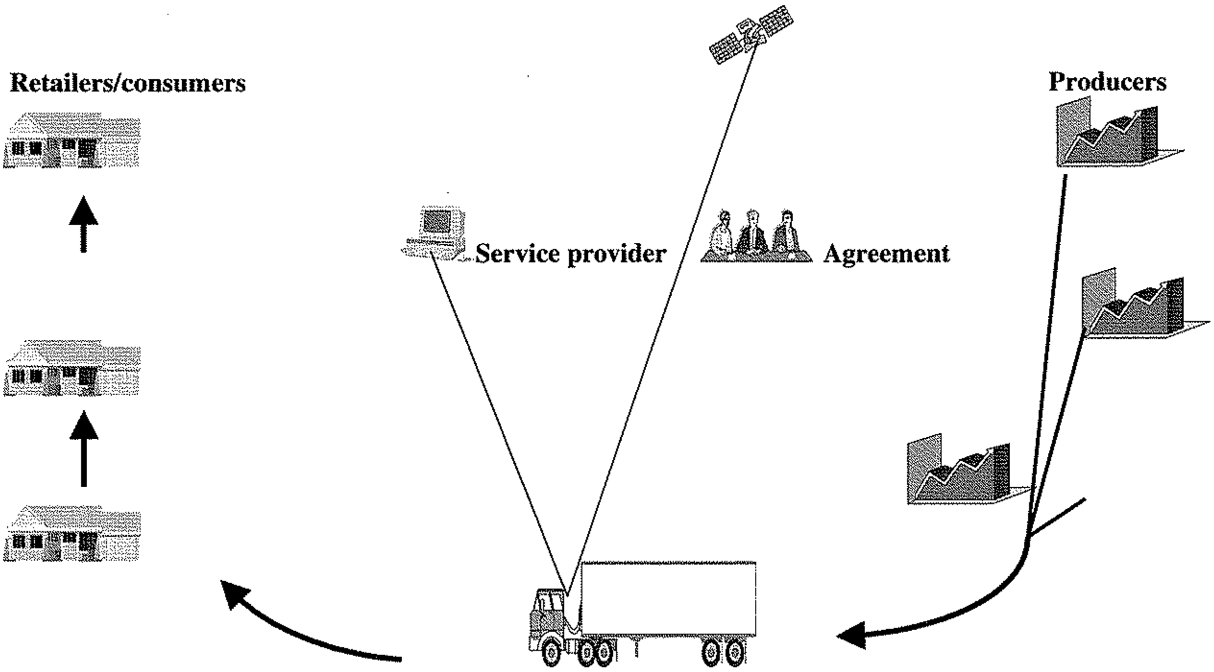
Promoting effective goods distribution through route optimization and coordination to attenuate environmental impact - the case of Uppsala

Girma Gebresenbet



Institutionen för lantbruksteknik

Rapport 240
Report 240

Swedish University of Agricultural Sciences
Department of Agricultural Engineering

Uppsala 1999
ISSN 00283-0086
ISRN SLU-LT-R-240-SE

Content **page**

Summary

Goods transport has steadily intensified in the last decades and its impact on environment increases analogously. Particularly, goods distribution in towns contributed not only to the negative environmental impact, but also creates congestion. The tendency of frequent deliveries in small parties of goods is growing in the contemporary distribution system following the principle of just in time, JIT. And thus vehicles are partially loaded and the number of vehicles per kilometre increases.
The current paper presents the study made on the food distribution in and around Uppsala town to map out the system and to investigate the possibilities of co-ordinated distribution to promote an economically effective and environmentally sustainable distribution system.

The project was conducted collaboratively by Swedish University of Agricultural Sciences, SLU, Transport Research Institute, TFK, and the environmental section of Uppsala communal administration. Thirteen producing and distributing companies have participated in the project.
The methods employed include conducting series of seminars, field measurement on distribution performance, conduct overall distribution simulation and optimisation, route optimisation in terms of sequences of delivery and distance, and computation of emissions. It was a participatory form of project were the main actors, i.e., producers and distributors actively participated particularly in the seminars where co-distribution constraints, field measurement results and possible solutions were discussed.

The measured parameters were time (driving, loading, unloading, motor-idling, resting, exact time of delivery for each customer, start and end of distribution), load carrying capacity utilisation level of vehicles in terms of weight and volume, transport distance, routes of distributions, vehicle's speed, and geographical locations of producers and delivery points. The latest three parameters were measured using the Global Positioning System, GPS.

The measured data was thereafter used to optimise distribution and to compute emissions generated from the vehicles using the distribution planning software, DPS, and the dynamic simulation model, MODTRANS, respectively. All together, 38 routes and 513 deliveries were made with 19 vehicles and the total transport distance was 4322 km. Route optimisation experiments were made for every route. The maximum time saved after optimisation for some companies was about 40% and the maximum distance reduced was about 34%. However, about 16% of the routes were well planned by the drivers.

Simulation experiments were also made to observe various possible combinations. It was found that almost all the producers lie very near to each other, and many of them (especially those distributing in the suburbs of Uppsala) follow similar routes and acquire many common customers. Combination of two or more routes reduced haulage by about 45%.
Those companies distributing bread products meet very often at the delivery points, and follow one another to the next delivery points.

Total optimisations of distribution was made for the whole routes and by group, for instance, bread or meat distributions. Total optimisation reduced the number of vehicles by 42%, routes by 58% and distance by 39%.

The vehicles’ load carrying capacity utilisation at the initial point of loading varied between 5% to 90%. Motor-idling at the delivery points was observed. Out of the 38 routes, the drivers allow the motor idling during unloading for 25 routes. The time distribution for driving, stop, and stop with motor idling were 71%, 21%, and 8% respectively.

The environmental impact of the contemporary distribution routine was estimated by computing emissions emanated from the vehicles for each route and presented in the report. Parameters such as vehicle’s weight, load, road conditions (slopes of the roads), vehicle’s speed and motor idling, were considered for emission estimation.

It may be concluded that, there is a potential to implement co-ordination in two stages. Companies distributing similar food products in the same route could develop a common delivery route without any technical development of vehicles. Those distributing in the same route, but their commodities require different temperature in the vehicle, may require vehicles with different compartments with different temperature.

1. Introduction

1.1. Back ground

Transport plays a controversial role and highly related to almost all human activities. It stimulates economy, improves the well being of human life, and at the same contributes to the environmental constraints in the form of pollution, depletion of ozone layers, global warming, depletion of resources, waste, noise, vibration, barriers and congestion .

There is a sustained trend in the intensification of goods transport activities to reach the demands from steadily growth of integrated and globalization of economy in the recent decades. Traditionally, goods transport increases at a similar rate with GNP. However, the recent distribution system where the principle of just in time (JIT), is successively applied, made the rate of transport growth, in terms of vehicles per kilometre faster than GNP.

Transport of food and agricultural produce is a significant component of goods transport as a whole in Sweden. It comprises about 13% and 18% of the total amount of transported goods and transport work in tonkm performed by lorries respectively (SCB, 1998).Transport of daily products continuously increases in the sector mainly due to rationalisation and centralisation of production and processing systems.

The potential impact of emissions generated from road transports up on the atmosphere is leading to an increase of environmental concern, both at a regional and global level. It is a common national, regional and global responsibility to attenuate the negative environmental impact and design strategies for the development of environmentally sustainable transport system within the context of sustainable economic and social development formulated by the UN commission on Environment and Development (1987**).** Thereafter, emission control polices have been adopted and being implemented by many nations to limit the adverse of environmental impact of economic activities. The United Nation conferences on environment held in Rio de Janeiro in 1992, Kyoto in 1997 and Buenos Aires in 1998, and the European Union adopted various environment and development related resolutions to reach the vision of sustainable development within the coming two to three decades. Emphasis was given on substantial reduction of emissions emanated from transport activities. Following the UN directives and the awareness and pressure from the society, the Swedish parliament and government developed ranges of proposals to successively reduce emissions from vehicles.

To date, transport of trucks are more and more specialised for specific goods and this discourages loading various goods on the same vehicle. Many vehicles are designed to transport specific commodities, for instance, milk, meat, bread, etc. Some commodities require specific packaging and atmospheric conditions. The other factor for specialisation is hygienic regulation of food products under transport, and thus the nature of the producers plays also an important role.

The other main factor for an increase of transport activities in the contemporary distribution system , as mentioned earlier, is the tendency of frequent deliveries in smaller parties, i.e., the concept of just in time. Most of the vehicles are moving with partially loaded and the average load carrying capacity utilisation level remains under 50%.Though an increase of transport work in terms of tonkm may gently increases every year, an increase of number of vehicles per kilometre is significant due the tendency of using JIT approach, specialisation of trucks and lack of co-ordination.

1.2. Some strategies to reduce environmental impact

To reach the goal of developing environmentally sustainable transport system, research institutions and other organisations put their efforts to promote the following strategies (Gebresenbet, 1998).

a) effective utilization of vehicles
b) improve vehicle's technology
c) improve fuel efficiency
d) searching for alternative fuel system
e) promote IT supported logistics system,
f) improve driving performances,
g) integrated production system
avoidance of transport demanding activities

In the recent years, development of effective models of distribution channels between various organisation in the supply, production and distribution has received significant attention (Dornier et al, 1998). Material flow between various links within the food production and distribution branches (Figure 1) used to be evaluated in terms of cost. However, the current conditions require evaluation and optimisation of ,material flow in terms of not only economy but also environmental consequences.

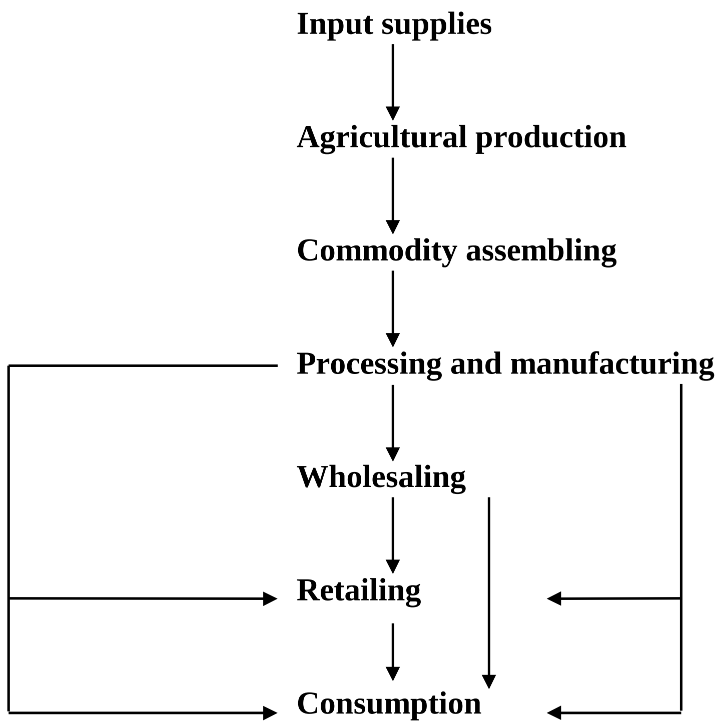


Figure 1. Distribution channels in the food production and distribution sector

The tendency of including third party system, some times referred as wholesaler, which uses a centralised terminal system to break the distribution system depicted in Figure 2 by minimising the number of transactions required to deliver product assortments (Bowersok and Closs, 1996) is in progress.

However, as illustrated in figure 3, the third party may not necessary mean to acquire depots. It could accomplish the role of service provider by co-ordinating orders and deliveries. After receiving orders from retailers and consumers, groupage of commodities will be made and appropriate vehicles will then be assigned to deliver for each route in accordance with the required time of delivery of each customers. Such a system may require special packaging system for the products and the vehicle may have different compartments to ensure the quality of the products during transport.

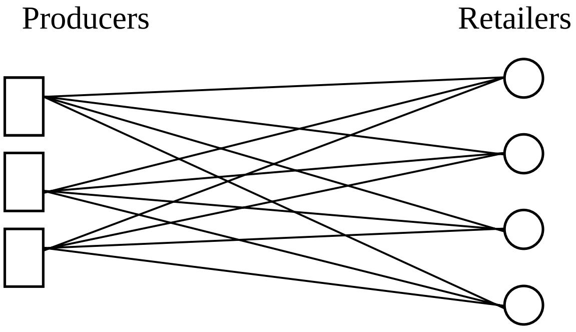


Figure 2. Distribution system with multiple transaction

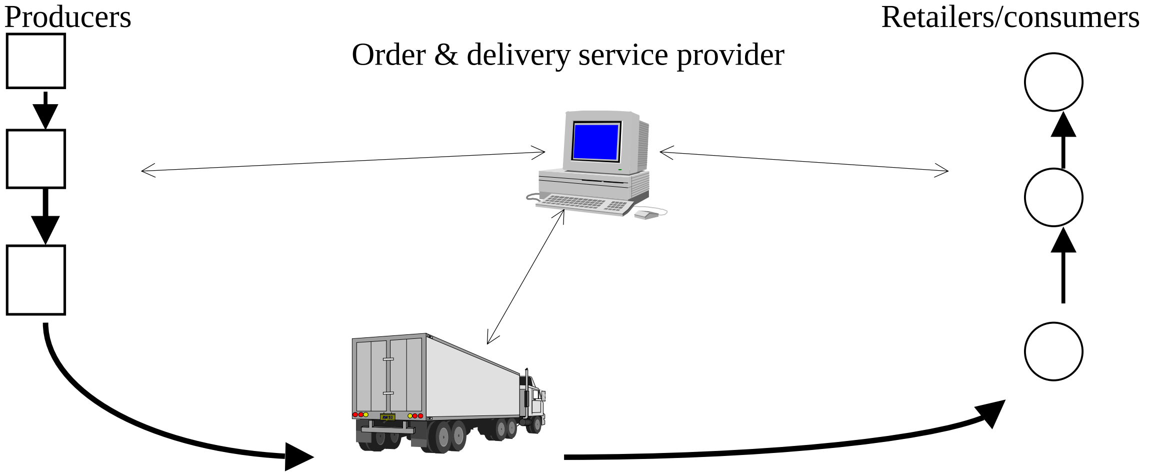


Figure 3. Co-ordinated distribution system using the third party, i.e., order and service provider. The thick and thin arrows depict material and information flows respectively

1.3. Earlier works

Important researches on a co-ordinated agricultural produces and food transport system were conducted at the beginning of 1980s. Westin (Westin,19982) assessed the food supply and distribution system to a sparsely populated area of Vilhelmina in relation to economy. Westin concluded that a co-ordinated transport system is economically viable and guarantee for the continued food supply in such areas.

Ottosson and Svensson (1982) investigated the possibility of combined and co-ordinated on-farm and off-farm transport including both collection and distribution. A model was developed to determine the effect of co-ordinated transport in terms of transport distance, transport work and vehicle utilisation. The main principle of the model was that a truck leaves terminals with full load, and unloads successively and loads also at the delivery points successively in such a way that when it arrives to the terminals, it will be fully loaded. According to their reports, the total haulage can be reduced by 20% if all companies involved integrate their transport system.

The Transport Research Commission (Ljungström, 1983) described the status of 'daily goods distribution' with especial emphasis on food distribution sector. Various valuable solutions, such as a co-ordinated transport system, were proposed and evaluated. Most of the suggested alternative solutions require technical development of the vehicle and its associated equipment.

A simulation model, MODTRANS, (Gebresenbet and Oostra, 1996).has been developed at the Department of Agricultural Engineering of SLU to study the goods transport in relation to environment. Especial emphasis was given to the material flow (both collection and distribution of agricultural and related products) . The model calculates also the emissions generated from trucks.

Kristiansson and Pettersson (1996) made an important study on goods distribution in the densely populated area of the city of Gothenburg. An inventory assessment was made using the response obtained from the concerned actors through questionnaires to determine the constraints and potentials for co-ordinated distribution. The authors reported that with the exception of retailers, all the involved organisations, such as producers, transport companies and the commune have shown a great of enhancing co-distribution. However, the problem associated with implementation remains un-answered. The transport research institute, TFK, (1997) conduct similar appraisal on urban goods distribution with especial emphasis on the role of information technology, IT, to develop better structure for urban distribution.

However, further comprehensive works are required to describe the material flow within local and regional perspective, continuous measurements of vehicle's and driver's performance, distribution route trucking, geographical locations of producers and delivery points, and simultaneous computation of emission, to develop an information technology supported distribution system and to determine the environmental benefits. This may necessitates to conduct the present study to provide better information on the contemporary distributions on local and regional levels.

2. Objectives

The main objective of the current work was to map out the current distribution system and determine the constraints and possibilities of developing a co-ordinated goods transport in and around Uppsala town, and to demonstrate the role of IT to promote economically effective and environmentally sustainable distribution system through co-ordination and route optimisation. It was assumed that the IT-supported co-distribution benefits:

- distributors by attenuating transport cost,
- customers to maintain minimum inventory, and
- society by reducing environmental degradation.

3. Methods

The method applied was a participatory form of work, where the main actors, i.e., producers and distributors actively participated in the identification of core problem and possible solutions. Implementation of the project had the following components:

- carry out series of seminar with the involved companies,
- conduct measurements on the distribution performances
- perform optimisation experiments at various levels, i.e., for each route, for each company , for companies distributing similar commodities, and all the companies as a whole
- estimate the environmental benefit in terms reduced emissions generated from the vehicles before and after optimisation

3.1. Parameters

The parameters considered for this study were:

- time for various activities (loading, unloading, resting, driving, stop with and without motor idling at the delivery points)
- vehicle utilisation level in terms of volume,
- goods' weight for every deliver,
- distance, vehicle's speed, road conditions,
- geographical position of producers or depots and delivery points,
- air emissions.

3.2. Participated companies

Totally thirteen companies of different branches, participated in the project and are listed below.

Uppodlarna	GK bakery
Scan Farmek	Blomstergrossisten
Chrono distribution	Skuttunge bakery
SkandiTransport	Adena Pickos
Lastbilscentralen	Kommuntransport
Kiab Martelleur,	Skogaholms bakery
Sätra bakery	

Field measurements were made for eight of them. Except the Skuttunge bakery, all the other seven companies are in Uppsala town and their geographical is shown in Figure 4. The companies are situated within the radius of approximately one kilometre.

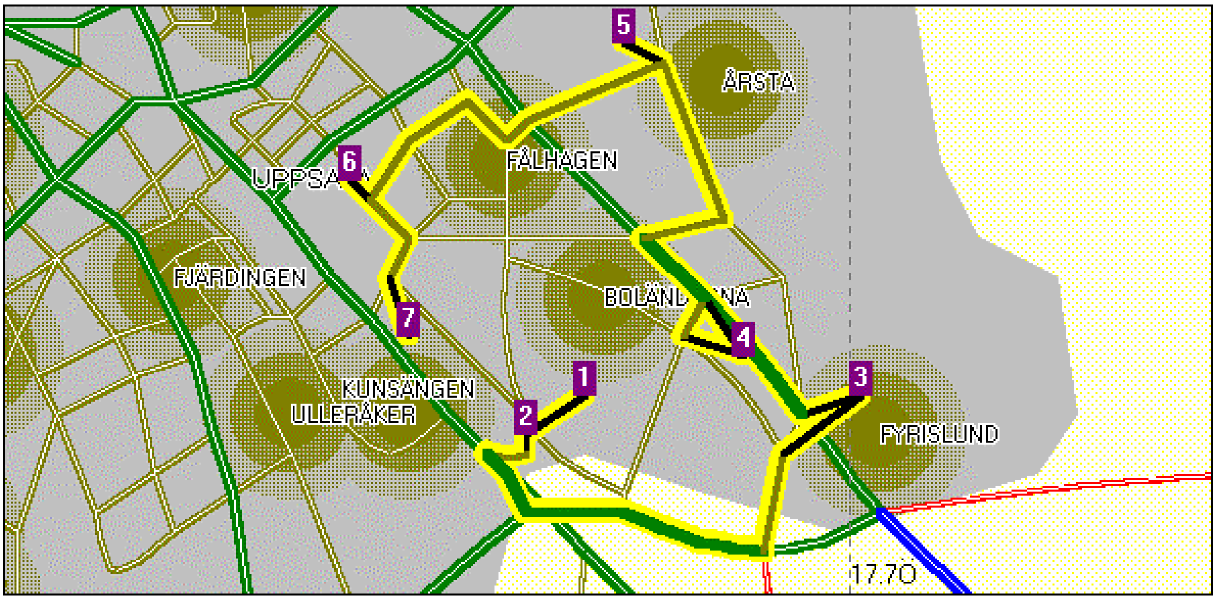


Figure 4. The numbers in the map denote the location of companies involved

3.3. Seminar

The main objective of the seminar were to

- discuss the economic and environmental advantages of co-ordinated distribution system,
- exchange experiences among the participants,
- discuss the available knowledge and technologies which may facilitate co-ordinated distribution,
- identify plausible and concrete solutions for the promotion of co-distribution in and around Uppsala.

Subject for the seminar

The subjects discussed during the seminars were

- urban and environment,
- technological possibilities for enhancing co-ordinated distribution activities (optimisation and route planning),
- computation of emissions to estimate environmental impacts
- companies economical aspects in relation to the possibilities of distribution co-ordination as a solution,
- competition and companies profile in co-ordinated goods distribution,
- technical and organisational solutions,
- transport management in the co-ordinated distribution system,
- possibilities, hindrance and judicial aspects of co-operative companies.

4. Measurements on distribution performance and data processing

4.1. Field measurement

Three packages of hardware and software were used for the measurement of distribution performances, optimisation of distribution and for the evaluation of the environmental consequences. Instrumentation of the Global Positioning System, GPS, was used to measure the routes of distribution, geographical locations of the producers and delivery points, vehicle's speed and terrain features of the roads.
The second package was the distribution planning software, DPS/LogiX, which enable to simulate and optimise the distribution, and determine distance reduced and time saved in the case of optimisation. The optimisation exercise was made for:

- a single route,
- a single company distributing in many routes,
- companies of the same branch, and
- all companies.

The third package was the dynamic simulation model, MODTRANS, which enable to describe material flow and compute air emissions emanated from the vehicles. Both the second and the third packages use the measured data on distribution and vehicle performances. As illustrated in Figure 5, MODTRANS, uses also the output data from LogiX to determine the environmental benefits in terms of reduced emissions.

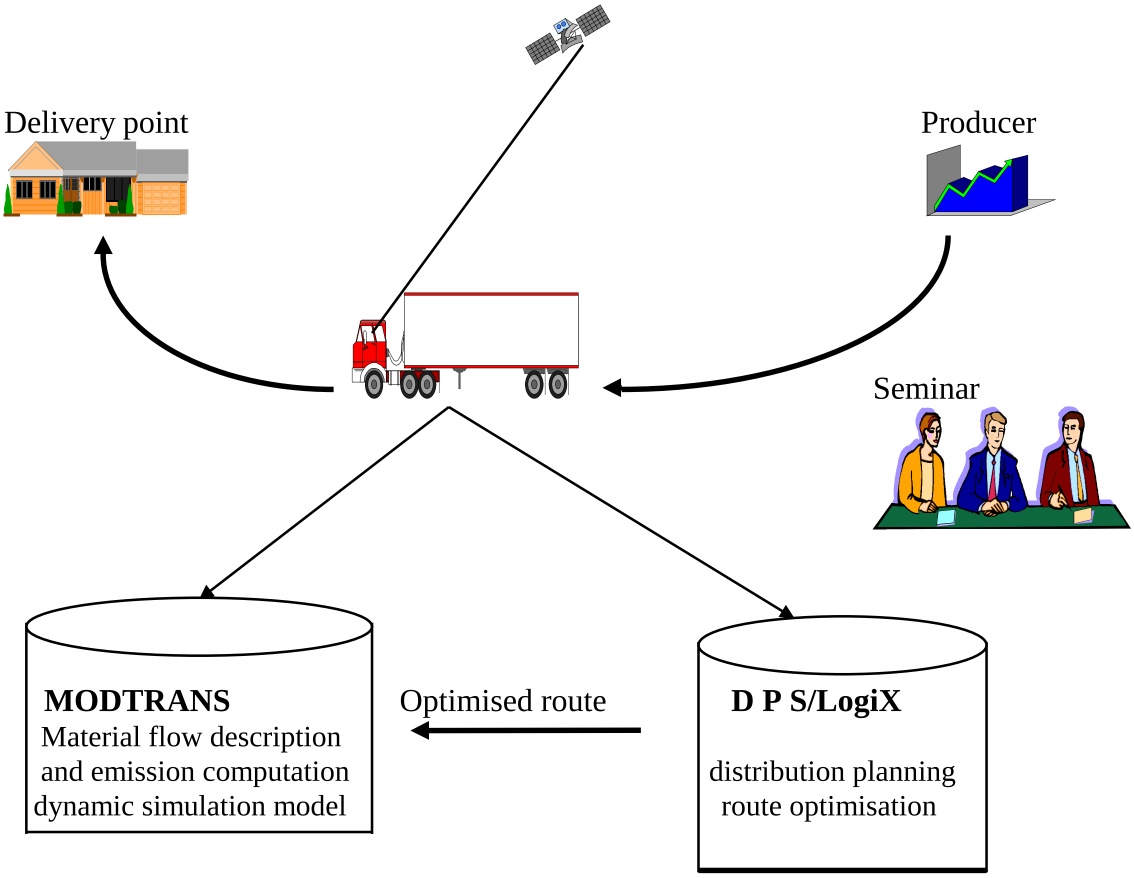


Figure 5. Distribution performance measurement, optimisation and evaluation packages

4.2. Simulation model, MODTRANS

The simulation model, MODTRANS, has been developed earlier by Gebresenbet and Oostra, (1996) using the Matlab/Simulink (MatWorks, 1991) software to study the environmental impact of goods transport. Simulink (1992).is an extension to the Matlab programme which can be used to simulate dynamic systems. It has a library of various blocks with specific functions and these block are used when developing a specific model by choosing the required blocks and connecting them by drawing lines between the blocks.

The main model is stratified into levels (Fig 6), where each level contains more detailed information than the preceding level. The highest level contains general information, about depots, distributors, environmental parameters and vehicles. The lowest level contain the most detailed information and the actual computations are carried out at this level. Once the model is built, the number of levels can easily be changed at any time, making it possible to expand the model. It is possible to simulate any single sub-model without interference from the other model components.

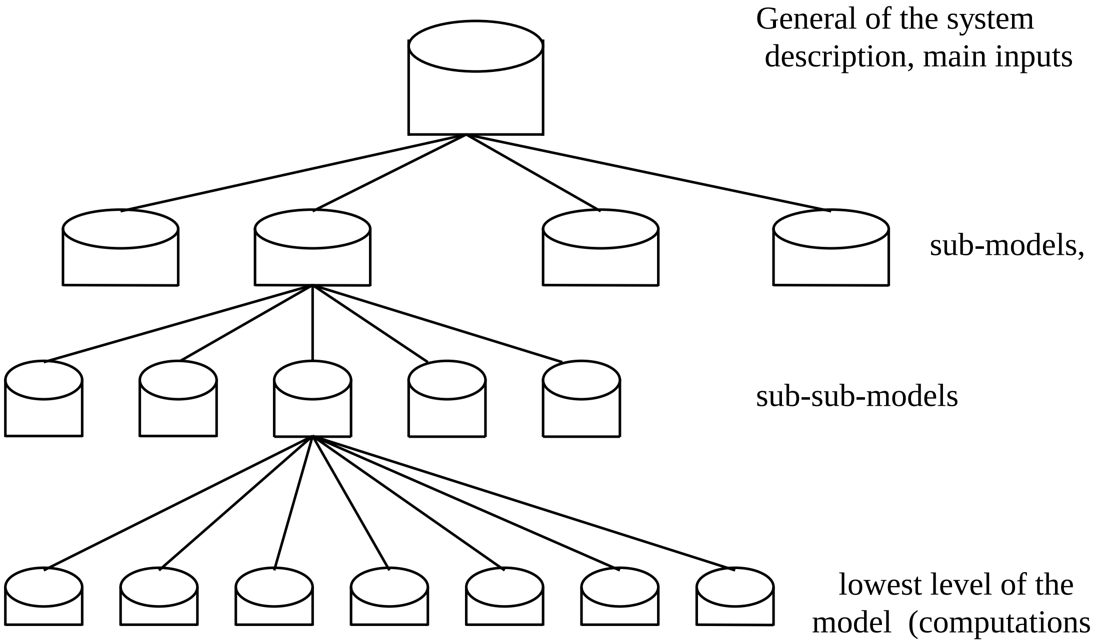


Figure 6. Schematic presentation of the hierarchic model structure

The main parameters included in the model are:

a) amount of goods flow,
b) transport distance,
c) transport work,
d) emissions from the trucks.

Vehicle's model

The model, shown in Figure 7, is the sub-system within the main model of MODTRAS. The distributing vehicle is idealised as a moving body whose mass varies, i.e., decreasing or increasing depending on whether the vehicle is distributing or collecting.

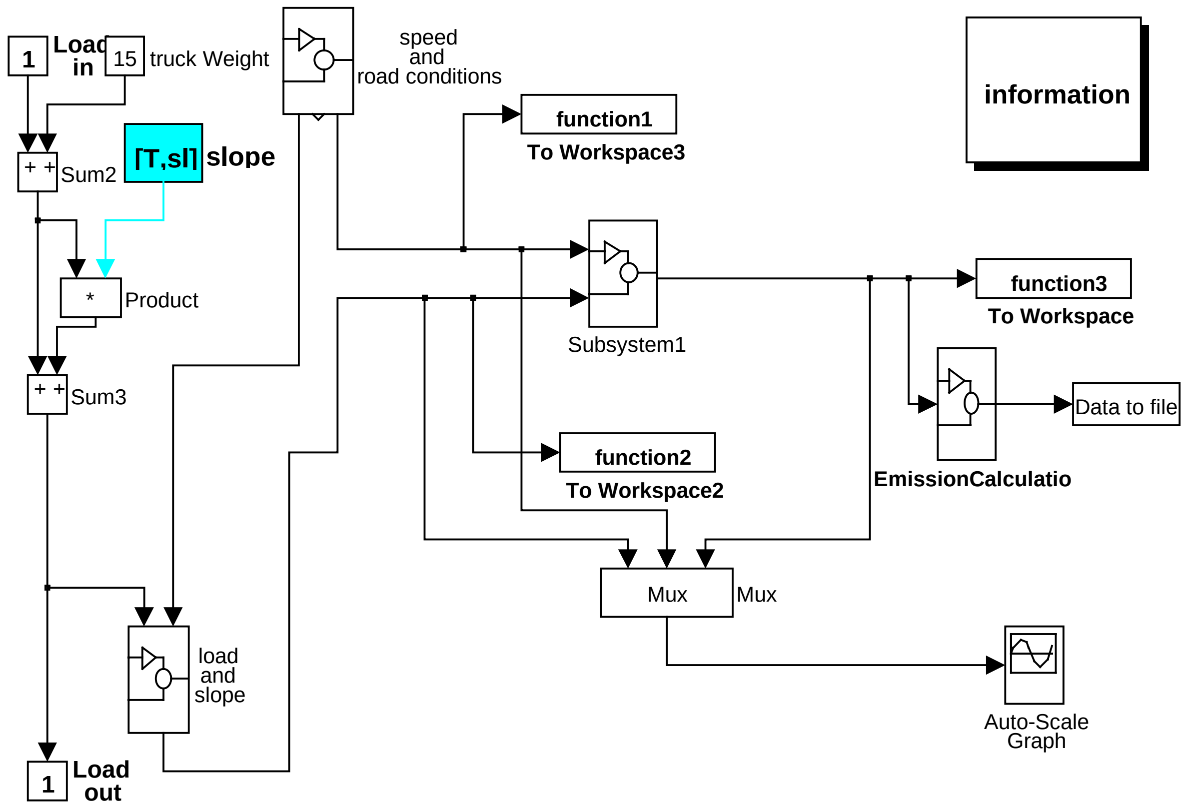


Figure 7. Truck performance description and emission computation sub-model of MODTRANS

For the computations of air emissions from the vehicle ,variables such as load, speed, distance, motor idling, area of distribution, road conditions, slopes and age of a truck were used considering them as the most important variables influencing the amount of emissions were then computed from fuel consumption. The simulation results can be presented either in a table form or in a graphic form. Some of the model out puts are material and speed variation profiles, emissions such as CO2, CO, HC, NOx, S, etc.

There are few studies made on the relationship between the above variables and fuel consumption. Demker et al (1994) reported the works of Backman (1984) and Scania (1989) about the effect of load on energy consumption. In both cases, the energy consumption increases linearly with an increase of load. The effect of vehicles speed on fuel consumption has, however, a parabolic shape (Commission, 1995, Lenner, 1995). These relations were considered during the model development.

4.3. Route and positions measurement

The distribution route and locations of producers and customers (retailers and consumers) were measured using the Global Positioning System, GPS. As noted earlier. Global Positioning System is a satellite based navigation system primarily developed for military use, and became accessible for civilian users the recent years. The system provides altitude over sea level, latitude and longitude positions. By using signals from at least three satellites and a GPS portable receiver the positions (both horizontal and vertical) and a speed of a moving vehicles can be determined. The position of the receiver is computed from the intersection of the satellites' cones (Bernhardsen, 1992).
The accuracy of the measurement can be improved up to a centimetre range using the Differential GPS system. This is done by simultaneously receiving signals from another receiver whose position is accurately known (see Figure 8).
For the current study DGPS was used to determine:

- locations of the producers
- locations of delivery points
- routes of distributions
- altitude from sea level, and
- speeds of vehicles

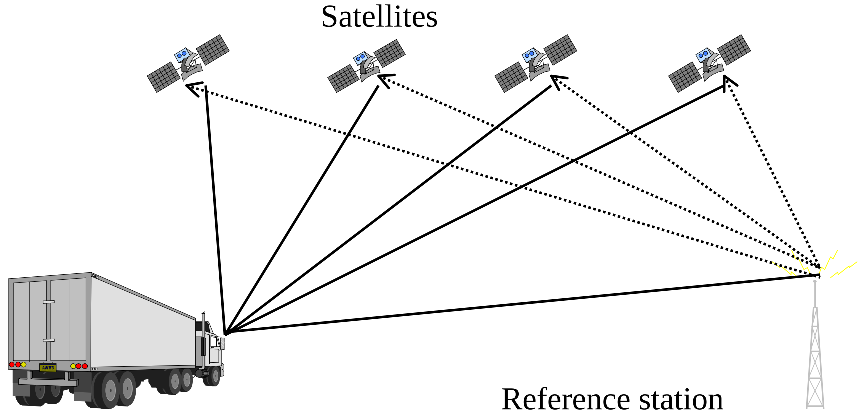


Figure. 8. Differential global positioning system ,DGPS, to increase accuracy of vehicle's position measurements

Altitude was measured to determine the terrain features (slopes) of roads. The measured data were simultaneously transferred to PC and stored and both the position and speed were displayed on the screen. The data from terrain features and speed of vehicles were thereafter used in the emission computation model to estimate the environmental impact. The other measured rote parameters were arranged to be used for route and distribution optimisation by DPS/LogiX. However, because of technical constraints during the measurement for many of the routes, only the locations of producers and delivery points were recorded.

4.4. Time distribution for various activities and load capacity utilisation

As noted earlier, time for various activities (loading, unloading, resting, stop with and without motor idling, total distribution) were measured manually. The total goods loaded, the amount delivered at every delivery point, vehicle's utilisation in terms of volume prior to first delivery point were estimated. The maximum allowable load carrying capacity of each vehicle, the distance between each interval and the total distance of each route or trip were documented.

5. Results

5.1. Data processing and general result

As mentioned earlier data processing was made using two softwares: Logix (for route and distribution optimisation), and MODTRANS (for material flow description and emission computation).

- Computer based optimisation experiments were made for different levels, i.e., all the involved companies, and in groups (for instance companies distributing bread in one group and those distributing meat in another group)
- Route optimisation for each trip
- Computation of emissions for each trip, route, company, group of companies and for the whole companies involved.

It may be worth to note that the accuracy of the measurement and problem noticed during the field measurement prior to the presentation of the results. The accuracy of the estimation of vehicle's load carrying capacity utilisation was low, because, in some cases it was estimated based on not measurement. To obtain the exact weight of goods delivered at each point was not easy either. The GPS signal receiver looses its contact with the satellites in forest areas and between high buildings.
The general summary of the measurement is given in Table 1. Totally, field measurements were made for 38 routes and 513 delivery points (most of the deliveries were made in Uppsala town). The total distance covered was 4322 km.

Table 1. Summary of the distribution

Company	No of routes	Type of goods delivered	No of delivery points	Distance, km
Company **A**	6	Meat	117	1254
Company **B**	7	Bread	74	163
Company **C**	10	Bread	104	310
Company **D**	3	Bread	46	235
Company **E**	3	Bread	65	956
Company **G**	3	Deep frizzed foods	58	538
Company **F**	2	Flower & accessories	21	523
Company **H**	4	Meat	28	343
Total	**38**		**513**	**4322**

5.2. Load carrying capacity utilisation level

Effective utilisation of vehicles is one of the strategies to reach the visions of promoting environmentally sustainable transport system. Thus, for the current work, the load carrying capacity utilisation level in terms of volume was estimated for each route. All the haulage trips were simple where vehicles travelled loaded in one direction and unloaded on the way back from the distribution to the producers garage.

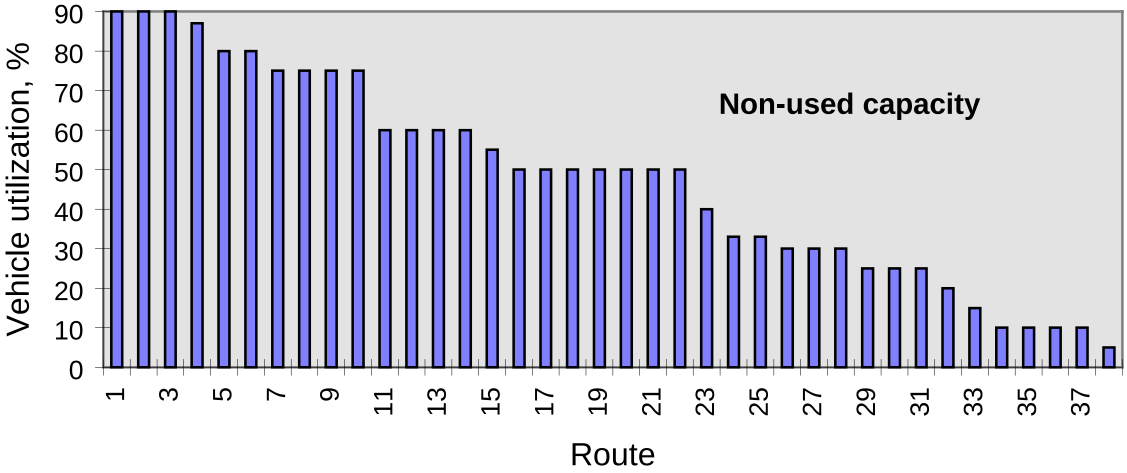


Figure. 9. Estimated vehicles load carrying capacity utilisation level of in terms of volume of 38 routes

The measured values lie within the range of 5 to 90%. The values for individual route and average value for each company are presented in Figures 9 and 10 respectively. As it may be observed from Figure 10, companies, for instance company C, which distributed in town frequently in small volume, and therefore about only 21% of the available loading space were used on average level.

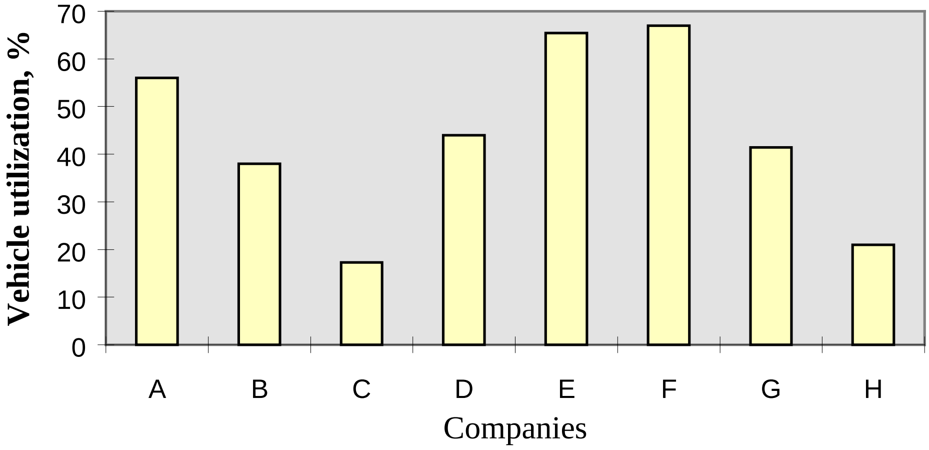


Figure. 10. Average vehicle's load carrying capacity utilisation for each company

The average utilisation level for all the 38 routes was 47.8%. However, it should be noted that these values are valid only for the initial loading at the producing companies up to the first delivery point, and the utilisation level is decreasing successively as delivery continuous. Thus, the above given values can be more than halved if efficiency over the whole route is considered.

5.3. Route optimisation

Distributions were made mainly to:

- retailers
- restaurants
- schools
- nurseries

In general, distributions to the above destinations were not according to the geographical locations of the above mentioned destinations. Rather deliveries were prioritised according to the delivery time demanded by the goods receivers. According to the drivers response to the questionnaires related to prioritisation, deliveries should be made on time to retailers first and then to restaurants. Schools and nurseries are low prioritised. However, drivers some time deliver to schools and nurseries if they are very near to the retailers or restaurants.

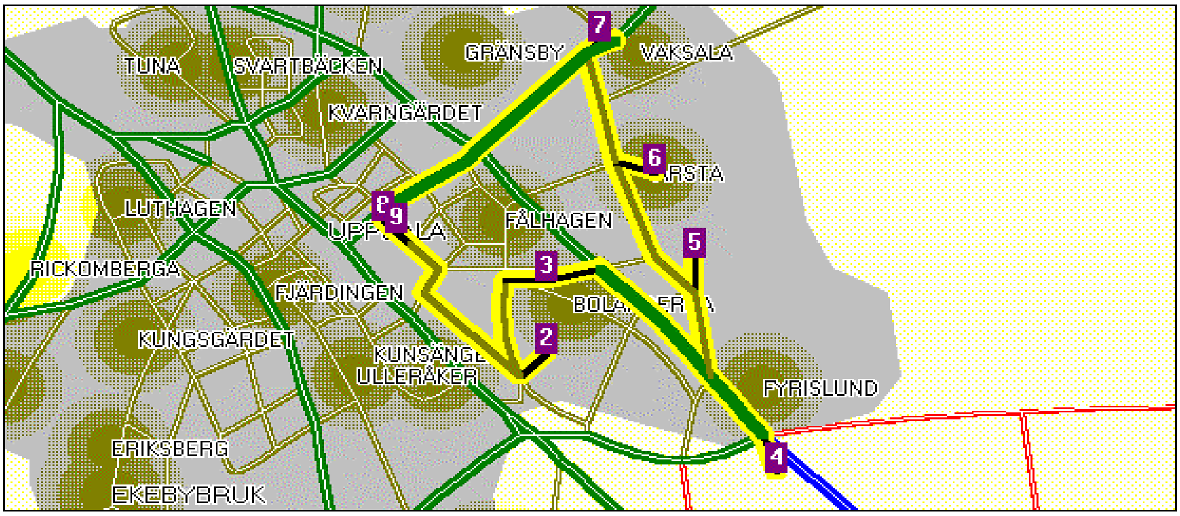


Figure 11a. Actual route

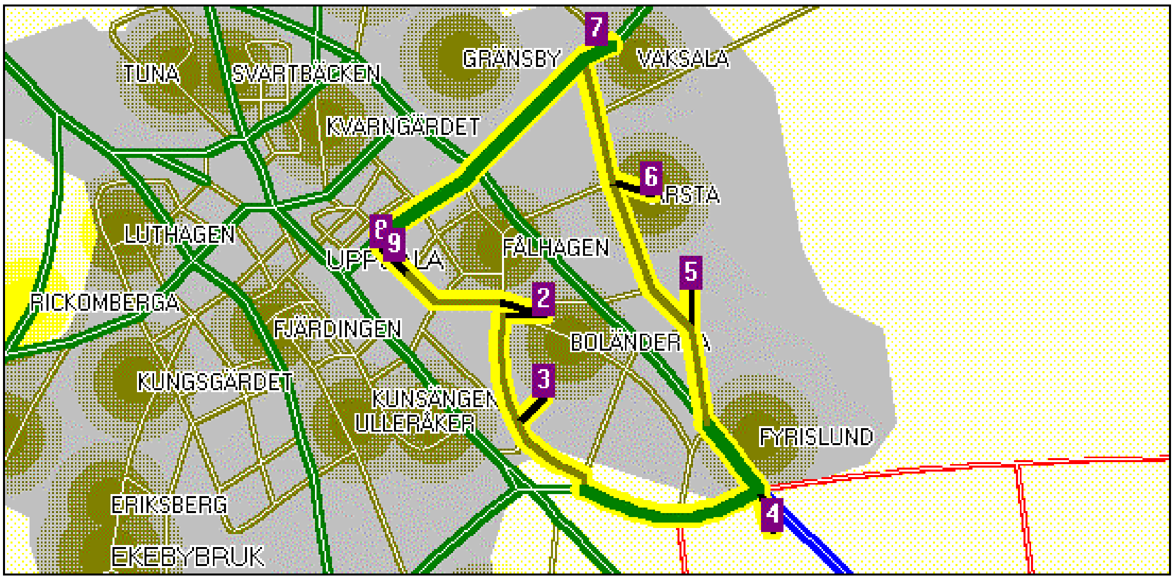


Figure 12b. Optimised route

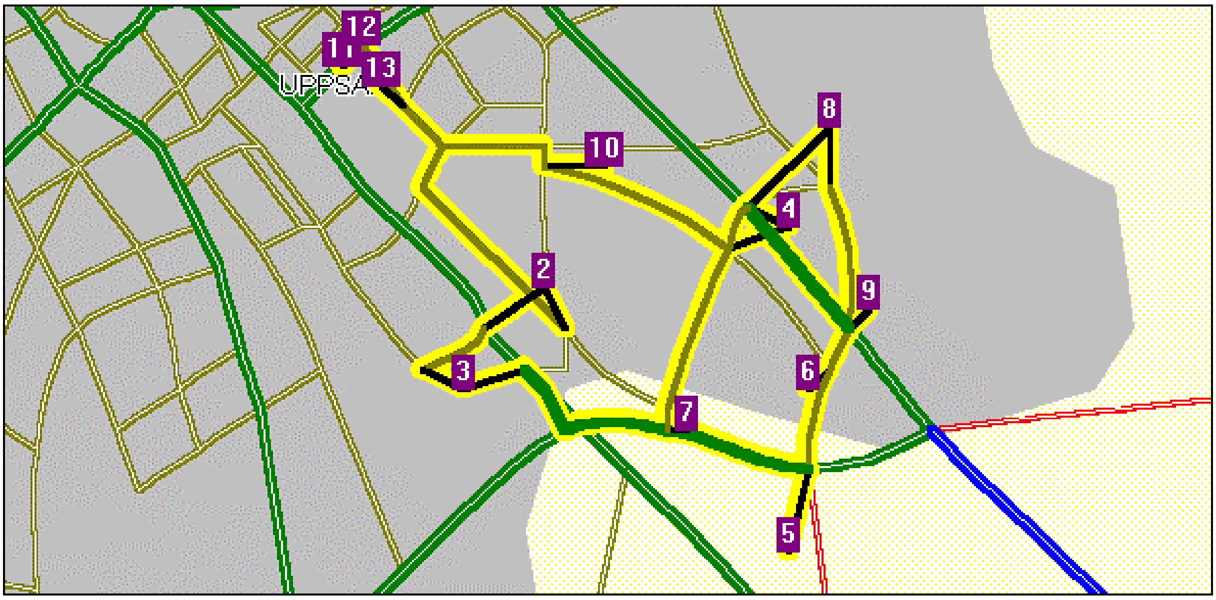


Fig 12C. Actual route

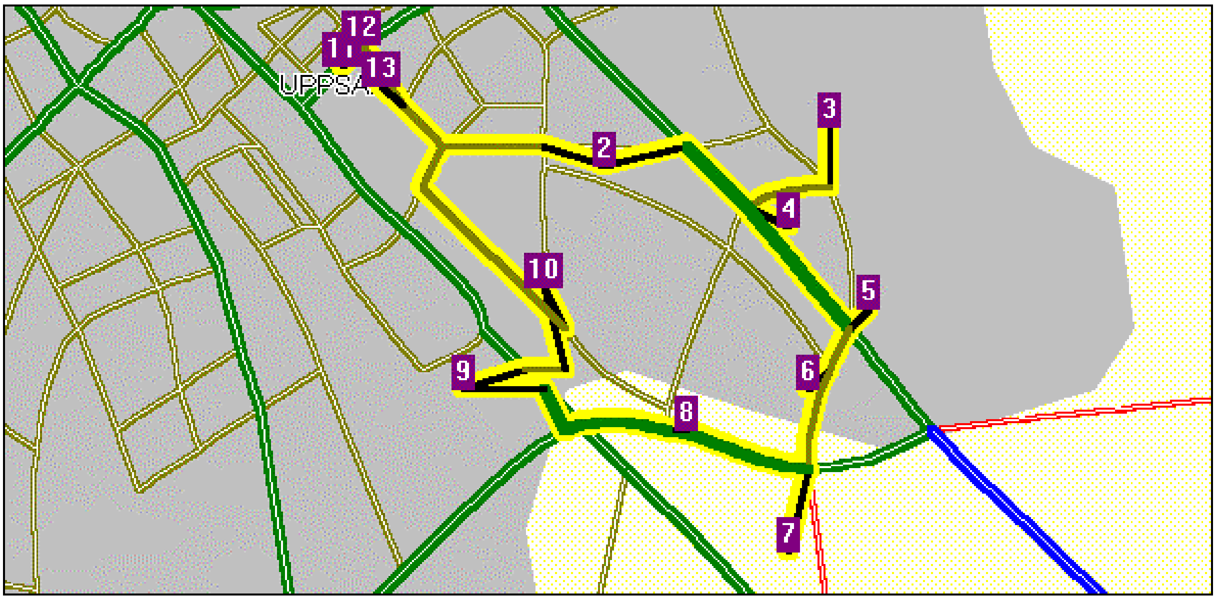


Fig 12d. Optimised route

In all the 38 routes, drivers determined the possible shortest and quickest routes, and the sequences of deliveries. The sequence of delivery was governed by the priorities mentioned earlier, but the routes were determined using driver's experiences.

As mentioned earlier, simulation and optimisation both in terms of network and sequences of delivery, was made to estimate the distance reduced and the time could have been saved if the optimisation was made prior to distribution. Figures 11 and 12 compare the actual and optimised routes. Optimisation reduced both distance and time by about 34%.

Table 3 reports the actual and optimised distances for all the 38 routes. About 20% of the total routes planned by the drivers perfectly. Distribution in the suburb and region were relatively planned better than those routes in the town. The optimisation result showed that the maximum distance which could be reduced and the maximum time which could be saved ranged up to 34% and 40% respectively (Table 2).

Table 2 reports route optimisation made for each and company and benefits in terms of reduced distance and time. Motor idling time in relation to the driving time, and the vehicles loading capacity utilisation for each route are also given in the Table.

The highest reduction of distance and time as a result of optimisation, and the highest ration of motor idling and driving time are for vehicles distributing in town as reported in Table 2.

5.4. Optimisation of distribution

Investigations were made to search for possible co-ordination of distribution on various levels, i.e., distribution of the same categories of food, for instance bread or meat, and co-distribution of foods of different categories. Distribution routes, delivery points, vehicles' utilisation level of each distributors were first determined. Thereafter, common delivery points and routes were determined and simulation experiments were made both for specific groups and for all the routes.

Total optimisation of distribution has also been conducted using all the routes and vehicles. The result showed that the total distance, number of vehicles and routes could be reduced by 39%, 42% and 58% respectively if the distribution was optimised before hand (Table 2).

The major factors which may enhance co-distribution observed by this study were that many of the participated companies acquire common customers, follow similar routes and vehicle load capacity utilisation level is low.

More over, most of the producers/distributors are located very near to each other (Figure 4), so that co-distribution can be made without the requirement of common terminal. Six of the producers lie within the radius of one kilometre.

From the current investigation, it may be noted that there is high potential of co-distribution without the requirement of making significant structural change. Particularly, companies distributing similar goods may kick off' co-distribution without any constraints.

Table 2. Actual and optimised distance and time, motor idling time at the delivery points in relation to total driving time

Company	Route	No of deliveries	Actual distance, km	Optimisation saved, %		Idling time driving, %	Vehicle utilisation, %	Distribution area
				by distance	by time			
A	R22	24	238	10.5	8.1	1.8	75	mixed
A	R 23	23	146	9.2	4.7	9.4	75	town
A	R 7	20	209	1.4	1.5	1.1	90	region 2
A	R 8	16	239	7.5	7.5	4.8	60	region 2
A	R 36	17	256	1.9	1.1	1.6	30	region 1
A	R 37	17	166	3.4	1.1	2.1	90	region 2
B	R 12	9	23	34.2	37.8	0	55	town
B	R 13	14	31	18.5	22.4	8.6	50	town
B	R 14	13	45	25	26.7	0	50	town
B	R 31	2	3	0	0	0	10	town
B	R 32	12	20	23	40.7	0	60	town
B	R 33	10	19	28.9	34.4	0	60	town
C	R 34	14	22	1.8	2.8	13.9	60	town
C	R 2	3	123	0	0	4.5	25	region 1
C	R 3	9	17	21.4	11.7	**41.9**	33	town
C	R 4	8	23	0	0	**24.7**	33	town
C	R 5	6	13	1.1	1.2	**48.6**	10	town
C	R 6	3	2	0	0	0	10	town
C	R 16	21	28	12.8	15.4	**27.5**	30	town
C	R 17	8	14	13.9	10.5	**15.9**	25	town
C	R 18	14	26	23.5	26.1	7.3	15	town
C	R 19	23	34	19.7	22.6	1.9	25	town
C	R 20	9	30	1.1	4.8	0	10	town
D	R 9	13	63	14.3	11.1	0	40	town
D	R 30	22	60	0.8	1.8	13.8	75	town
D	R 35	11	112	7.2	9.4	0	50	mixed
E	R11	17	391	20.6	16.5	13.9	80	region 2
E	R 15	22	264	16.9	17.8	**17.6**	75	region 1
E	R 38	26	301	9.2	10.9	11.6	90	region 1
F	R 10	9	36	1.7	0.8	2.4	80	town
F	R 21	12	209	0.3	0.4	0	87	region 1
G	R 24	15	228	2.5	1.7	13	50	region 1
G	R 25	19	183	25	22	**17.6**	50	mixed
G	R 29	24	127	-----	------	**63.7**	55	region 1
H	R 26	3	11	0	0	0	5	town
H	R 27	4	100	0.5	0.8	6.3	20	mixed
H	R 28	5	22	0	0	0	25	town
H	R 1	16	210	2.1	1.8	0	50	region 2
Average				**9.7**	**9.3**	**9.9**	**46.8**	

The notations mixed, region1 and region2 means town and regional , regions which are far from town and near to town respectively

Table 3. Summary of total optimisation

Parameters	Non-optimised	Optimised	Reduction, %
Distance, Km	4322	2636	39
Vehicles	19	11	42
Routes	38	16	58

5.5. Possible co-ordination

A typical example of combination of two route is illustrated using Figures 13 through 16 to demonstrate the benefits in terms of distance and time.

5.5.1. Example 1: North-East of Uppsala

Route	Distance, km	Time
Route 24	225	4hrs 52m
Route 22	256	4hrs 2m
Both routes together	481	9hrs 24m
If co-ordinated	276	6h
Reduced by	**205,** or **43%**	**3hrs 24m,** or **36%**

(see Figs 13a through 13c)

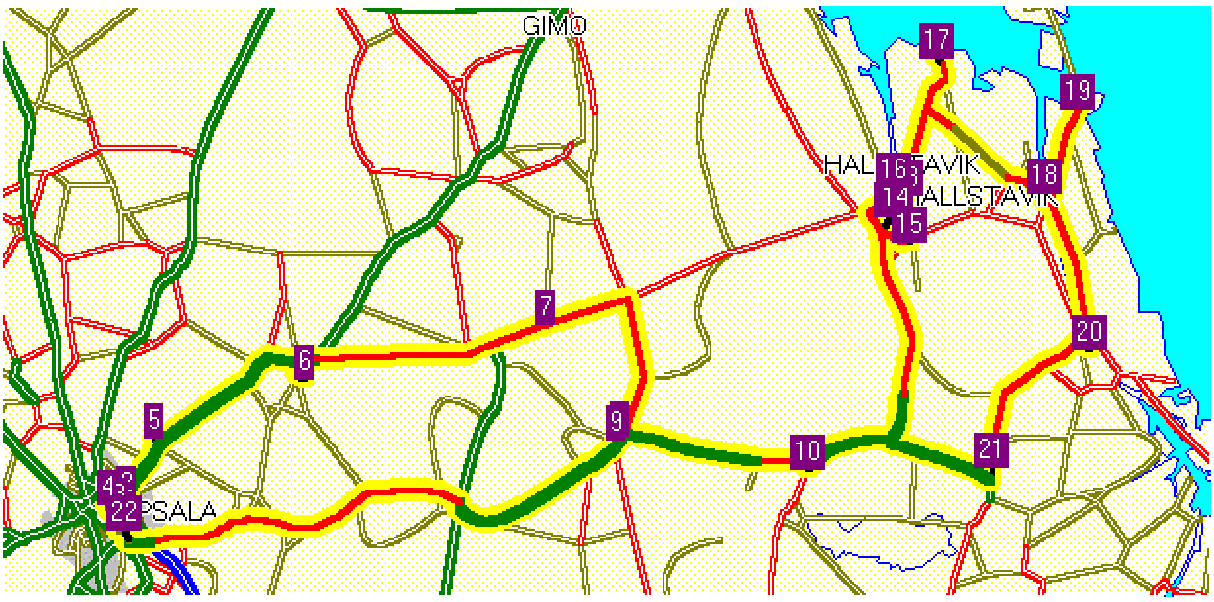


Figure 13a. Route 22

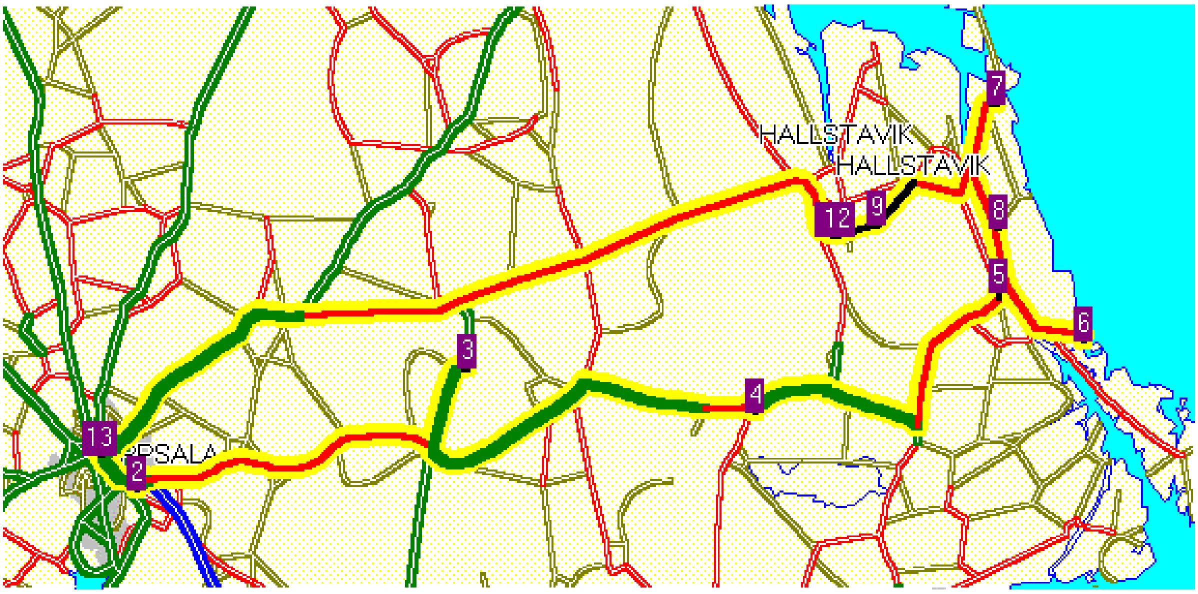


Figure 13b. Route 24

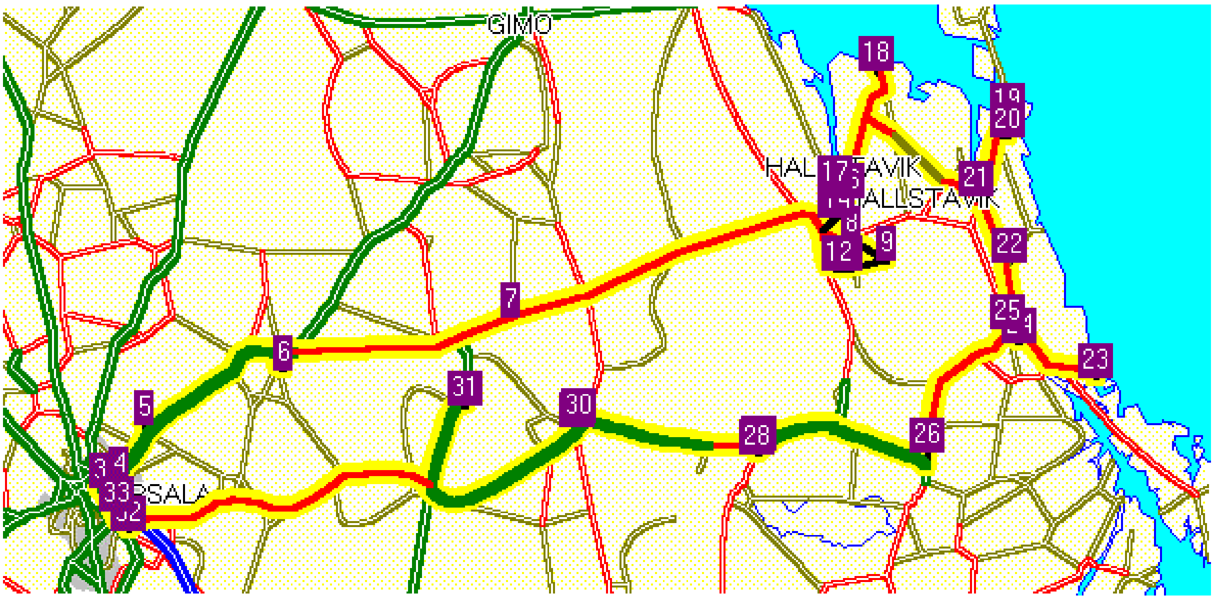


Figure 13c. Combination of routes 22 and 24

5.5.2. Example 2: North-East of Uppsala

Vehicle/route	Distance, km	Time
JWU359(KIAB)	225	4h52m
JMB228-1(Scan)	256	4h32m
PJO548(Skogaholms)	284	4h47m
All the three routes	765	14h11m
If co-ordinated	410	8h21m

Distance decreased by **355 km** which is **46%** of the total distance, and the time decreased by **42%.**

5.5.3. Example 3: South-West of Uppsala

Route	Distance, km	Time
Route 37	169	4h44m
Route 21	209	3h35m
Both routes	378	8h19m
If co-ordinated	283	6h26m

Distance decreased by **95 km** which is **25%** of the total distance, and the time decreased by **23%** (see Figs 14a, 14b and 14c).

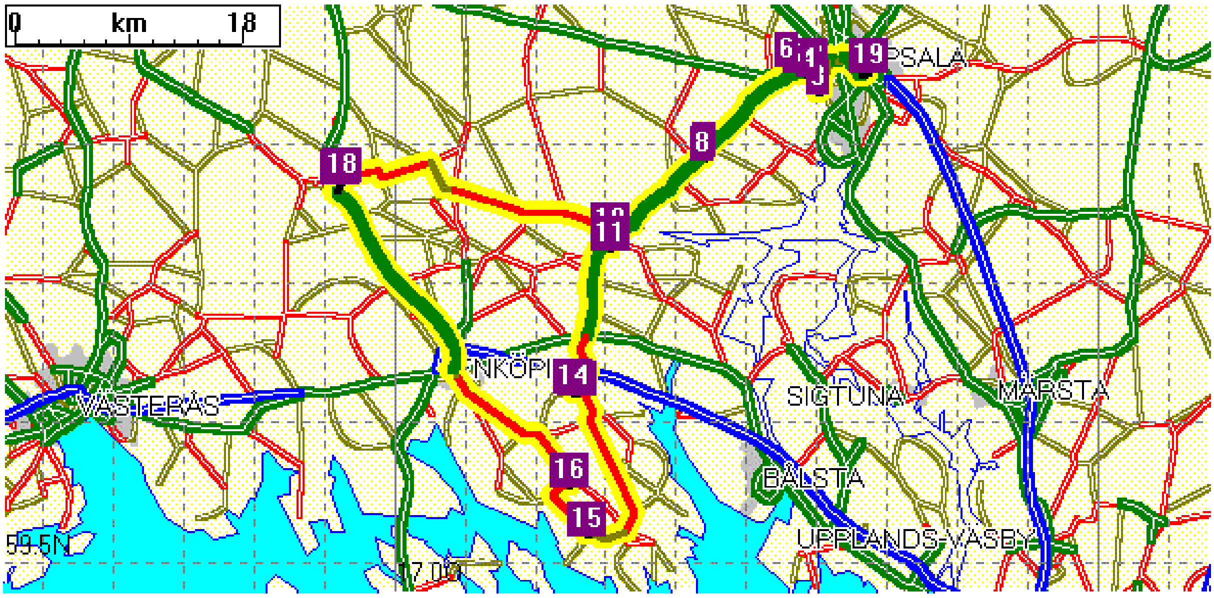


Figure 14a. Route 37

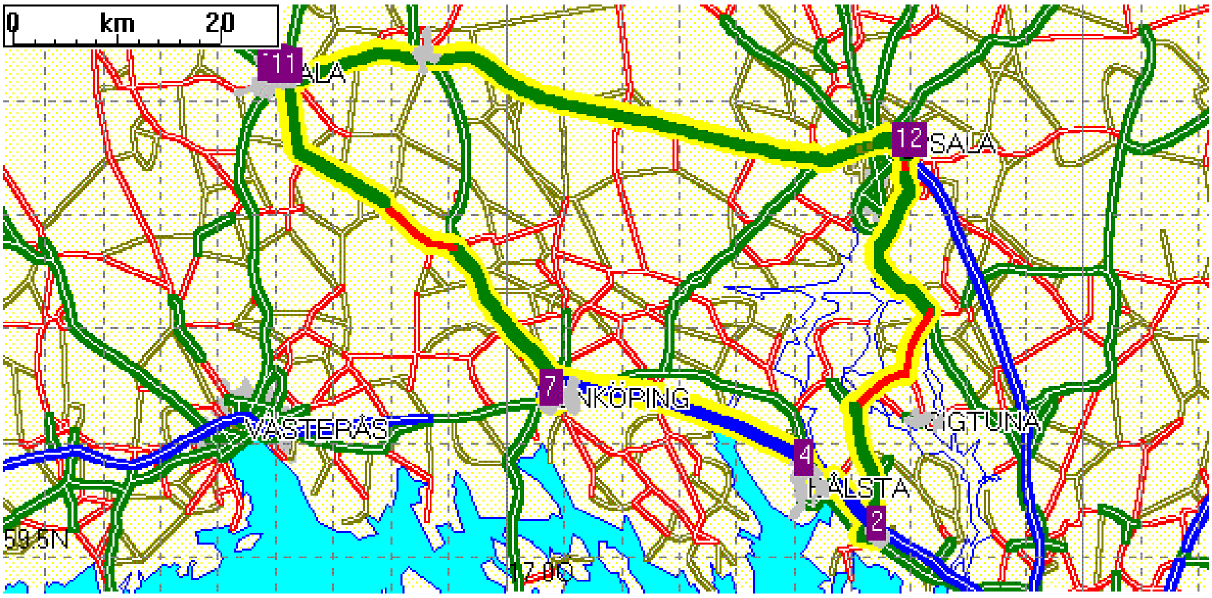


Figure 14b. Route 21

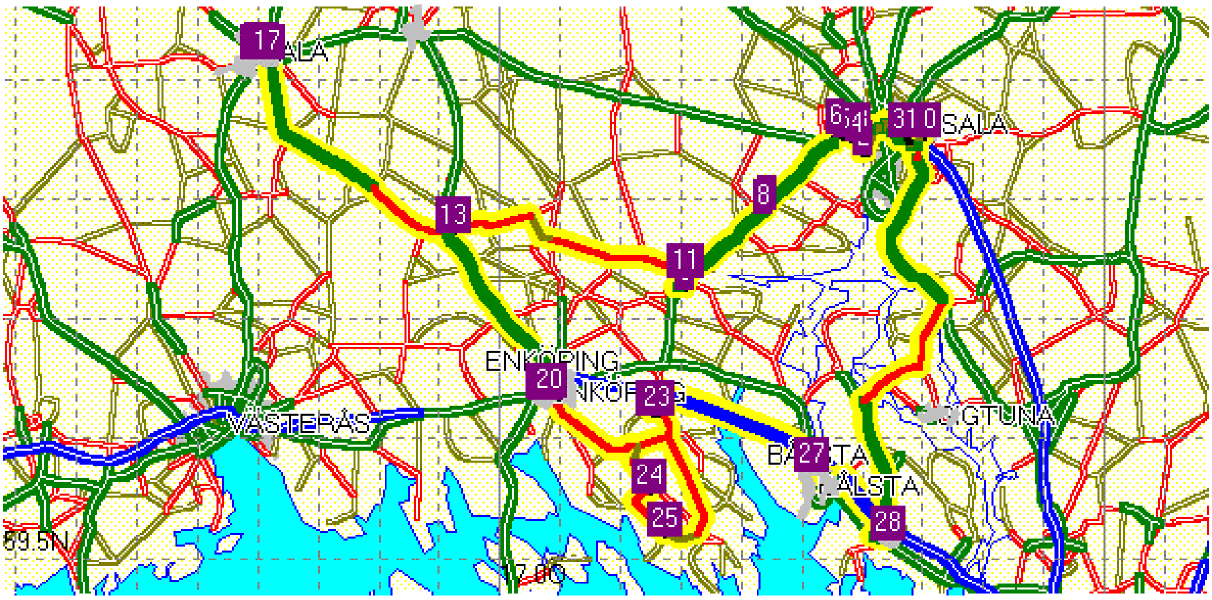


Figure 14c. Combination of routes 37 and 21

5.5.4. Example 4: Uppsala-Enköping

Route	Distance, km	Time
JMB228-2(Scan)	154	5H41m
KTB389-1(KIAB)	101	1h56m
Both routes	255	7h37m
If co-ordinated	145	5h35m

Distance decreased by **110 km** which is **43%** of the total distance, and the time decreased by **26%**).
Several combinations can be made for distributions in the northern areas of Uppsala

5.5.5. Example 5: Northern Uppsala

Route	Distance, km	Time taken
BRE206-2(Scan)	242	3H58m
DZS636 (Skogaholms)	395	8h04m
Both routes	637	12h02m
If co-ordinated	397	8h19m

Distance decreased by **240 km** which is **38%** of the total distance, and the time decreased by 3h43m, which is **31%** of the total time taken by the two vehicles. The vehicles followed the same route, and many delivery points are in common (see Figs 15a, 15b, and 15c)**.**

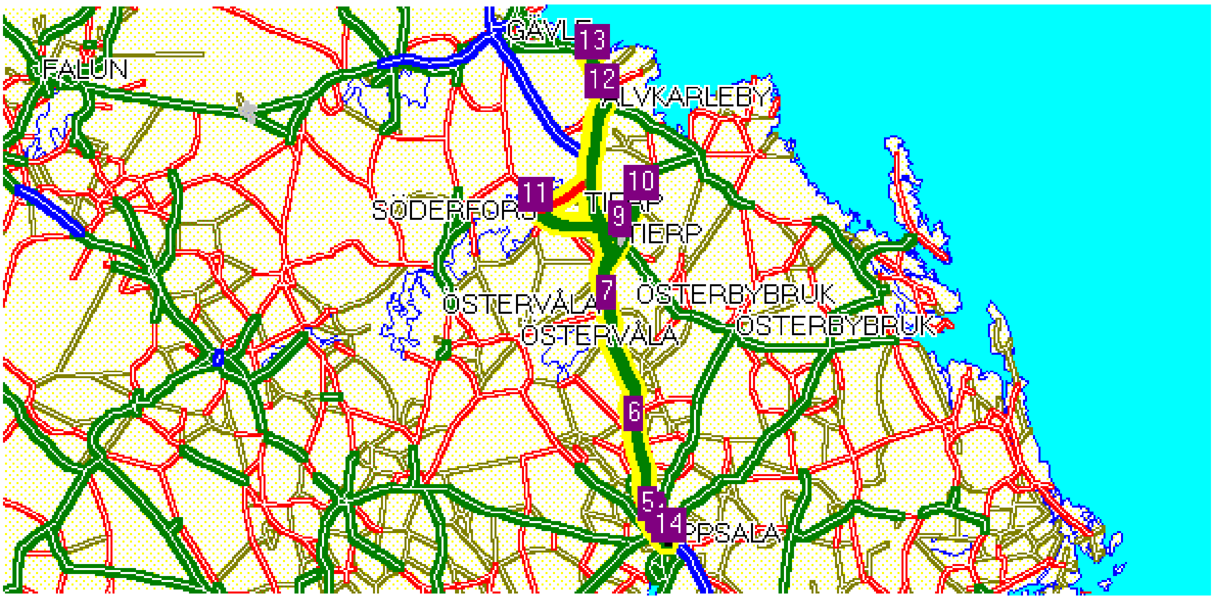


Figure 15a. Route 8

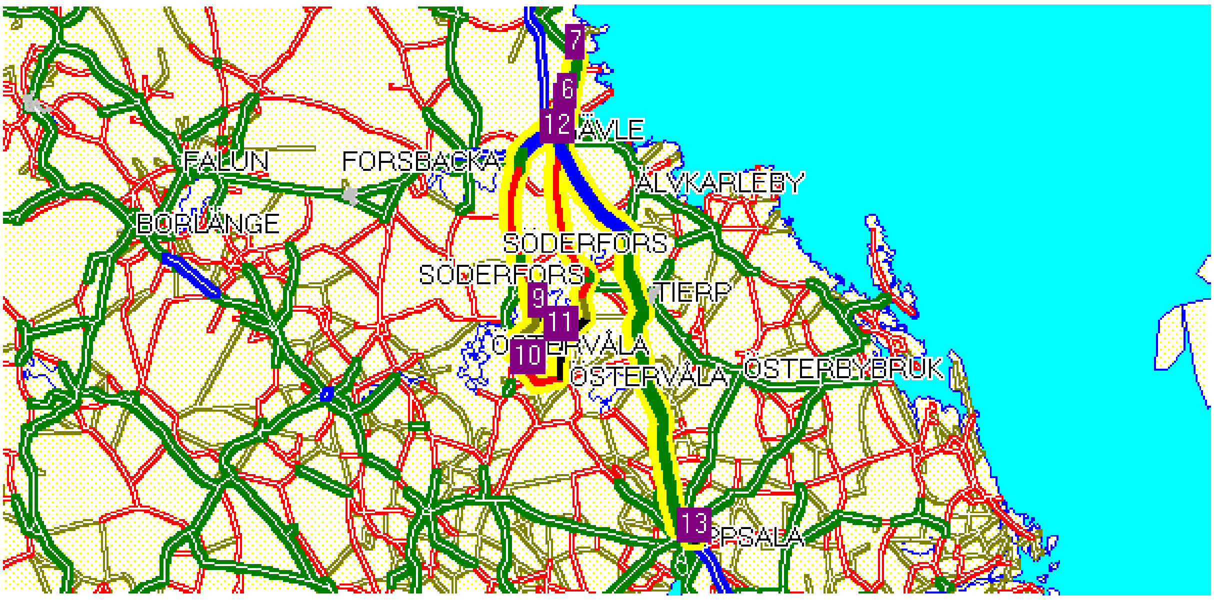


Figure 15b. Route 11

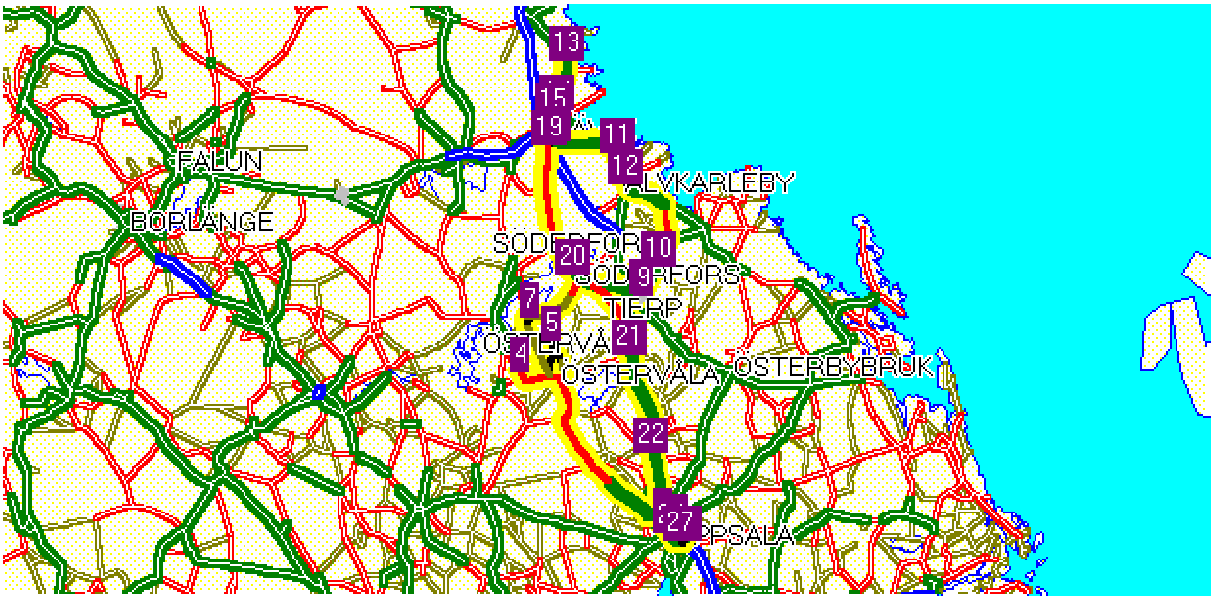


Figure 15c. Combination of routes 8 and 11

5.5.6. Example 6: East and North of Uppsala

Route	distance	time taken
PJO548	284	4h47m
PDO173-1	254	6h25m
Both together	538	11h12m
if coordinated 394		9h01m

(see Figs 16a, 16b and 16c)

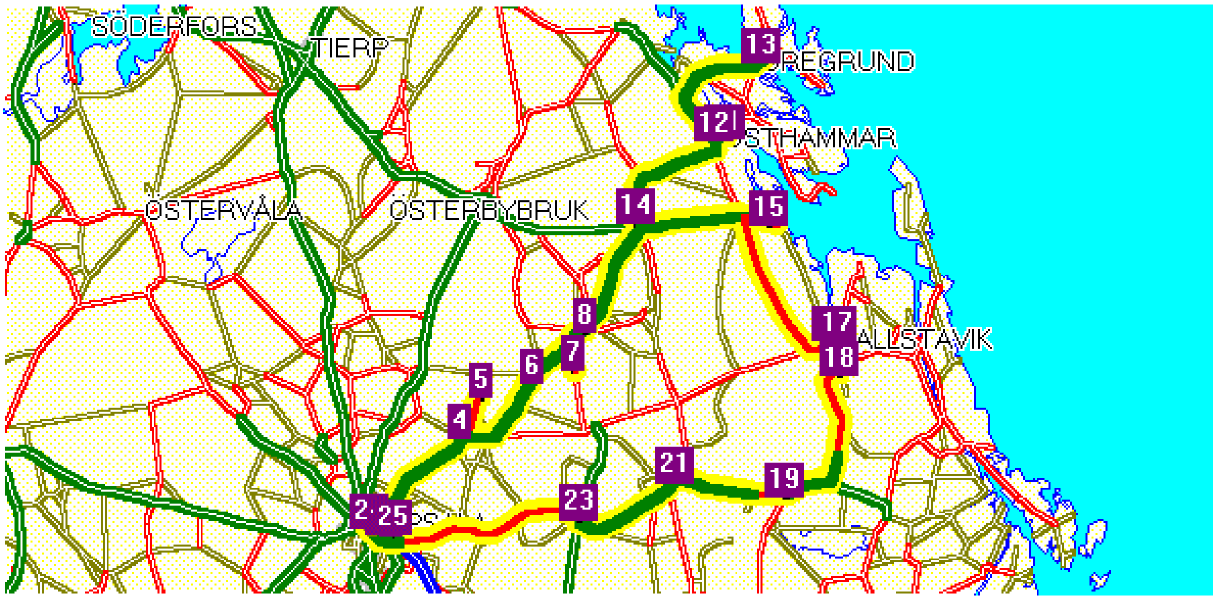


Figure 16a. Route 38

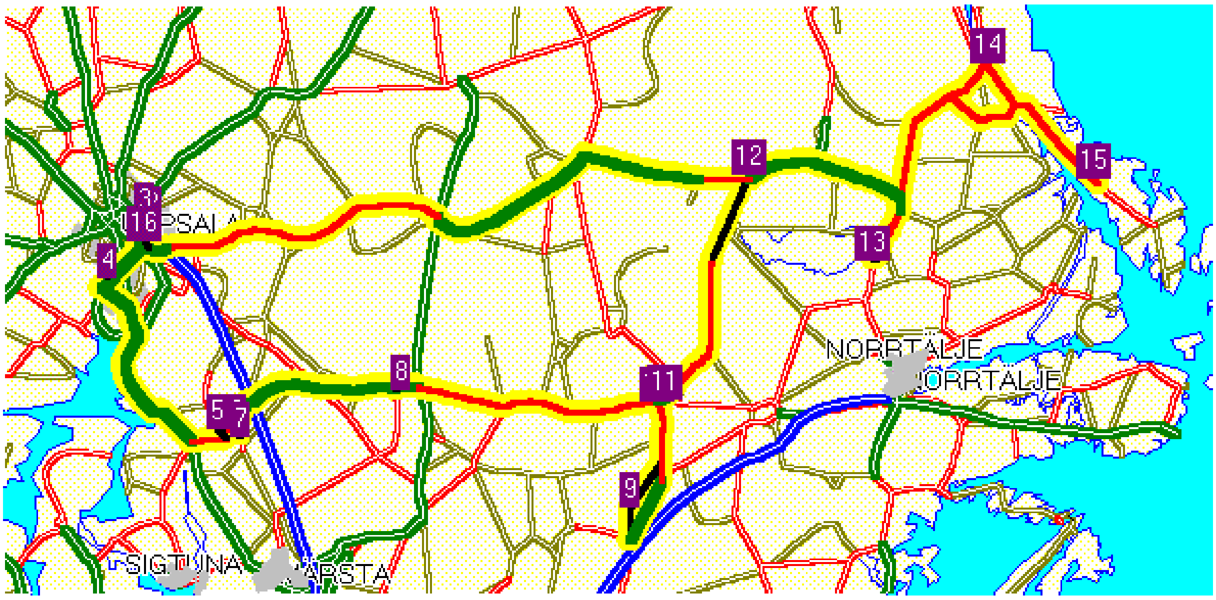


Figure 16b. Route 36

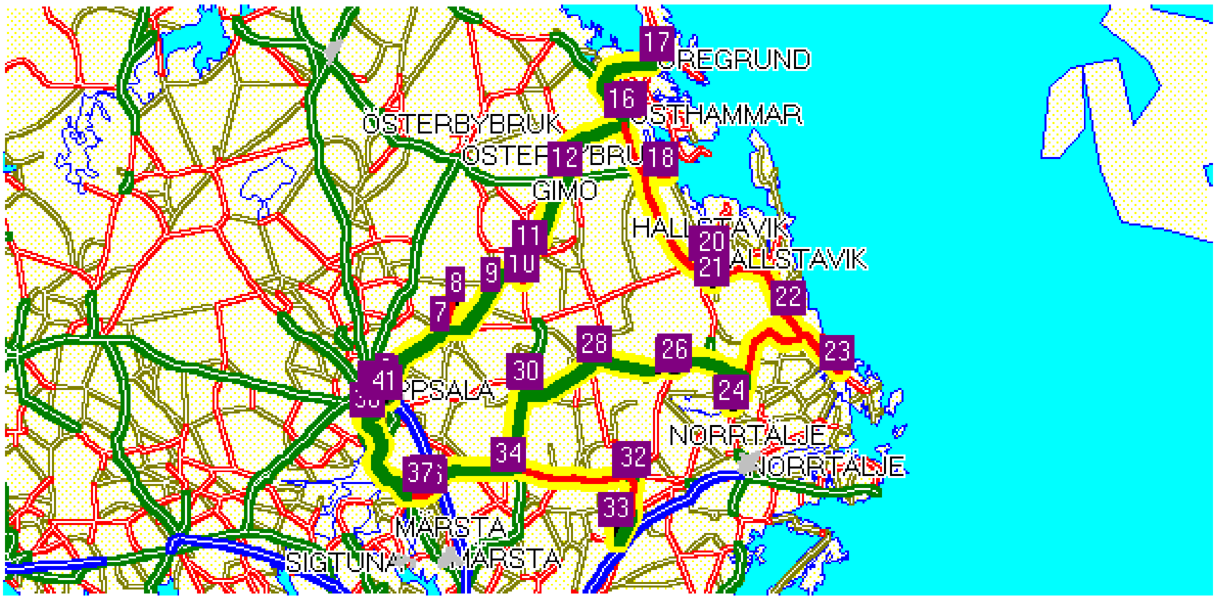


Figure 16c. Combination of routes 38 and 36

5.6. Motor idling

During the field measurement, observation was made whether the drivers stop the motor during unloading. Motor idling duration was measured to include in the emission computation.

Out of the 38 routes, motor idling was observed for 25 routes, which is about 66% of the total routes. For about 13 routes (i.e., 34%), the drivers never stopped the motor where as the remaining 12 routes (which is about 32%) the drivers some times stopped and some times not. Allowing the motor idling is common for those routes performed in the town, and thus the relation between motor idling and driving time reached about 50% for some cases. The

average time distribution of driving, stop with and without motor idling of those routes where motor idling observed is given in Figure17.
Motor idling at the delivery points is unnecessary and its environmental impact is significant. Usually, continuous motor running may be required for the ventilation system to control the temperature in the loading zone. However, many of the routes which acquired higher percentage of motor idling time never required such operation.

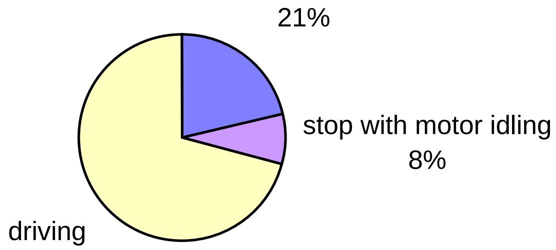


Figure 17. The average time distribution of driving, stop with and without motor idling of those routes where motor idling observed

5.7. Environmental impact

Scrutinising the environmental impact of the contemporary distribution system in and around Uppsala town was among the main objectives of the current investigation. Emissions generated from the vehicles were computed using MODTRANS model for each route and the gathered data of load, speed, road conditions and motor idling duration. Table 4 reports the summary of the total emissions of CO, CO_2 ,NO_X, HC and S for each company. The typical results of cumulated emissions of CO_2 from a single route is illustrated in Figure 18. Company **C**, has distributed almost only in the town and company **A** distributed mainly in the region. Allowing the vehicles idling at the delivery points were common for company **C**, and therefore emissions per kilometre for company **C** is higher than that of company **A**, even though the fuel consumption of vehicle's used for the company **C** were less than those of vehicles used by company **A.**

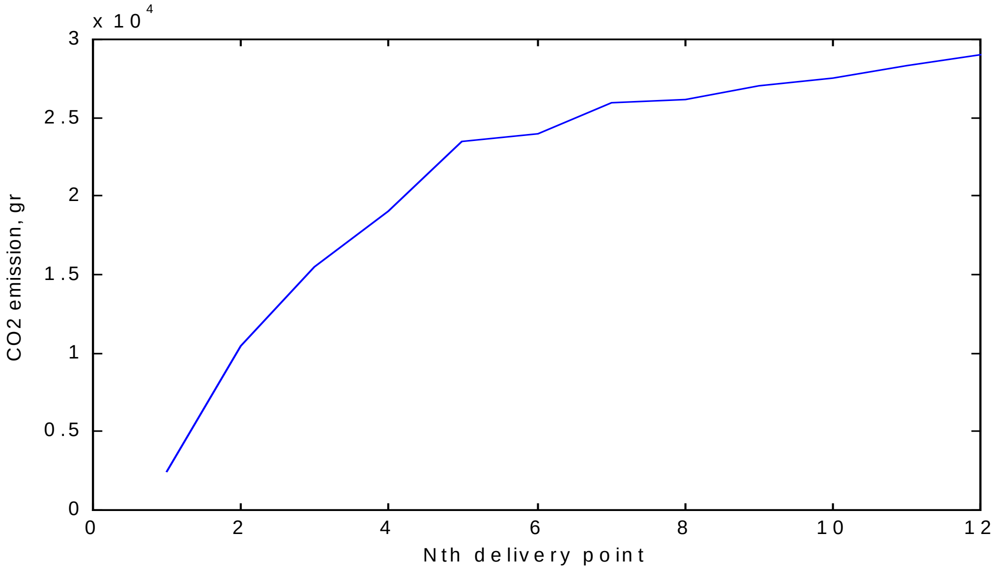


Figure 18. Cumulated CO2 emissions from one simple trip, and 12 deliveries, with the total distance of 36 km

Table 4. Summary on environmental impact (factors such as load, motor idling and area of distribution were considered, and emissions were calculated g/tkm)

Company	**Number of routes**	**Distance, km**	**Emissions, kg**				
			CO	**CO2**	**NOx**	**HC**	**SO2**
A	6	1254	1.51	489.06	9.78	1.13	0.007
B	7	163	0.25	79.46	1.59	0.19	0.0009
C	10	310	0.70	226.69	4.54	0.53	0.003
D	3	235	0.14	45.83	0.92	0.11	0.0007
E	3	956	0.57	186.42	3.73	0.43	0.003
F	2	523	0.21	67.99	1.36	0.16	0.0009
G	3	538	0.32	104.91	2.10	0.24	0.002
H	4	343	0.28	89.18	1.78	0.21	0.002
Total before optimization	**38**	**4322**	**3.98**	**1289.54**	**25.80**	**3.00**	**0.02**
Total after optimization	**16**	**2636**	**2.07**	**670.56**	**13.42**	**1.56**	**0.01**

Company C and B distributed their goods only in Uppsala town.

6. Concluding remarks

The study made to map out the distribution activities within and around Uppsala showed that many of the participated distributors are situated very near to each other, acquire many common customers and follow similar routes. Especially those delivered bread, very often meet at the delivery points at the same time and follow each other for the next delivery point. This implies that there is a high potential, for these companies to co-ordinate their distribution.

It was noticed that deliveries were made not according to the shortest driving distance, but rather priorities were made in the following order: shops, restaurants, schools or nurseries. Some drivers,(about 66% of the total route) particularly those distributing in the town, allowed the vehicles' motor idling while unloading and delivering. Emission computation has showed that emissions per kilometre in the town is much more higher than in the region due to mainly lower speeds and motor idling at the delivery points. To avoid unnecessary motor idling, sensitisation of the drivers is required to lift up the environmental issue associated with distribution.

The optimisation made showed that route and sequences of delivery planning of individual route could reduced distance by 34% and saved time by 40%. The total optimisation reduced the routes, the number of vehicles, and the total distance by 58%, 42% and 39% respectively. This resulted in the reduction of emissions by 48%.

Examples of several possibilities of combination of routes without any technological modification of vehicles and the requirement of common depots were identified and illustrated using the network digital map.

This study confirms that IT-supported route optimisation for various levels of distributions is among the main strategies which may enhance the promotion of economically effective and environmentally sustainable distribution system.

The observed constraints which may retard co-distribution were competition among the producers, between large scale and small scale transport companies, the nature of goods, and un-clarity around the question of who takes the initiative.

References

Backman H., Cordi I. 1984. Energieffektivitet i framtidens godstransport. Rapport 1984:1, TFK, Stockholm

Bernhadsen T. 1992. Geographical information system. Viak IT and Norwegian Mapping Authority, Arendal, Norway

Bowersox D., Closs D.J. 1996. Logistical Management, the integrated supply chain process. The McGraw-Hill companies, New York

Demker G., Flodström E., Sjöbris A, Williamson M. 1994. Miljöeffekter av transportmedelval för godstransport. KFB rapport 1994:6, Stockholm

Dornier, P.P., Ernst R., Fender M., Kouvelis P. 1998. Global Operations and Logistics. John Wiley and Sons INC, New York

Gebresenbet, G.; and Oostra, H. 1996. Environmental Impact of Goods Transport with Special Emphasis on Agricultural and Related Products. Part I: Modtrans, A Simulation Model to Study Goods Transport in Relation to Environment, Energy and Economy. Department of Agricultural Engineering, SLU, Rapport 129

Gebresenbet, G., 1998. Environmentally Sustainable Goods Transport in the Agricultural Sector: The role of SLU in Agricultural and Forestry Transport. A discussion paper presented on the seminar on agricultural transport, October 6, 1998, SLU, Uppsala, Sweden

Institute för transportforskning,TFK, 1997. Intelligent citylogistik ur ett samhällsperspektiv, Publication 1997:23, Vägverket

Kristiansson L, Petersson M. 1996. Varudistribution i Innerstad, Möjligheter och hinder för en samordnad livsmedeldistribution. Rapport 1996:6, Chalmers tekniska högskola, Institutionen för stadsbyggnad, Göteborg

Lenner M 1995. Measurement by on board apparatus of passengers cars real-world exhaust emissions and fuel consumption. VTI medelande No 771a

Ljungström, B. 1983. Framtidens teknik för distribution av dagligavaror. Transport Forsknings Kommissionen (TFK) Rapport 1983:6

MathWorks, Inc. 1991. Matlab User's Guide. Masschusetts

MathWorks, Inc. 1992. Simulink, a programme for simulating dynamic system. Masschusetts

Ottosson, T.; and Svensson, S. 1982. Samordningsmöjligheter inom Jordbrukets Utomg†rdstransporter. Institutionen för Transportteknik, Chalmers Tekniska H”gskola, Göteborg

Scania AB, 1989. Trafiken och miljö. Bilagedel. Saab Scania AB Söderttälje

Statistiska centralbyrån, SCB, 1998. När mat kommer på tal

Westin Kerstin, 1982. Samordnade Livsmedelstransporter till Glessbygd, förslag till transportl”sning i Vilhelmina. ISSN 0280-1906. Trafik- och transportforskningsenheten, Ume† Universitet

World Commission on Environment and Development, 1987. Our Common Future. Oxford University Press, Oxford, New York

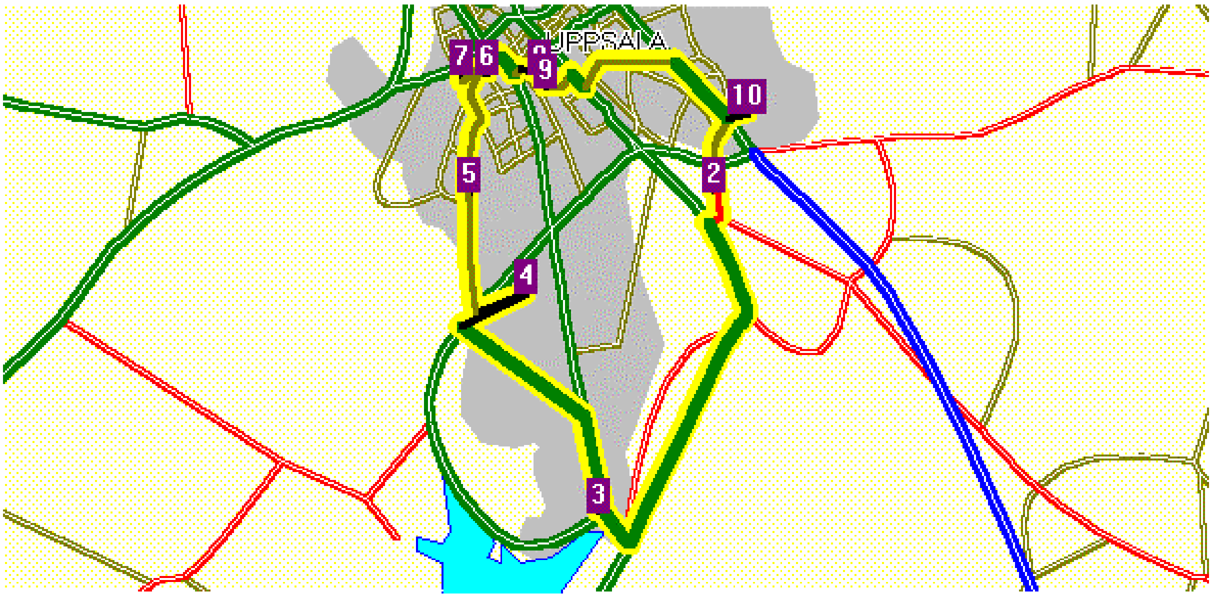
Appendix A: Possible coordination

Area of distribution and possible combinations

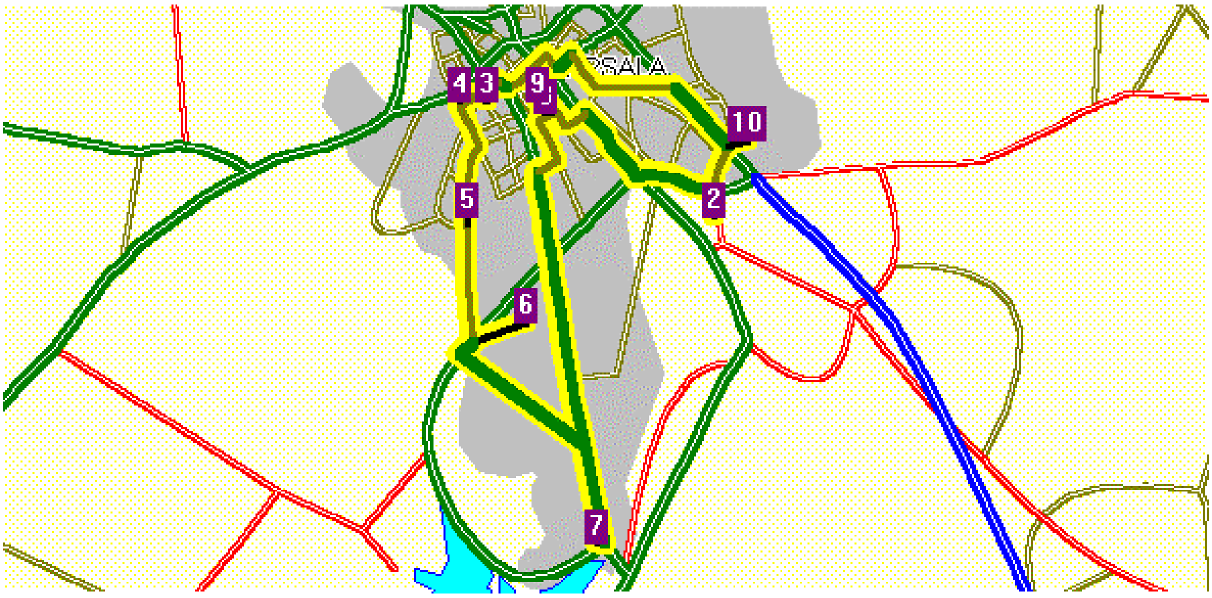
Route	Company	Area of distribution	Possible coordination with routes
JMB228-1	Scan Farmek	North-east of Uppsala	PJO548; JWU359; AEC004-1
JMB228-2	Scan Farmek	Enköping	KTB389-1
BRE206-1	Scan Farmek	North-west of Uppsala	FBW651
BRE206-2	Scan Farmek	North of Uppsala	DZS636
PDO173-1	Scan Farmek	East of Uppsala	PJO548
PDO173-2	Scan Farmek	South-west of Uppsala	HNX915
ERV195-1	GK Bageriet	Uppsala town	those distributing in town
ERV195-2	GK Bageriet	Uppsala town	those distributing in town
ERV195-3	GK Bageriet	Uppsala town	those distributing in town
ODO668-1	GK Bageriet	Uppsala town	those distributing in town
ODO668-2	GK Bageriet	Uppsala town	those distributing in town
ODO668-3	GK Bageriet	Uppsala town	those distributing in town
ODO668-4	GK Bageriet	Uppsala town	those distributing in town
BGR559C	Sätra Bagariet	Uppsala and Marsta	those distributing in town
BGR559-1	Sätra Bagariet	Uppsala town	those distributing in town
BGR559-2	Sätra Bagariet	Uppsala town	those distributing in town
BGR559-3	Sätra Bagariet	Uppsala town	those distributing in town
BGR559-4	Sätra Bagariet	Uppsala town	those distributing in town
HMP732-1	Sätra Bagariet	Uppsala town	those distributing in town
HMP732-2	Sätra Bagariet	Uppsala town	those distributing in town
HMP732-3	Sätra Bagariet	Uppsala town	those distributing in town
HMP732-4	Sätra Bagariet	Uppsala town	those distributing in town
HMP732-5	Sätra Bagariet	Uppsala town	those distributing in town
CXZ625	Skuttunge bageriet	Uppsala town	those distributing in town
MXU081	Skuttunge bageriet	Uppsala town	those distributing in town
OED660-1	Skuttunge bageriet	Uppsala town and Knivsta	those distributing in town
DZS636	Skogaholms bageriet	North of Uppsala	BRE206-2
FBW651	Skogaholms bageriet	North-west of Uppsala	BRE206-1
PJO548	Skogaholms bageriet	North-east of Uppsala	JMB228-1; JWU359
DOU805	Blomstergrossisten	Uppsala town	Those distributing in town
HNX915	Blomstergrossisten	South-west of Uppsala	PDO173-2
JWU359	KIAB Martelleur	North-east of Uppsala	JMB228-1; PJ0548; AEC004-1
JWU359-1	KIAB Martelleur	North of Uppsala (1 place at the east)	
MNT289	KIAB Martelleur	-------	
KTB389	Charkman	Uppsala town	those distributing in town
KTB389-1	Charkman	Uppsala and Enköping	JMB228-2
KTB389-2	Charkman	Uppsala town	Those distributing in town
AEC004-1	Charkman	North and north-east of Uppsala	JMB228-1; PJ0548; JWU359

Appendix B: Examples of actual and optimised routes

B.1. Actual and optimized routes of distribution of Blomstergrossisten

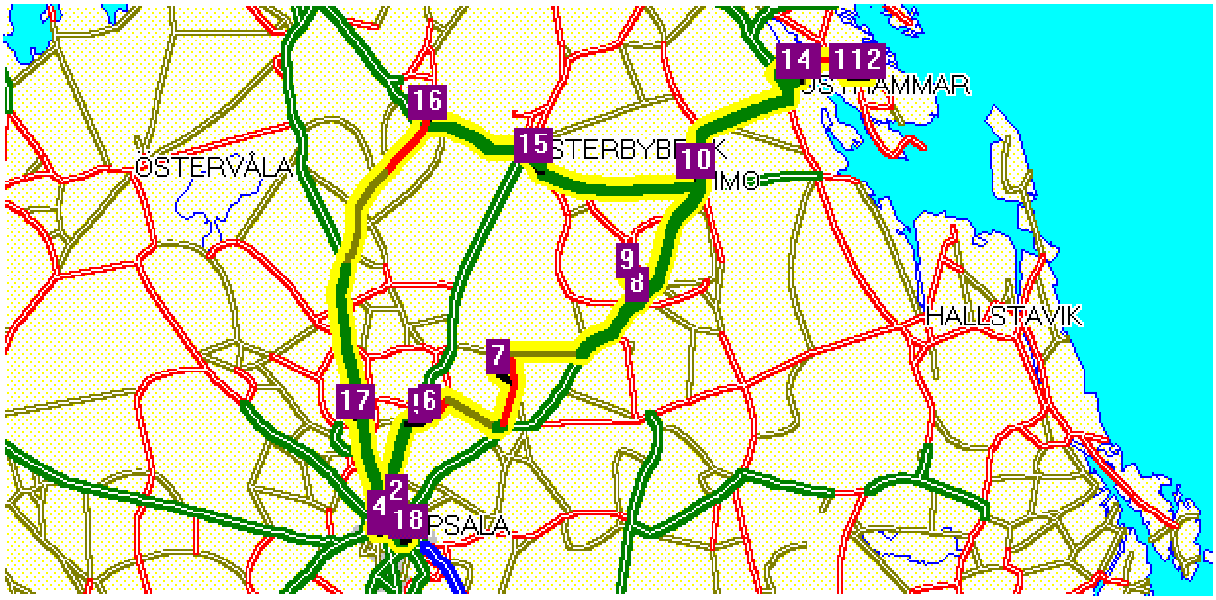


Actual route (36 km)

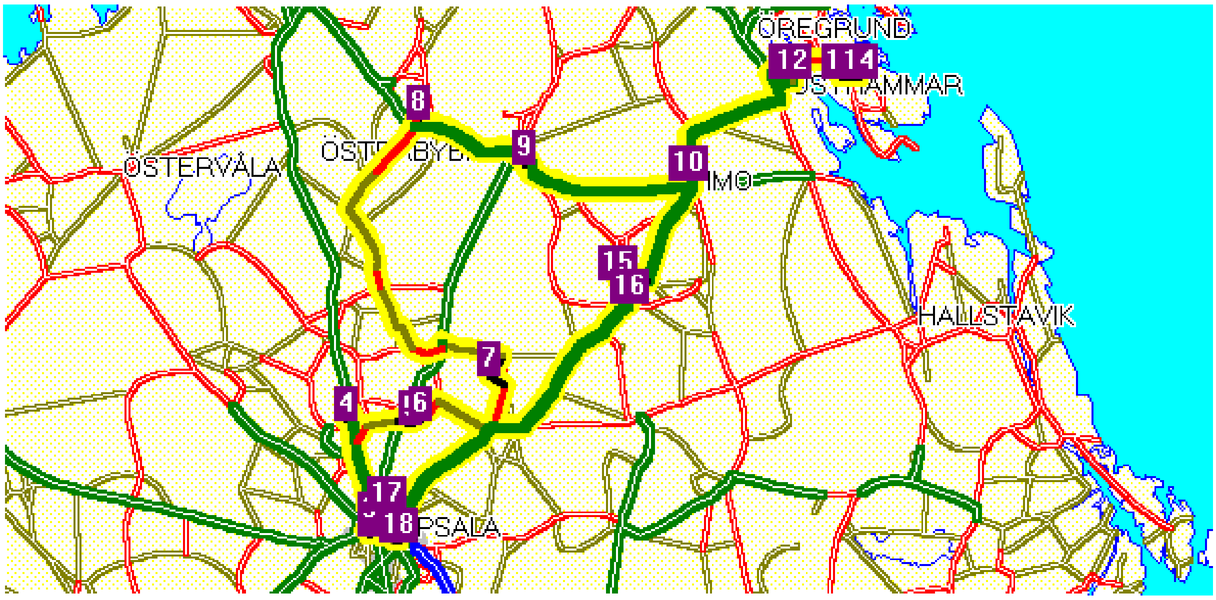


Optimized route (34 km)

B.2. Actual and optimized routes of distribution of Charkman

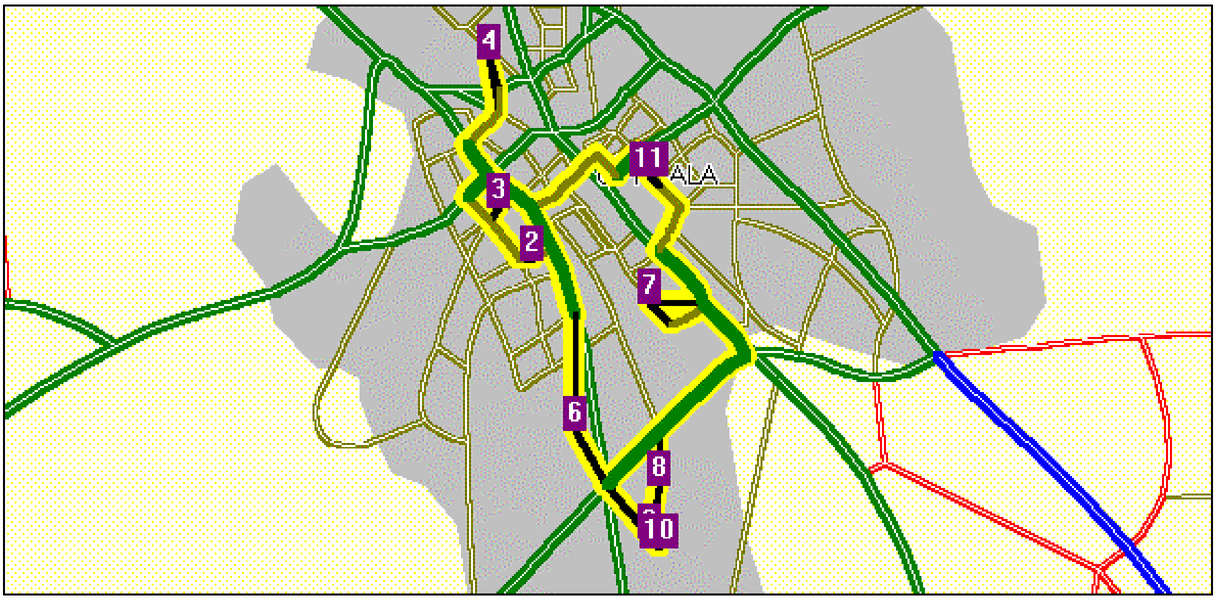


Actual route (210 km)

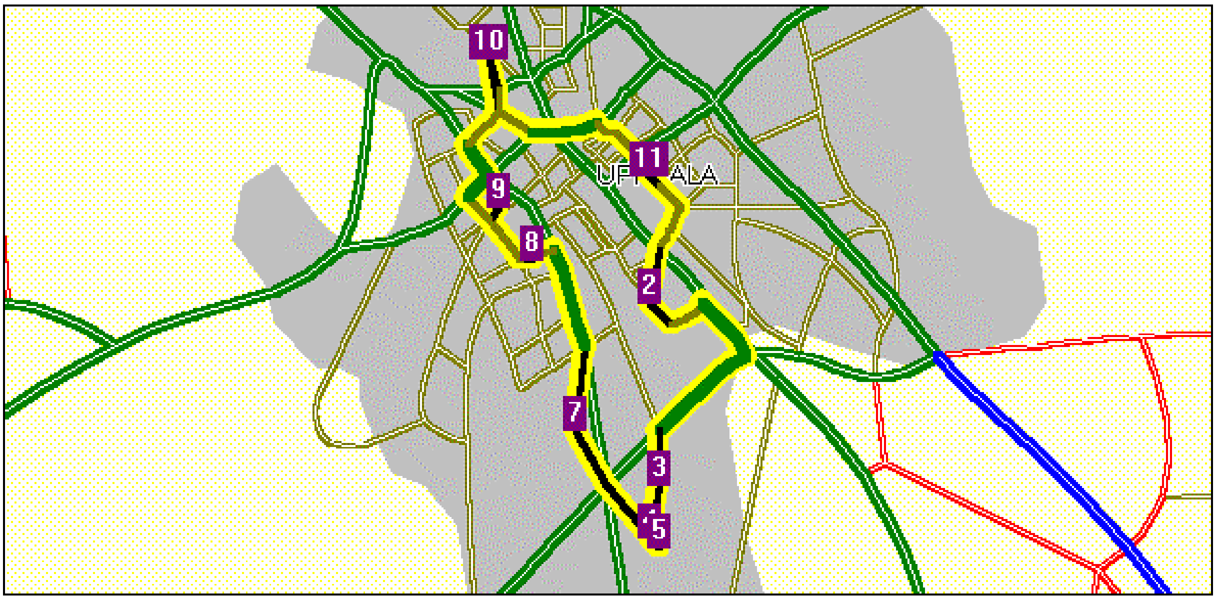


Optimized route (201 km)

B 3. Actual and optimized routes of distribution of GK bakery

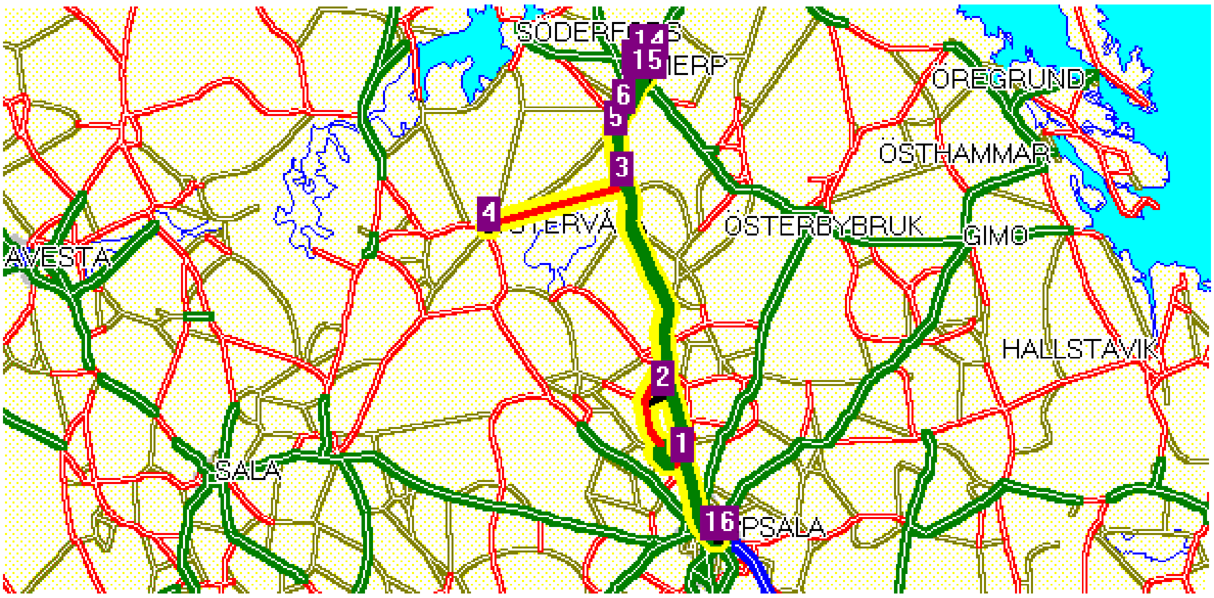


Actual route (23 km)

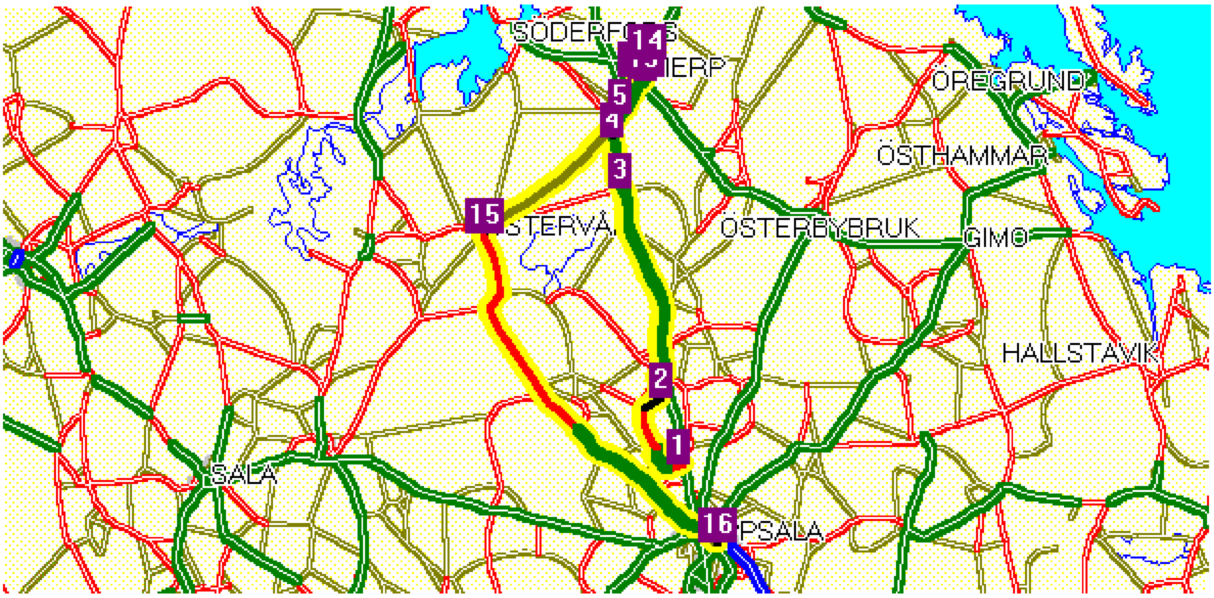


Optimized route (15 km)

B 4. Actual and optimized routes of distribution of KIAB Matelleur

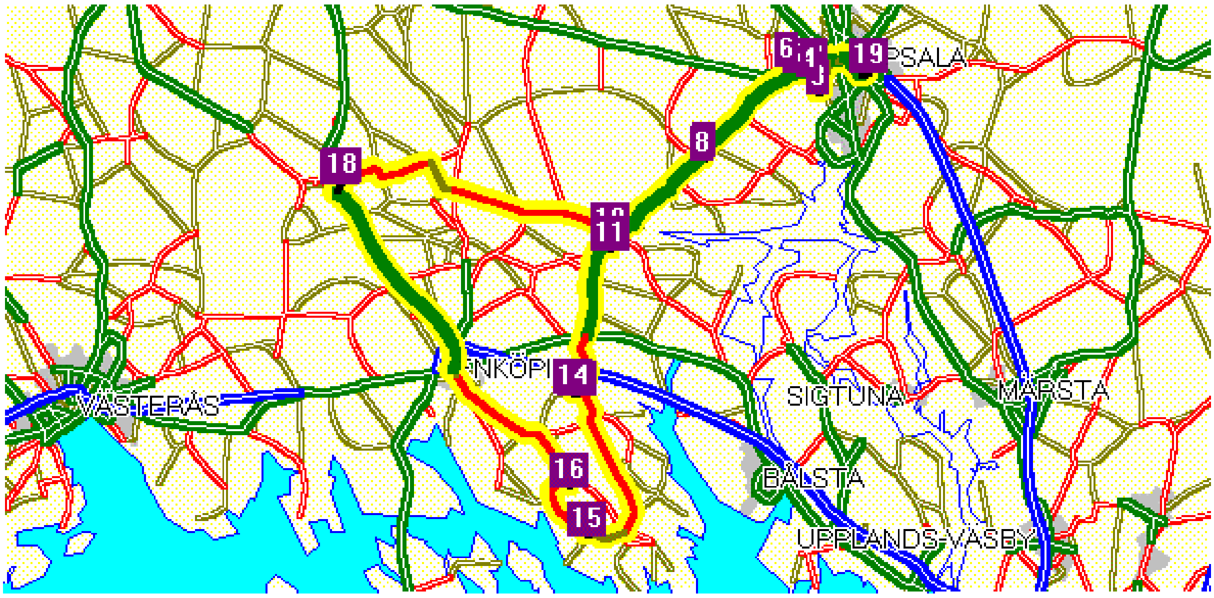


Actual route (183 km)

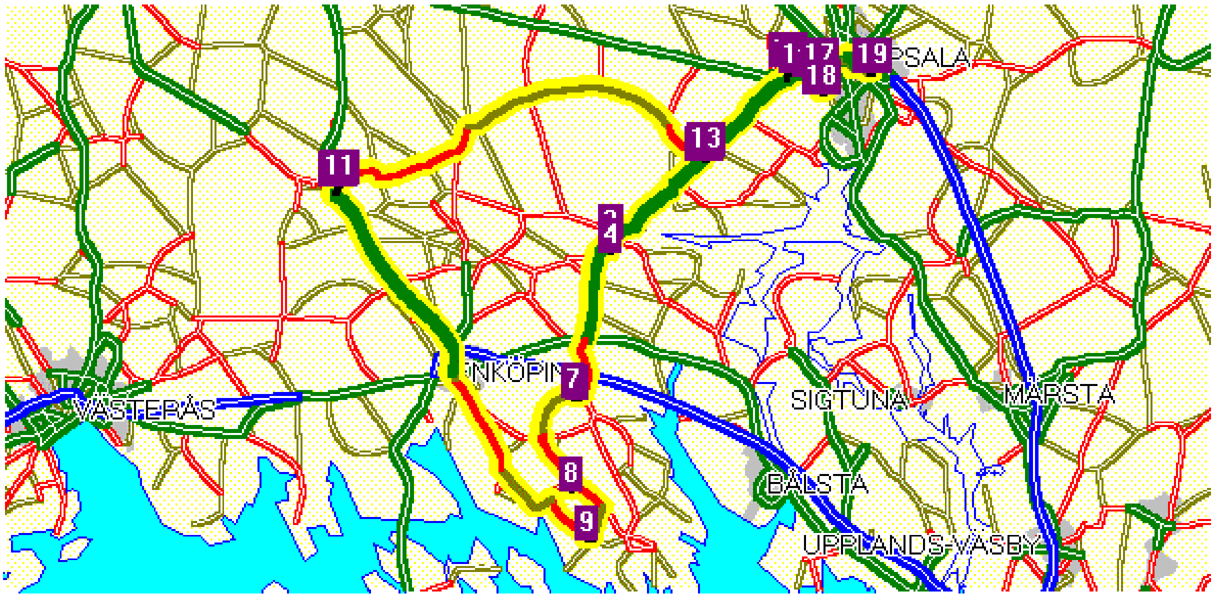


Optimized (148 km)

B 5. Actual and optimized routes of distribution of Scan Farmek

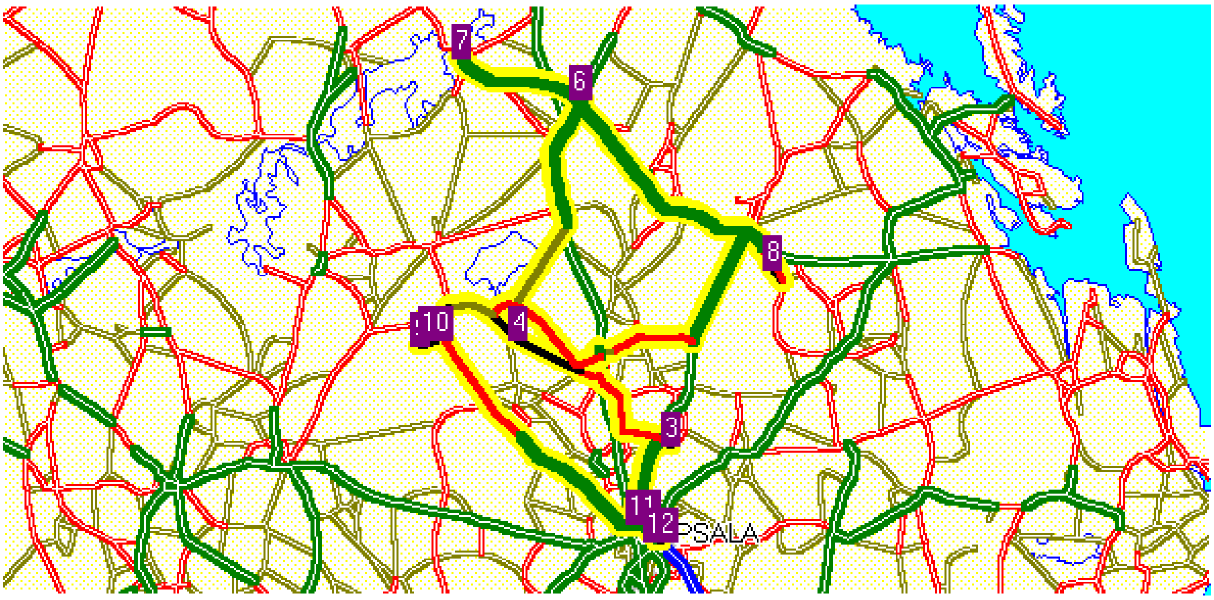


Actual route (166 km)

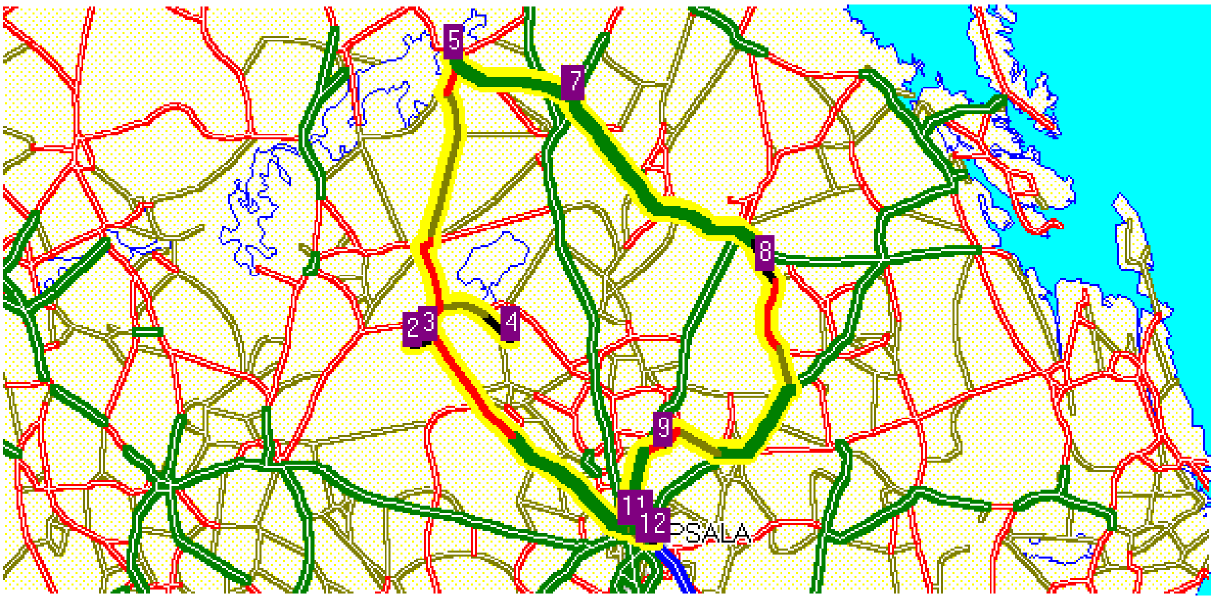


Optimized route (154 km)

B 6. Actual and optimized routes of distribution of Skogaholm bakery



Actual route (264 km)



Optimized (219 km)