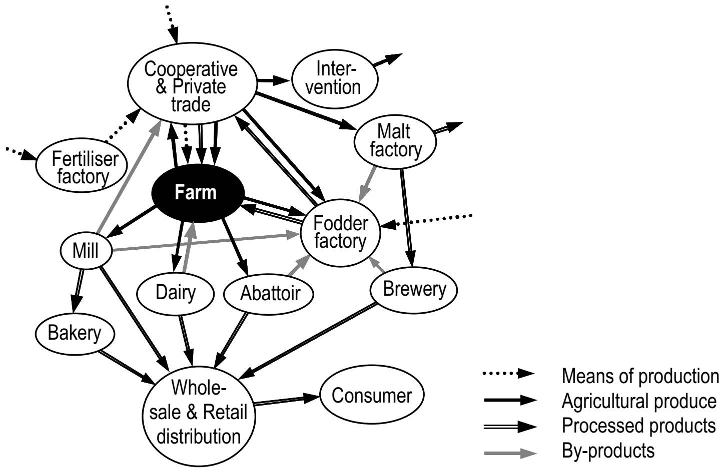

Figure 2. Major material flows of agricultural produce and related means of production, processed products and by-products, to and from farms and industries in the agricultural and food supply chain in the Uppsala region, Sweden.

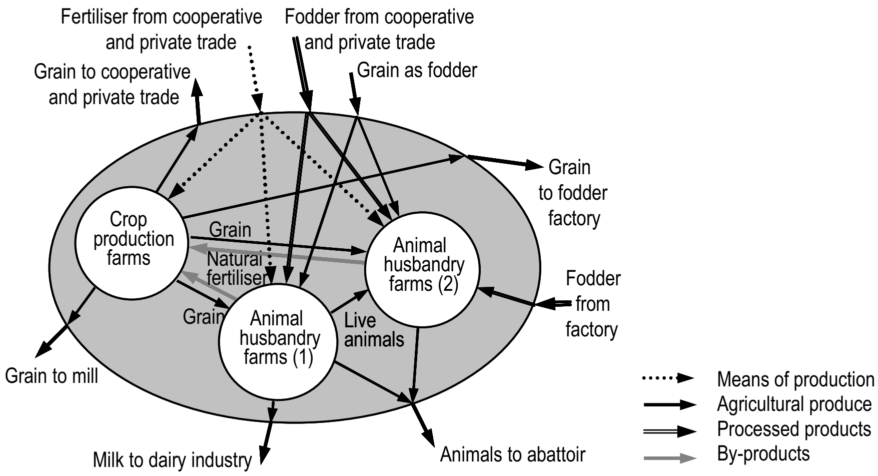

Figure 3. Material flow to, from and between farms; animal husbandry farms (1) include live animals production and dairy production, while animal husbandry farms (2) includes meat production (detail of the 'Farms' block in Figure 2).

As indicated in Table 1, the largest quantities are related to grain production, and in addition, these are characterised by a seasonal concentration to the harvest period. It is therefore of interest to study grain deliveries from the farm. The term 'delivery strategy' could be used to describe the series of choices defining how, when and where to deliver a product to a customer. For a grain supplier, a delivery strategy may be illustrated as the path from harvest to a selling point in a network (Figure 4). As described in the network that is depicted in Figure 4, alternative grain delivery strategies affect subsequent operations and transport demand.

Integrating the delivery strategy with the rest of the supply chain would open possibilities for avoiding transport.

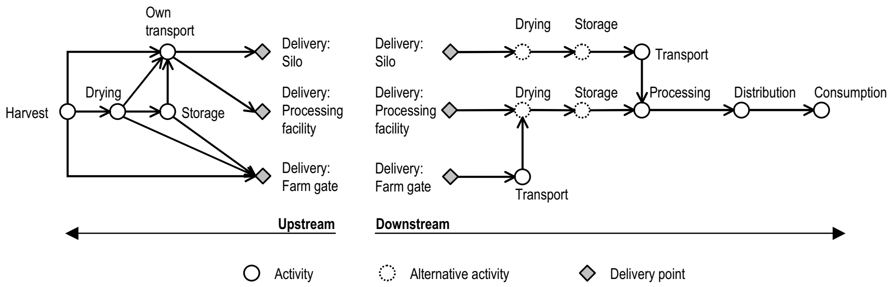

Figure 4. Network representations of upstream and downstream parts of a grain supply chain, with alternative supplier delivery strategies illustrated as paths from harvest to a delivery point (in the downstream part, the status of alternative activities are dependent on upstream activities).

Transport operations in the food and agricultural supply chain have different characteristics in different parts of the chain. On the supply side of the chain, the operations are characterised by

(a) collection from geographically scattered production units in rural areas
(b) seasonal and weather-dependent patterns of production
(c) uncertainty in transport, loading and unloading times due to traffic conditions (weather dependent, *e.g.* winter and spring time), animal behaviour and queues at delivery
(d) bulk handling of grain and milk
(e) traceability requirements
(f) hygienic and temperature regulations concerning food products
(g) regulations and concerns for animal welfare

On the demand side, the operations are characterised by

(a) distribution to wholesale and retail sector, primarily in urban areas
(b) seasonal, weather-dependent and irregular patterns of consumption
(c) uncertainty in transport, loading and unloading times due to traffic conditions (congestion) and queues at delivery
(d) consumer packaging of goods
(e) traceability requirements
(f) hygienic and temperature regulations concerning food products

1.5.2 Research approach for the food and agricultural supply chain

Considering the significance of transport operations in the agriculture and food chain, from economic as well as environmental perspectives, and the rapid structural transitions from small-scale to large-scale in primary production and processing industries, there is a need for research in agricultural logistics. Learning from the development of logistics and transport systems in other sectors, there may be opportunities to apply theory, organisation and technology to the field of agriculture and food chain logistics, so that efficiency and quality are improved.

From the reflection of developments in the field of logistics above, optimisation of operations, coordination of activities within and across organisations and integration in the supply chain, may be identified among the key strategies for improving logistics performance. At the same time, agricultural and food chain logistics have certain specific characteristics (*e.g.* the combination of collection and distribution, the discrepancies between seasonal patterns in production and consumption, the characteristics of biological products), to be considered. Although the interest in some aspects of this area (*e.g.* value chains) may be growing, research integrating the perspectives of economic and environmental performance (such integration was strongly emphasised in the area of city logistics, as found in the review) is still limited.

For the development of a research approach for the food and agricultural supply chain, integrating the concerns for economic performance, product quality and environmental effects, New and Payne (1995) presented relevant examples. The authors discussed research frameworks in the field of logistics and supply chain management, recognising that a trade-off between real-world applicability and scientific rigour makes it difficult to find a single method to combine the two. Mangan *et al* (2002) argued that research in logistics could benefit from the utilisation of methodological triangulation, where quantitative methodologies (which are generally associated with a positivist research paradigm) and qualitative methodologies (which are generally associated with a phenomenological research paradigm) are combined.

In this thesis, a case study approach was applied, in which four case studies of logistics systems in the agriculture and food chain were conducted. In each of the case studies, a range of data collection methodology (including key informant interviews, surveys, direct observations and measurements) was employed, and tools for improving logistics performance (route optimisation, coordinated distribution, integrated logistics) guided the analysis of the observed systems.

2 Objectives and structure of the work

The strategic objective of this thesis is to promote effective transport systems in food and agricultural supply chains, for improved economy, environment and quality. It is intended that the knowledge gained could contribute to the development of effective transport and logistics systems for multiple-actor chains of agriculture and food supply.

Figure 5 illustrates the scope of the study; the use of tools (integrated logistics, coordinated transport, optimisation) for improving the performance of a system (the agriculture and food supply chain) in relation to objectives of different effect categories (economically profitable, environmentally sustainable products of high quality, including animal welfare concerns).

In order to address the strategic objective, the partial studies presented in Paper I through IV, were conducted in a regional perspective. In each of the studies, specific objectives, contributing to the strategic objectives, were addressed.

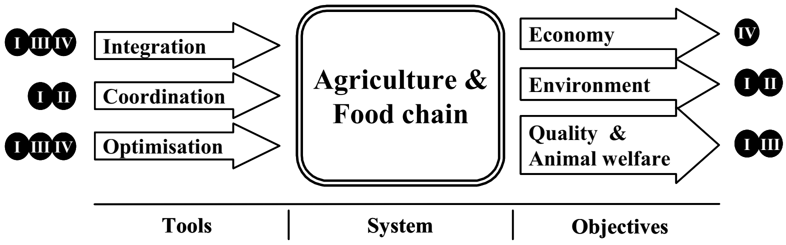

Figure 5. Scope of the study, indicating the focus areas addressed by Paper I–IV.

This thesis summarises and synthesises the findings of the partial studies. The supply chain context of the papers is illustrated in Figure 6. The grain supply chain is treated in Papers I and IV, milk collection in Paper I, dairy distribution in Papers I and II, animal transport in Papers I and III, meat distribution in Papers I and II, and retail distribution of food and other consumer goods in Paper II.

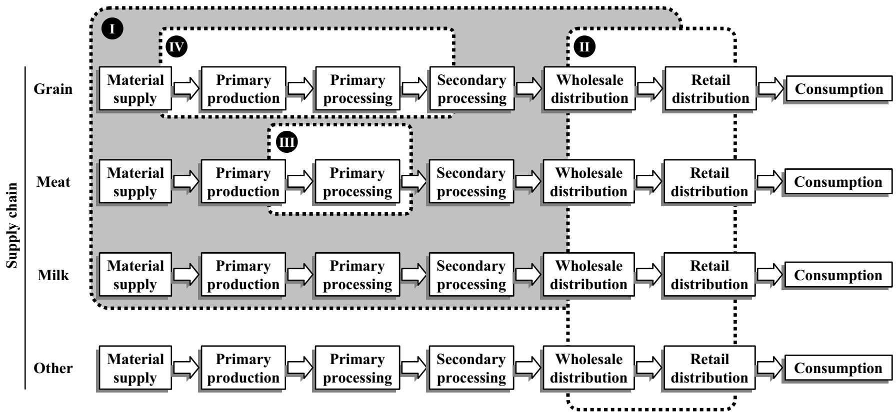

Figure 6. Supply chain context of Paper I-IV.

The main objective of Paper I was to map out the material flow and to investigate the possibilities of IT-supported co-ordinated transport of agricultural produce and agricultural means of production in Uppsala region in Sweden. It was assumed that the gathered data could be used to develop an effective transport-logistics system to enable an efficient utilisation of vehicles and meet the demand for attenuating environmental impacts. Specific objectives of the study were to

(a) map out goods flow from, to and between farms;
(b) investigate possibilities of loading different goods on the same truck during the same trip, and also integration of goods collection and distribution and thus co-ordinate transports in the region as a whole;
(c) identify constraints that may limit the possibilities of co-ordination; and

(d) study the effect of route and distribution optimisation and its environmental benefits.

The objective of Paper II was to map out the pattern of goods distribution to retail shops in four shopping galleria in Uppsala city, in order to investigate the potential for coordinated goods distribution to contribute to reduced financial cost, congestion and environmental impact. In addition to Paper II, a field trial was carried out with the objective of demonstrating the potential of coordinated distribution to city centre retail outlets, in practice.

Paper III aimed to describe in detail the logistics chain of animal transport and abattoir operations, in order to demonstrate the potential effect of operations planning and route optimisation on animal welfare, meat quality and environment. The operation considered involves the activities of loading at the farm, transport, unloading of slaughter animals at the abattoir, and operations in the slaughter chain from lairage box to cooling room for carcasses.

In Paper IV, the objective was to develop a model for grain delivery strategy, which could be used as a decision support tool for grain suppliers, and to apply the model in an analysis of the consequences for individual suppliers facing recent and planned closing of silos and other grain-handling facilities.

3 Methodology

The study was concentrated to the region surrounding Uppsala, Sweden (59°51'35"N, 17°38'26"E). Statistics of agricultural production refer to Uppsala county, while the geographic limitation of system descriptions depend on the location of major delivery destinations for the products concerned. The study of urban goods distribution (Paper II) concerned deliveries to retail shops in the city centre of Uppsala, with a focus on four shopping galleria (comprising about 100 shops). Paper IV was concentrated to grain producers supplying a commercial silo in Örsundsbro, 25 km south-west of Uppsala city. The following section summarises the methodology used in the partial studies.

3.1 Mapping out material flow and organisation of logistics in the agriculture and food supply chain

3.1.1 Interviews and surveys

Key informant interviews were utilised to collect information regarding the organisation of logistics and transport, in Paper I, II and III. Information regarding deliveries to city-centre retail shops was collected through a hand-out questionnaire survey (Paper II). In Paper IV, farm-specific information was gathered in a limited telephone survey of grain suppliers. Interview and questionnaire sources of quantitative data are summarised in Table 2.

Table 2. Interview data sources (number of respondents given in parentheses)

	Key informant interviews	Survey
Paper I	Operations manager (3), Driver (1)	-
Paper II	Transport manager (12)	Hand-out questionnaires (27)
Paper III	Operations manager, Driver (5)	-
Paper IV	-	Telephone interviews (9)

3.2 Observation of logistics and transport system characteristics

3.2.1 Route registration

Data regarding collection and distribution were collected through on-board registration of transport routes using the Global Positioning System (GPS). Hand-held GPS receivers (Magellan GPS 3000 and Magellan GPS 315), with an accuracy of 15 m RMS as stated by the producer, were utilised to record the latitude and longitude of loading and unloading stops, the route choice, and the time used for loading, unloading and other activities. In Paper I, 196 routes were registered, for collection of live animals, grain, and milk from farms to processing facilities, and distribution of dairy and meat products from dairy and abattoir to retail shops. Most of the routes were registered by a person following in the vehicle, although some of the grain transport routes were registered by the drivers. However, a number of the routes registered by drivers, especially when using the GPS 3000 (which had a longer response time), were found invalid. In Paper III, 22 routes were registered, for transport of live animals from farms to abattoir. The route registration is summarised in Table 3.

Table 3. Registered transport routes

	Paper I	Paper III
Grain transport	76[a]	-
Milk collection	60	-
Dairy distribution	28	-
Animal transport	15	22[b]
Meat distribution	17	-

[a]Valid registration of route choice: 41 routes; [b]Valid registration of route choice: 19 routes

3.2.2 Observation of loading and unloading operations

In addition to the observations of loading and unloading during route registration, detailed registration of loading and unloading operations was done at abattoir and retail shop unloading zones. Observations of unloading at retail shops in four shopping galleria in Uppsala city were made during 174 hours (Paper II).

During the observations, the following parameters were registered; vehicle registration number or name of the transport company, destination of delivery, time of vehicle arrival and departure, duration of waiting and preparations, duration of unloading, amount of goods (number of pallets, roll cages or individual packages) and type of goods (beverages, bread, flowers, food, other goods).

At most of the observed unloading zones, deliveries could take place in parallel, although they could be obstructing each other. Thus, queuing time was usually not directly observed, but in the data analysis, a delivery was regarded as a 'queue observation' if the vehicle arrived at a loading bay before the previous delivery at the same loading bay was finished.

Detailed registration of unloading at the abattoir, was made during 30 hours of observation (Paper III). The following parameters were registered; vehicle registration number, time of vehicle arrival and departure, duration of waiting and preparations, duration of unloading and number of animals (cattle, calves, pigs, sheep and goats).

3.2.3 Observation of activities in the cattle slaughter chain

For the activities after unloading from vehicles; *i.e.* lairage, stunning and through the slaughter chain for cattle, waiting times, starting and finish times and number of animals handled were registered during 20 hours of observation.

3.2.4 Load rate observation

During route registration and observation of loading and unloading operations, the load rates of transport vehicles were observed. For route registration (Paper I), where the loaded quantities and vehicle capacities were known, the load rate was based on the vehicle load carrying capacity in terms of goods weight, and the highest observation during the route was noted. For observations at the unloading zones (Paper II), the load rate was based on occupied floor space estimation, which is easily observed and was considered to reflect a 'practical' utilisation of load capacity. The load rate observations were made before delivery (after all loading stops for collection routes and before first delivery for distribution routes). Observations at the unloading zones (Paper II) did not distinguish whether the observed delivery was early or late in the delivery route.

3.3 Route optimisation

Using commercial route optimisation software (RouteLogiX Professional; DPS, 1996), the registered routes were compared to optimised routes. The software calculates shortest or quickest path, optimal sequence of locations ('call points') and joint optimisation for scheduling of several vehicles, based on a road database containing information regarding distances, speed limits and constraints for heavy vehicle traffic for each road link.

First, the software was used for calculating the registered routes. In order to force the software to calculate the registered route, and to improve the approximations for call points located off road network in the database, reference points were included in the call sequence. Thereafter, the reference points were removed and the routes recalculated to find the optimal sequence and routes between call points. This method was used for all routes. In Paper I, joint optimisation of multiple routes was carried out for milk collection, dairy distribution, animal transport and meat distribution (routes where all vehicles had a common origin or destination). All route optimisations were made with respect to travel time, assuming that this would result in more economic solutions and avoid the use of narrow roads, as compared to shortest path optimisation.

Comparing the optimised routes to the registered routes, the potential savings in time, distance and number of vehicles, were calculated. Furthermore, the potential reduction in the emissions of CO_2, was calculated (Paper I).

3.4 Demonstration of coordinated distribution

The study presented in Paper II was complemented by a field trial, demonstrating the potential of coordinated distribution to city centre retail outlets in practice. In contrast to many of the reported previous attempts, a retailer approach to the implementation of coordinated goods distribution was tested in the trial, recognising that the retailers had the ability to control the delivery address of all deliveries. The demonstration trial has been reported by Ljungberg *et al* (2002).

The retailer approach relied on voluntary participation from the retailers and the process of gaining support and engagement was critical. A first step in this process was to identify the stakeholders of the distribution system. As the most relevant actors to include in this process, retailers, key persons at manager level in retail chain stores, local retailer associations and coordinators of retailers in the shopping galleria, estate owners, locally based transport operators, and municipal policy makers were identified. The project was presented to these actors and to the broader public through a series of meetings, seminars and media contacts, and in personal contacts, and the problems and solutions were discussed. Retailers were approached in visits and telephone contact, in order to encourage participation in a free-of-charge, voluntary trial of coordinated distribution.

The conditions for retailers to participate were that when ordering goods, the address of a consolidation terminal (located outside the city centre) was given as the delivery address. The goods arriving at the terminal was coordinated and delivered to city centre retail shops (in two trips per day) and participation was free-of-charge for the retailers. Figure 7 illustrates goods distribution in the unchanged situation, in full implementation and in the case of a partial implementation.

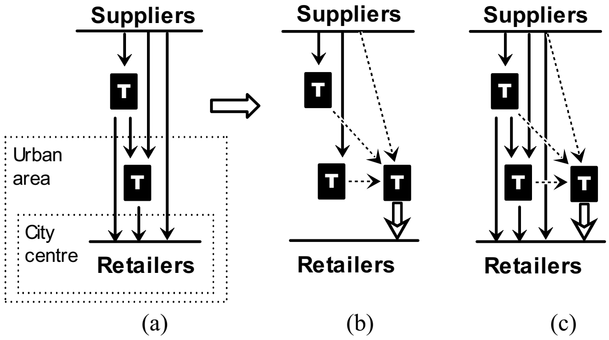

Figure 7. Concept of coordination of goods from suppliers, through terminals (T) to retailers, during (a) initial (unchanged) situation, (b) full implementation and (c) partial implementation

3.5 Optimisation model development

A model was developed for optimising grain suppliers' choice of delivery strategy (Paper IV). In a variable cost linear programming model, the net profit (*Z*) from grain delivery was described as the revenue (*R*) minus the costs of transport (*T*) to the delivery destination, drying (*D*) and storage (*S*), or $Z = R - T - D - S$. The model maximises the net profit for a farm by allocating the available supply of each product (grain variety) from the farm to a delivery strategy; *i.e.* delivery destination, moisture content and time of delivery are assigned to all available supply of the product.

The calculation of revenue was based on national average producer prices for grain in Sweden during the harvest season and after storage, including contract and storage compensations (Swedish Board of Agriculture, 2006), and the terms of delivery (Lantmännen ODAL, 2000; Svenska Lantmännen, 2005a), describing the reduction in revenue depending on *e.g.* moisture content, destination of delivery and, if the grain was collected from the farm, the freight tariff for collection (Svenska Lantmännen, 2005b). The drying, storage and own-account transport costs were based on information regarding a 100 ha farm, from a producer of farm-level drying and storage equipment (in: Westlin *et al*, 2006) and agricultural extension services (Maskinkalkylgruppen, 2004).

The model was applied to grain suppliers, in a region affected by structural rationalisation, where two delivery destinations were closed after the harvest season 2000 and several more will be closed before 2010. Four scenarios were modeled, reflecting changes in grain production, facility location and price levels: *Scenario 1* – for the situation in 2000, with all delivery destinations open and grain prices as reported from 2000; *Scenario 2* – for the situation in 2005, with two locations closed and average of grain prices from 2000-2004; *Scenario 3* – for simulating the potential effect if the two grain silos remained open, while using the same grain prices as in Scenario 2, and; *Scenario 4* – for simulating the situation in 2010, when only one of the delivery destinations is planned to remain. In Scenario 4, the producer prices were increased by 100 SEK/tonne, as compared to

Scenario 2 (this level of increase was foreseen as a result of the planned structural rationalisations Svenska Lantmännen, 2006).

4 Results and discussion

4.1 Characteristics of the studied transport systems

4.1.1 Organisation of transport operations

Grain transport

Most of the grain transport routes observed (collection from farms or transport between facilities) involved one loading stop (full vehicle load) and one delivery stop. Four routes for distribution of agricultural supplies (seed, fertiliser and fodder packaged in bags) to multiple farms were observed. The transport operations were planned manually; tasks were assigned to transport operators by a central transport manager and each operator planned their routes in detail manually. The assignment was flexible but in general based on the geographic location of the transport operators.

Milk collection

Milk was collected from each of 444 milk-producing farms in the region every second day, by five transport companies following regular routes with 2-16 collection points.

Animal transport

In animal transport, the average route for collection of slaughter animals included five collection stops (varying from 1-9), loading 3 (1-16) cattle at each farm, according to driver interviews. Transport managers at the abattoir assigned tasks to transport operators. The assignment was based on a division of the region supplying the abattoir in sectors, each covered by one transporter.

Meat and dairy distribution

Meat distribution from the abattoir in Uppsala involved eight vehicles, following regular routes in the urban and rural areas. For dairy distribution, eight vehicles were used in the urban area and five in the rural area, in regular routes departing from a terminal in the urban area.

Retail distribution

More than 100 different transport operators were identified in the observations of loading and unloading operations at delivery zones of city centre retailers, most of them observed at only a few occasions. Seven transport operators, operating from consolidation terminals in the urban area (outside the city centre), were among the most commonly observed. Some of these operators were independent, while others were organised in national or international networks, with different sub-contracting arrangements. The routines for goods delivery varied slightly depending on transport operators and differences in the layouts of unloading zones, but the most common sequence was the following: arrival – queue – parking – contacting the addressee – unloading – delivery signature – loading of return goods and packaging – departure. In total, these transport operators made 23 routes per day in the city centre, each including 15-25 stops.

4.1.2 Size of deliveries to retail shops

According to the questionnaire study, most of the retailers received 1–3 deliveries per day (some up to 20 per week). The retailers had 1–100 different suppliers and 81% did not have fixed times of delivery. Three transport operators were reported to carry out deliveries to most of the shops, each mentioned by *ca*. 60%. Other transport operators were reported to deliver to 20% of the retailers, or less.

About 120 deliveries per day and up to 14 per hour arrived at the studied unloading zones (food deliveries accounting for 40%) and the size of most deliveries was small. Packages accounted for the largest number of deliveries (57%, Figure 8) and in two thirds of the deliveries, less than 5 packages were unloaded (Figure 9). For all types of deliveries (packages, pallets and roll cages), one item was the most common size of delivery.

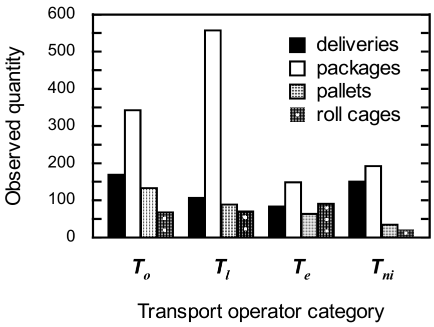

Figure 8. Number of observed deliveries and recorded goods volumes by externally based (T_e), suppliers' own-account (T_o), locally based (T_l) and not identified (T_{ni}) transport operators

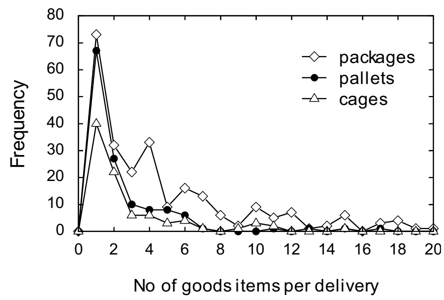

Figure 9. Delivery size distribution for packages, pallets and roll cages

4.1.3 Utilisation of transport capacity

Observations of vehicle load capacity utilisation during transport routes, and during unloading operations, are summarised in Figure 10.

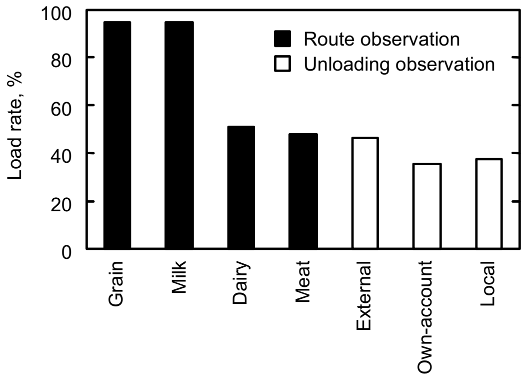

Figure 10. Load rates observed during routes (grain and milk collection, dairy and meat distribution) and unloading operations (by externally based, own-account and locally based transport operators); highest observed load rate based on weight during routes and load rate based on occupied floor space in the vehicle before delivery for unloading observations

Higher load rates were observed for transport of primary products (collection of grain and milk from farms), than for processed products (meat and dairy distribution). For unloading observations at city centre retail shops, the load rates were lower than for route observations of processed products (especially own-account distribution and locally based transport operators)

The load rates presented should not be compared uncritically, since different methods were used in the observations; while the route observations represent highest load rate during the route, the unloading observations could be early or late in a distribution route. While lower values could be expected for the latter, observation based on the utilisation of vehicle floor space is a ‘generous’ measure, as 100% could theoretically be achieved even with a lot of empty space in the loading compartment. Comparing the load rate for own-account transport in unloading operations (36%) to the route observations of meat and dairy distribution (48% and 51%, respectively), it could not be concluded whether the observed differences were attributed to method or real differences.

However, the difference between primary products and processed products remain as a general observation, not surprisingly when considering that the lower goods value makes primary products more sensitive to transport cost and indicate a potential for improved utilisation of vehicle capacity for transport of processed products. Thus, the statements by managers of locally based transport operators about high capacity utilisation in the terminal-based distribution were contradicted by the observations of load rate. A previous study in the same geographic region (Gebresenbet, 1999) reported 48% as the average load rate for own-account food distribution routes after loading at the terminal. In addition, the reported vehicle capacity in use indicated considerable over-capacity in relation to the goods volumes observed to be delivered to the retail shops.

In addition to the load rates reported, it should be considered that the total efficiency of transport operations was affected by empty haulage. A grain transport operator reported that the vehicles carried goods in 62% of the total mileage (Anonymous, 2000). The corresponding figure for road transport in

Sweden was 81% (SIKA, 2006*a*) empty-running for specific sectors was not presented). A compilation of load rate statistics from the UK, Denmark and the Netherlands indicated load factors (calculated as the percentage of available tonne-km, including empty-running), of less than 50% and slightly declining since 1990 (EEA, 2005).

4.1.4 Seasonal and temporal characteristics

Seasonal variations were identified in the supply of agricultural products from farms to the food industries, and in retail distribution. Figure 11, Figure 12, and Figure 13 illustrate volumes in the grain, meat and dairy supply chains, respectively, on a monthly basis. Standard deviations based on the indexed values, by month, ranged from 0.065 (for milk supply) to 1.26 (for grain supply). Figure 14 illustrates the seasonal variations in goods delivery to city centre retail shops, as an average of assessments by six transport managers based in Uppsala.

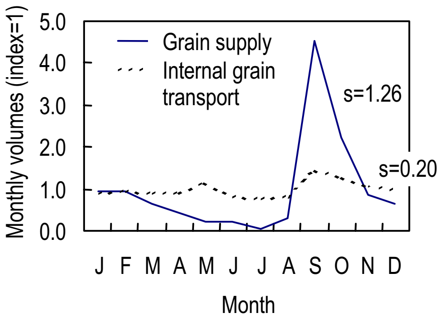

Figure 11. Seasonal variations (1997) in grain supply from farms to one of the storage locations of Svenska Lantmännen, and in the internal transport of grain (including transport between facilities and delivery to customers (s=standard deviation).

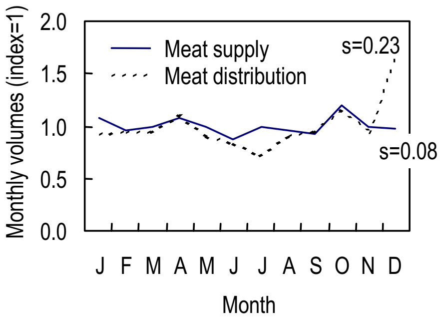

Figure 12. Seasonal variations in the supply of slaughter animals (number of cattle, pigs, goats and sheep) delivered to the abattoir in Uppsala, and in meat distribution from the same abattoir (s=standard deviation).

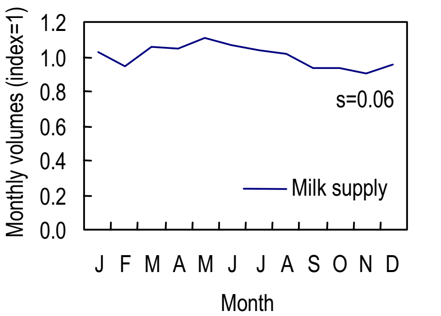

Figure 13. Seasonal variations in the supply of milk to Arla Foods, from Uppsala county (s=standard deviation).

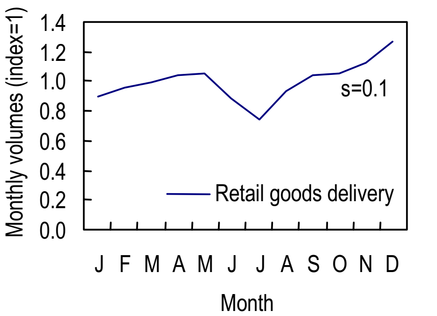

Figure 14. Seasonal variation in the distribution of goods to retail shops in Uppsala city centre, by transport operators (average of 6 operators) based in Uppsala (s=standard deviation).

The extreme seasonal concentration in grain supply in itself is a challenge for managing the transport system. During the harvest season, a section of Svenska Lantmännen increased the number of vehicles in use from the yearly average of 40, to more than 100. The high capacity for transport and handling required for the peak season is not appropriate for the rest of the year and generates high costs for unused capacity. In addition, the discrepancy to the evenly distributed demand for bread, animal fodder and other grain-related products created a need for storage and handling capacity. Important seasonal variations were also found in meat supply and distribution (larger than illustrated in Figure 12, when the seasonal patterns for beef, pork and lamb meat were considered). Although smaller in numerical terms, the variations in milk supply were of importance, given the limited durability of dairy products. Goods delivery to retail shops (Figure 14), indicated the demand-generated seasonal variations in general consumer goods, with a significant peak before Christmas and a down-turn during the summer months. In addition to the long-term variations illustrated, predictable (e.g between weekdays) and unpredictable (e.g. weather-dependent) short-term variations of importance for all the studied transport systems, were identified.

4.1.5 Timing and duration of loading and unloading operations

Grain transport

The average duration of loading at farms, loading at silos and unloading at silos were 28.1 min, 24.3 min and 27.6 min, respectively. During the observed grain transport routes, 46% of the time was spent in driving and 54% in loading and unloading. The average speed including loading and unloading stops was 28.4 km/h. In comparison, 36 km/h was reported by a grain transport operator in the studied region (Anonymous, 2000).

Animal transport

Animal transport drivers estimated the loading times at farms to 26 minutes per farm, with possible variations from 10 to 180 minutes. Vehicle design, human behaviour, number of animals, farmer's behaviour, design and penning system at the loading or unloading location, and animal's reactions, were the main factors determining the loading and unloading times, as reported by the drivers. In addition, queues at the abattoir were reported to delay up to 20% of the deliveries.

Figure 15 describes the duration of activities in the cattle transport chain. For activities during transport (loading to stunning), the values were based on observations, while data regarding the activities following after suspension and bleeding in the slaughter chain were obtained from interviews. For loading and driving, average durations were compiled for a transport route involving loading of cattle at four farms.

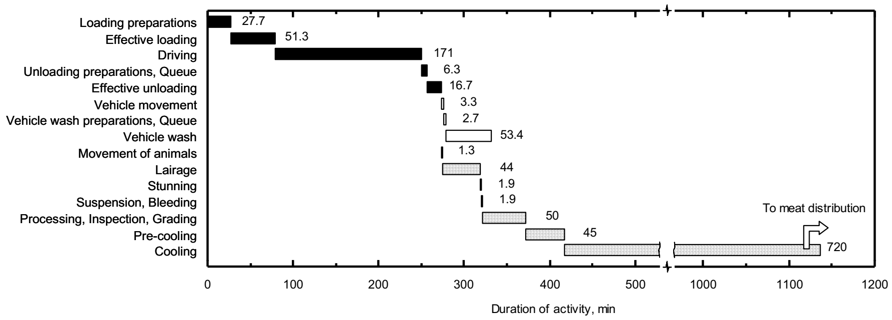

Figure 15. Duration of activities in the cattle transport chain, from loading to slaughter (observed mean values for a typical transport route involving four loading stops); ▬ , full vehicle; ▭ , empty vehicle; ▒ , animal/carcass

In the transport route (Figure 15) driving time constituted 51%, loading preparations and queues 28% and effective loading and unloading (including vehicle wash after unloading), 21%. The average driving speed for the registered routes was 32.8 km/h, including loading and unloading stops. Considering the large variation in loading times, the loading system may need revision regarding the routines and equipment involved (on the vehicle and at the farm). A potential effect of improving the loading operations is that the duration and variation in loading times could be reduced, which could reduce the uncertainty in arrival times.

Retail distribution

Transport managers estimated the total duration of a city centre distribution route from a terminal in the urban area to 3.5 h. Transport accounted for 14%, loading preparations and waiting times for 48% and effective unloading for 38%. Figure 16 reports the number of vehicle arrivals for delivery at the unloading zones of four shopping galleria in central Uppsala. The average duration of a delivery was 13.4 min, of which the effective unloading represented 43% (9.6 min). At three of the shopping galleria (G_1, G_2 and G_3), the deliveries were frequently affected by queues (94%, 34% and 25%, respectively) and the effect on the duration of delivery is given in Table 4.

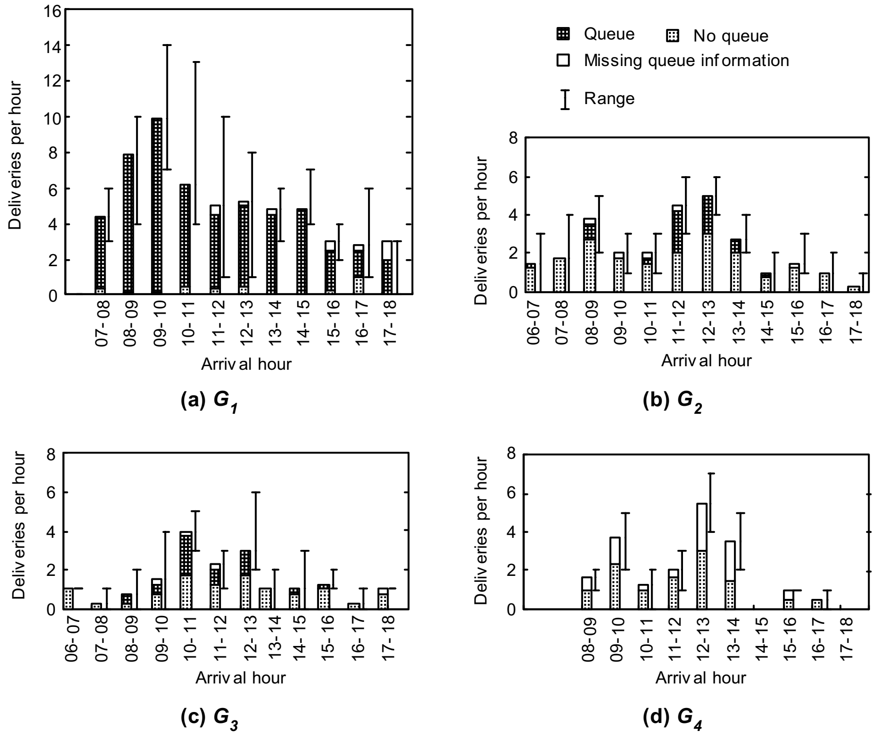

Figure 16. Average and range of arrival rates for deliveries at four galleria (G_1 – G_4), with and without queue

Table 4. Duration of delivery with and without queue

Galleria	Duration of delivery (min)		p-value[1]
	No queue	Queue	
G_1	12.9	13.7	0.984
G_2	9.1	22.8	<0.001
G_3	10.0	27.0	<0.001

[1]single-sided t-test of H_0: no difference in log(duration) depending on queue (assuming unequal variances)

The retailer questionnaire revealed (as summarised in Table 5) that most retailers were satisfied with the service of goods delivery into the shop, short lead times and punctual deliveries. However, deliveries at non-suitable times, frequent deliveries of small quantities, and incorrect address or content of deliveries were mentioned as recurring problems and the lack of fixed delivery times made it difficult to plan for goods reception. Missing or damaged goods or packing were mentioned as occasional problems. The most preferred improvements to the delivery system concerned delivery times (mentioned by 67%), and consolidation to reduce the number of deliveries. Regarding preferred delivery times, none of the respondents preferred lunch-time (*i.e.* 12 am to 2 pm). Environmental issues were rated as important by the retailers, but it was commented that quality and safety of the delivery service were more important.

Table 5. City centre retailers' response to open-ended questions regarding current and preferred delivery systems (ranked in order of frequency)

Rank order	Requirements for deliveries	Causes of current problems	Preferred improvements	Preferred delivery time windows
1.	Punctual	Timing of deliveries	Fixed delivery times	8–10 am
2.	Undamaged goods	Damage to goods and packing	Fewer, coordinated deliveries	10–12 am
3.	Short lead time (from order to delivery)	Incorrect (address, goods or quantity)	Careful handling	2–4 pm
4.	Correct (address, goods and quantity)	Lack of fixed delivery times	Tracking of goods	-
5.	Fixed delivery times	Large number of deliveries	Improved service at delivery	-
6.	Service	Inadequate service	-	-

The timing and duration of deliveries revealed a significant effect of queues, and the time used for preparations before each unloading reduced the influence of the amount of goods unloaded, on the duration. As a consequence, fewer and larger deliveries could strongly reduce the total time required for unloading (this would also reduce the probability of queues). In contradiction to the retailers' preferences as stated in Table 5, many of the deliveries took place during lunch-time.

The survey indicated that service was of higher priority than environmental concerns and this could be among the reasons for the observations of inefficiency in the system (low load rates, small size of deliveries). However, the consequence of the current pattern of deliveries could be negative for the service level; the numerous small deliveries were time-consuming for the retailers to receive and queues at the unloading zones added uncertainty in the timing of deliveries and made it difficult to plan the work.

4.2 Optimisation of grain delivery strategy

The survey of delivery strategies revealed a reduction in own account transport among the farmers during the recent years. However, before as well as after the structural rationalisation (closing of two silos), farm gate collection of dried grain after storage, was the preferred delivery strategy and own account transport was only used as a complement, primarily for small lots, less than a vehicle load.

However, the model results were in contrast to the survey. For all the farms modelled and all scenarios, the optimised strategy was to deliver at the farm gate during the harvest season. The average net profit for the eight farms was 700 SEK/tonne for Scenario 1, 691 SEK/tonne for Scenarios 2 and 3 and 783 SEK/tonne for Scenario 4. The net profit of Scenario 4 was significantly higher than for Scenario 1 and Scenario 2&3; $p<0.05$). Including an additional constraint in the model, restricting the harvest season deliveries to 65% of total farm supply, resulted in a reduction in net profit of 68 SEK/tonne, or 8.7%. Additional sensitivity analyses in the model are presented in Table 6.

Table 6. Threshold levels for change of optimised delivery strategy

Parameter changed	Wheat	Barley	Unit
Least increase in the storage price for choosing storage	270	280	SEK/tonne
Max cost of drying and storage for choosing storage	230	210	SEK/tonne
Transport cost (range for farms) for choosing own account transport	0.12-0.19	0.17-0.22	SEK/tonne-km

Although there was a contradiction between survey and model results, no negative economic effects could be stated according to either of them. The suppliers dried and stored at the farm already before the silo was closed. In the model, investment in drying and storage at the farm was far from economic. However, the costs of drying and storage equipment are strongly size-dependent (Westlin *et al*, 2006) and for larger farms, or farms in collaboration, the maximum cost levels indicated in the sensitivity analysis could be achieved. When reducing the own-account transport cost, only processing locations were chosen (not silo deliveries). Possible reasons for the contradiction between the survey and model results were that: the farmers did not account for the capital costs, working time cost, and maintenance costs as the model; farm drying was considered a safer alternative; significantly higher prices than the statistical could be obtained after storage; drying and storage was chosen by tradition.

Increasing the farm-level drying and storage would be desirable for the cooperative, and beneficial for the grain supply chain as a whole, because the seasonal concentration and the demand for transport and central handling capacity is reduced whereas the possibilities for return transport coordination increases. However, as indicated in the optimisation model, there is a risk that although beneficial in the supply chain perspective, the ongoing structural rationalisation will lead to increased costs at the farm level. Thus, there is a need for further research into the terms of grain delivery, and the costs and benefits of grain delivery strategies.

4.3 Route optimisation

Results of the route optimisations are presented in Table 7. The potential savings calculated ranged from 0 to 32% in time, for individual routes. Calculated savings in terms of emissions of CO_2 ranged from 6.3% to 21.9%, for different types of routes.

Table 7. Summary of registered routes in terms of distance and time, before and after optimisation

Type of route	Number of routes		Distance			Time		
	Before	After	Before, km	After, km	Reduc-tion, %	Before, h	After, h	Reduc-tion, %
Grain, Norrköping	8	-	1102	1032	6.4	24	23	3.9
Grain, Uppsala	37	-	3893	3645	6.4	73	69	6.0
Milk collection	60	49	6357	5958	6.3	185	156	16
Dairy distribution	28	21	2234	1742	22	92	70	24
Animal transport[a]	15	12	2750	2255	18	46	36	22
Meat distribution	17	14	1638	1359	17	62	49	21
Animal transport[b]	19	-	3256	3138	3.6	56	53	4.1

[a]Paper I; [b]Paper III

The results reveal potential to improve manually planned routes by optimisation, in particular, for optimisation of multiple routes, with savings of more than 20% for all except milk collection. The potential for savings was larger for the regular transport routes (similar from day to day) of meat and dairy distribution, than for milk collection. Although limited, even when individual routes were optimised, potential savings were possible.

The complexity involved in planning up to 60 multi-stop routes is a plausible reason behind the differences in results between the types of routes. Planning individual routes from one pickup location to one destination (as for most of the grain transport routes), is a less complicated task, with limited potential to improve a manually planned route by optimisation.

4.4 Demonstration of coordinated distribution

Eight non-food retailers participated in the demonstration trial (which was active during 12 months), motivating their participation by the possibility of reduced number of deliveries, fixed times of deliveries and improved handling of deliveries. Some of those who did not choose to participate mentioned that they would join if all in the galleria participated, while others were worried about delays or reluctant to changes in general.

On average, the number of deliveries to the participating retailers was reduced by 40% (yet, not even all the deliveries to the retailers were incorporated in the coordinated delivery). On the system level, positive effects could not be obtained due to the limited goods volumes involved in the trial. It is possible that during the demonstration, some of the transport operators made an extra stop for delivery at the coordination terminal, before proceeding for other deliveries in the city centre as usual.

4.5 Coordination and integration

In the studied transport systems, several possibilities for coordination of agricultural goods and food transport were identified.

4.5.1 Distribution of farm supplies and collection of grain

Distribution of fodder to farms in bulk form was observed to be coordinated with collection of grain (which could also be handled in the specialised vehicles). However, this form of back-hauling was limited by the concentration of grain production to specialised farms (not in need for fodder deliveries).

Furthermore, potential for back-hauling was identified in the distribution of farm supplies (*e.g.* fertiliser and seed), which could also be coordinated with grain collection from farms specialised in crop production.

The concentration of grain deliveries to the harvest season and grain delivery by tractor, limited this coordination in practice. Increasing farm drying and storage would be required for increasing the back-hauling potential.

4.5.2 Meat and dairy distribution

The registration and optimisation of food distribution routes in the region revealed common delivery stops and similar routes in delivery of meat and dairy products. The products had the same environmental requirements, and considering the load rates of about 50%, coordinating this distribution by means of combined loading could result in significant reductions in the number of vehicles used.

4.5.3 Deliveries to city centre retailers

The observed pattern of deliveries to retail shops in Uppsala city revealed several indications of inefficiency. The observed load rates were low and the reported use of transport capacity in terminal-based distribution indicated over-capacity in relation to the observed amounts of goods. Concerning the size and frequency of deliveries, fewer delivery stops at each galleria could serve most retailers with the same amount of goods, without reducing the frequency of deliveries from each supplier. As reported by Ruske (1994), transport activity could be reduced by 50-65% when implementing city logistics. The demonstration trial did illustrate some of these possibilities, but also the challenges involved in the implementation of coordinated distribution.

4.5.4 Possibilities and hindrances for coordinated distribution

The potential constraints to coordinated distribution, which were discussed in the introduction, could also be identified in the studied transport systems. Laws and regulations restricted coordination with animal transport or milk collection (although milk collection could be coordinated with delivery of by-products animal feed to farms, in limited volumes). The type of goods restricted combined loading of palletised goods with bulk goods (such as grain and fodder). Technical constraints limited the combined loading of food with other goods in the city centre distribution. However, development of loading compartments (or closed containers) with differentiated zones, could help to solve this problem.

Competition between transport companies could affect the coordination of city centre deliveries (hence, the need for involving transport companies in the process, even with retailer approach taken in the demonstration trial) and coordination of own-account distribution of meat and dairy products (vehicles advertising the product brand names). Furthermore, reluctance to change was clearly illustrated among the retailers who did not join the demonstration trial.

In response to the experiences and the constraints identified, the following requirements should be addressed in a coordinated transport system:

(a) The importance of the process of gaining support (among all relevant stakeholders) cannot be over-estimated, when involving actors not usually involved in transport and logistics decisions;

(b) A critical goods volume is required in order to obtain improvements in the city logistics (and consequently, for gaining support for the process);

(c) Communication along the transport chain is required to create transparency in the terms of participation and responsibilities, and to transmit information regarding delivery arrivals;

(d) Flexibility, allowing for special handling of e.g urgent deliveries is required; and

(e) Systems for coordinated distribution should probably be integrated in a market-oriented system in order to maintain efficiency.

5 Concluding remarks

The studies of transport systems in food and agricultural supply chains showed that constraints associated with environmental effects and effective utilisation of transport resources were significant and therefore, comprehensive research and development are required to minimise the environmental impact and promote the economic competitiveness of transport systems in the food and agricultural sector.

5.1 Efficiency of current transport operations

Load rates were high (around 95%) in transport of primary products, although empty-running was common, whereas small, frequent deliveries and low (less than 50%) load rates characterised the distribution of consumer products.

Seasonal concentration caused obstacles to transport planning and coordination, most significant in grain delivery, but substantial effects were found in all the studied supply chains.

Large variation in the duration of loading and unloading operations created uncertainty in the timing of deliveries, for animal transport routes as well as city centre deliveries. In turn, uneven distribution of delivery arrivals created queues, resulting in prolonged delivery operations, local pollution from motor idling at city centre unloading zones, and animal stress while waiting for unloading at the abattoir. In animal transport, 32% of the vehicle route was spent in loading and unloading, and in city centre retail deliveries, more than 85% of the vehicle route was spent during loading and unloading.

5.2 Optimisation

At the time of the study, manual transport planning and the division of collection and distribution areas in geographic sectors limited the possibilities for obtaining optimal transport routes.

Transport time and distance could be reduced through the use of route optimisation. The savings from optimisation of single routes (normally less than 5% although occasionally exceeding 20%) were limited, joint optimisation of multiple routes frequently resulted in savings of more than 20%, in transport of primary products as well as in retail distribution.

5.3 Coordination and integration

Several possibilities for coordination of agricultural goods transport were identified in the case studies:

- → coordination of grain collection from farms with delivery of agricultural supplies by back-hauling
- → combined loading in delivery of food products currently in own-account distribution by suppliers, including meat and milk, to rural areas
- → combined loading in delivery to city centre retailers

The potential improvements identified for coordinated distribution include more effective delivery operations for retailers and transport operators, improved vehicle utilisation, and improved traffic and environmental conditions.

The trial of coordinated city centre retail distribution demonstrated the potential for effective delivery operations by a 40% reduction of the number of deliveries to participating retail shops.

Implementation in the demonstration of coordinated distribution to city centre retailers was challenged by the reluctance to changes among the retailers. For a more successful implementation, the process of gaining support among stakeholder was identified as a critical requirement. Furthermore, the requirements for a critical mass of goods, effective communications, flexibility and a market-oriented coordination concept, were emphasised.

Farm drying and storage could benefit the grain supply chain by reducing transport demand, and the seasonal effects on the transport system, in addition to saving costs in central facilities. The developed LP model could support grain suppliers in the choice of delivery strategy. Applied to a group of farmers in the Uppsala region, the model results indicated that drying and storage was not beneficial for the suppliers.

5.4 Further research

Many of the conclusions of the study raised issues for further research, to minimise the environmental impact and promote the economic competitiveness of the food and agricultural sector.

Improving the interface between the farm penning system and the transport vehicle, *i.e.*, loading facilities and methods, could facilitate a smoother handling where animal stress (which is also connected to meat quality) could be reduced and thus, the duration and variation in loading times could be reduced. This possibility should be addressed in further research regarding methods and equipment for loading and unloading animals.

The model for grain delivery strategy could be applied to grain suppliers in other regions, in order to validate the model and investigate how the case study results could be generalised and how the economic terms of delivery could be adjusted, in order to promote farm drying and storage. Furthermore, the possibilities to reduce costs and add value to grain at the farm level should be further investigated.

Further development of the concept for coordinated distribution and the approach to implementation is required, considering how to improve stakeholders' commitment, and how legal and economic incentives could be used to encourage participation.

Real-time exchange of vehicle status information during collection and distribution, in combination with dynamic vehicle routing and scheduling could assist in reducing queuing time and improve efficiency in loading and unloading operations. However, further research is required, regarding how these systems should be adapted to food and agricultural supply chains, and whether the hypothesised benefits could be realised.

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