LAST MILE LOGISTICS AND SPATIAL STRUCTURE

Heike FLÄMIG; *Institute for Transport Planning and Logistics, Hamburg University of Technology*

ABSTRACT

The limited reserve of space and the competition between different functions in urban regions as well as the negative impacts (noise, gashouse emissions) of the environment of logistics nodes are reasons for the suburbanisation of the logistics function outside of towns. Often, the relationship between the presence of the logistics function and the prosperity of cities and their economical and social development are not considered in urban development policy, even though some cities are (only) existing, because of the prominence of the logistical function for this regions.

Empirical findings show an interrelation between the type of good and the spatial structure with the spatio-temporal organization of the logistics system and their impacts on the traffic generation and the environment. In the discussion about the impacts of the re-organization of the supply chain in urban regions the need for different delivery chains for different spatial structures, products and services are mostly forgotten.

The paper will show the prominence of distribution operations (consolidation, home delivery service, cross docking etc.), the types (distribution center, transshipment point) and choice of logistical locations and infrastructure (regional e-logistics centers, pickup points, etc.) and the connected traffic generation for the prosperity of our cities.

The theoretical framework is developed on the basis of a new understanding of the role and the shape of the elements of logistical systems (e.g. the redefinition of vessels, facilities and 'new' modes for freight transport). This model enables to simulate the impacts on the traffic system and the contribution to air emissions depending on a change of type, number and location of distribution nodes (shops, distribution center, pick-up points etc.) as well as of type and number of vehicles. It also shows the options of various distribution strategies and their impacts on the urban development as well as the necessity to save space for logistics node in urban regions and inner cities.

spatial structure, distribution system, emissions, logistics nodes

INTRODUCTION

The food sector is subject to permanent structural changes (Eggert 1998, Beisheim 1999). They are characterised by consolidation (M + M EURODATA 2000), an increasing significance of discounters (EHI 2000, pp. 84) and a growth of floor area (EHI 2000, pp. 86). With respect to spatial organisation, both, a suburbanisation of the retail function and a withdrawal from rural areas, are prevalent. This leads to a decreasing density of grocery shops in residential areas, thus affecting location structures (Bayerisches Staatsministerium für Wirtschaft, Verkehr und Technologie 1999, p. 25), logistic strategies (Hultkranz/Lumsden 2000) and customers mobility patterns (Reinhold et al. 1997). In recent years the development of traffic patterns are particularly influenced by new shopping facilities in non-integrated locations. This means that the transportation of goods is partly shifted to the customers, who preferentially use their private cars.

A relatively new driving force in this transformation process is constituted by the internet-based technologies that allow changes in traditional business processes. A new development here is the so-called e-commerce in the B2C (business to consumer) segment, i. E. the trade between sellers and end customers using electronic media.

E-commerce bears chances and risks. On the one hand, markets can be accessed independently of location. This enables companies to choose locations at low real estate cost. Additionally, the new business models connected to e-commerce provide the opportunity to adequately supply people living in peripheral locations.

On the other hand, e-commerce impacts on traffic and environment are being controversially discussed. One basic promise of e-commerce is to reduce the number of individual motorised shopping trips, which would be substituted by delivery traffic (Luley et al. 2002), another is directed to cost reduction. In this context, new logistic delivery concepts have been developed recently to reduce costs (Siebel 2000, Heyden 2001). The basic idea was to investigate how and where goods could be handed over to the customer because these two aspects define the logistic process, the resulting traffic generation and thus the impacts on the environment.

This paper deals with the correlations between new delivery chains created by e-commerce in the B2C segment, spatial structure and the impacts on traffic and the environment in three ways. Firstly, current research on this topic was analysed and is presented. Secondly, different logistic process models regarding new delivery concepts were developed and applied to different types of regions (rural areas, urban areas, high density urban areas). To investigate the impacts on traffic and the environment, these delivery scenarios were then compared to the classic shopping trip to a retail outlet. The final step dealt with the question of how much individual motorised traffic can be substituted by commercial traffic. Maximum substitution potentials of three different types of shopping locations (urban neighbourhood, city centre, greenfield) have been demonstrated.

E-COMMERCE AND ITS CONSEQUENCES FOR TRAFFIC AND THE ENVIRONMENT – STATE OF RESEARCH

Current studies on the B2C distance trade deal with the traffic and/or environmental impacts of delivery services, sometimes under consideration of space. They include conceptional analyses and ideas about the plausibility of correlations between e-commerce and traffic (Weltevrede/Rotem-Mindali 2009, Mokhtarian 2003, Mokhtarian/Salomon 2002, Janz 2001,), polls concentrating on tele-shoppers (Tacken 1990, Handy/Yantis 1997, Gould 1996, Gould/Golob 1997, Gould/Golob/Barwise 1998, Luley et al. 2002) and projections of the trips generated by e-commerce onto the entire commercial traffic volume (TLN 2000). There are also studies concerning the home delivery of groceries – the subject examined in this paper. These studies mostly deal with more or less extensive simulations of real and precisely defined areas (Cairns 1998, 2003, 2005, Punakivi/Saranen 2001, Punakivi/Holmström 2001). Another study examines the emissions caused by the “last mile” in different distribution concepts (Orremo et al. 1999, 2000).

For the evaluation of e-commerce and its traffic impact preparatory work was done by Cairns first published in 1996. Her study contains a number of factors and parameters enabling a realistic simulation under the assumptions made here. Other simulation studies available are based on these calculations and achieve similar results. Depending on the chosen variables and their characteristics according to scenario or service model, the simulations indicate that between 50 and 90 per cent of the mileage could be saved per food purchase by using a delivery service (Punakivi/Saranen 2001, Punakivi/Holmström 2001, Cairns 2003). Palmer’s (2001) calculations allow the conclusion that, regarding traffic generation, delivery out of shops is more efficient than delivery via fulfilment centres or distribution warehouses.

The direct comparison of the amount of kilometres per delivery vehicle to the amount of private car kilometres saved is a problem most studies have in common. Regarding the impacts on traffic and the environment, this comparison is incomplete as, for example, an average private car needs less space and produces less noise and pollutants than the average van or truck. Therefore, each figure represents a potential maximum saving, as for reasons of complexity reduction the assumptions made are not wholly realistic, e. g. 100 per cent substitution of shopping traffic by delivery traffic and a number of parameters were neglected such as alternative uses of the car, exhaust emissions and in some cases modal-split.

Orremo et al. (1999, 2000) and Punakivi et al. (Punakivi/Saranen 2001, Punakivi/Homström 2001) tried to overcome this deficit by evaluating the emissions in rural and urban areas which are linked to shopping and delivery traffic. Depending on the delivery concept, the reduction potentials of air pollution are very different, ranging between 15 and 90 per cent. In general, both calculations conclude that a delivery is always energetically more efficient than a customer’s trip to the shop by car.

Studies on tele-options primarily contain empirical data on how far individual and commercial traffic can be substituted by distance trade. At least, regarding the purchasing of groceries, it seems that people who buy their food online use their car less (Tacken 1990, Gould 1996, Handy/Yantis 1997).

Overall, a few studies are currently available that indicate the impacts of e-commerce on traffic and the environment precisely (Esser/Korte 2005, 2007). Especially for the impacts of new delivery concepts, no further conclusions have been drawn so far. In addition, the studies at hand are of limited comparability, as they differ in their assumptions, e. g. concerning unloading times or the loading capacity of the vehicles.

DELIVERY CONCEPTS IN THE SPATIAL CONTEXT– IMPACTS ON TRAFFIC AND ENVIRONMENT

Even though a home delivery service has been part of the customer service of many proprietor-run outlets of the stationary food retail business for many years, operating the so-called “last mile” generates nowadays substantial problems in order processing. This includes firstly product specific and legal requirements (especially in terms of food hygiene regulations), resulting at present in a high logistical input but low delivery density. Secondly, a gap exists between the costs for this service and the customers’ willingness to pay for it. To solve these problems, new logistics concepts for the delivery of goods have been developed and are in some cases already in use. The delivery concepts can be divided into direct and indirect systems (Flämig 2002b). In the direct systems, goods are delivered personally to the customer's workplace, home or a neighbour. In the case of indirect delivery, the goods are deposited at a convenience store[i] to be handed over or are stored at a transfer station. Typically these transfer stations are permanently installed, computer-backed locker systems with up to 600 boxes located near houses, on housing estates or in commercial buildings.

In order to make a reliable prediction which logistic solution is appropriate for which delivery concept and area type, 15 delivery scenarios were evaluated for each of the three area types. The status-quo scenario $V1_{SQ,}$ in which all customers use their car for shopping trips, served as the starting point. In the simulation, the share of motorised shopping trips was estimated to be 100 per cent, because from an ecological point of view only these can usefully be substituted by delivery traffic.

The scenarios modelled in the following combine different area types and various delivery concepts with their corresponding logistics option for the preliminary transport chain. This approach was chosen to ensure that the impacts on traffic and the environment not only of the last mile, but of the entire transport chain, are taken into account. In a separate calculation step, possible substitutions of individual travel by goods traffic are also included. The research on environmental impacts has been limited to air pollutants.

The following sample calculations are based on figures that come close to reality but cannot reflect the real logistic processes precisely. The issue is too complex, local conditions are too different and the future is too uncertain for a completely accurate representation. Thus these calculations can only provide a general understanding of delivery transport chains and their impacts on traffic and the environment in different areas.

DESCRIPTION OF SYSTEM ELEMENTS AND CENTRAL ASSUMPTIONS

The logistics system is conceptualised as follows. First of all, it was important to categorise the possible logistic nodal points. The supplier (L) stands for the location of a manufacturer or producer, a wholesaler or an importer. Depending on the level of distribution system, the goods are transported to a regional fulfilment centre or the distribution warehouse of a wholesaler or retailer (DC), to a transfer station (TS) or an outlet (F) or directly to the customer (C). Every place wherefrom the goods are being delivered to the customer can serve as a transfer station (TS). In this case, a transfer station can mean a wide range of logistic solutions: convenience store, different box systems or the workplace.

To ensure that the scenarios can be compared with each other, a common reference value was identified. The comparability is based on an analysis of the transport chain and an allocation of kilometres per shipment. The scenario development begins with the largest transport container in the transport chain, a lorry of a payload between 32 and 40t. For this type of vehicle, which can carry up to 24t, a full utilisation of 36 pallets in long-distance transport is assumed. The conversion factor for these figures is a shipment unit, which represents one customer's shopping process. The average shopping load in Germany was assumed to be 30kg for the distance trade (own survey) and 10kg (own calculation based on A.C. Nielsen, Frankfurt a. M. in: EHI 2001, p. 95) for the stationary trade in Germany.

In order to compare the scenarios with each other, the average loading factor of the vehicle types used and the distances between distributor and distribution centres have been assumed to be identical. Regarding various supply situations, the distance covered by the customer (per shopping journey, depending on the type of area) was varied. This factor influences the distances covered at other distribution levels depending on the level and kind of distribution system. For this, three area types are defined: the reference area, the urban area and the rural area. The reference area is an abstract concept based on average values available from statistics for Germany.

For the calculation of air pollutants the Mobilev emission model (Mobilev 1997) was used, complemented by the work on the distribution of mileage on different road types in Germany by Regniet and Schmidt (Regniet/Schmidt 1995). To begin with, all emission calculations assume that all car-based shopping trips within the reference area can be fully substituted by delivery trips. This approach is certainly hypothetical, yet it is chosen to identify the substitution potential depending on the type of delivery concept. The maximum substitution potential inherent in e-commerce, substituting motorised shopping traffic by goods traffic, has been integrated into the model separately and will be described on its own beneath.

OVERVIEW OVER THE MODELLED SCENARIOS

The following figure 1 gives an overview over individual assumptions in the modelling process. They will be explained in more detail hereafter.

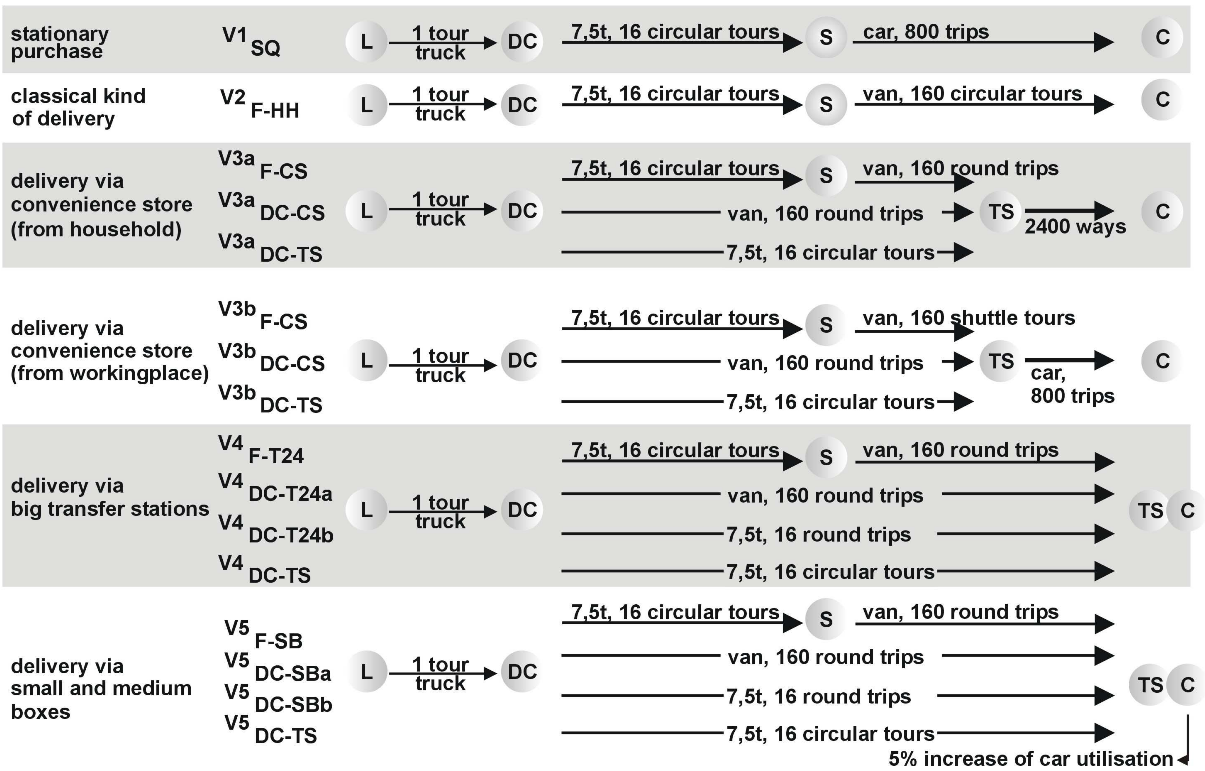

Figure 1:Overview of the scenarios

Scenario V1SQ: Shopping in a stationary shop (status quo)

In the initial scenario V1SQ the customers travel by car from their home to the outlet and back (cf. Figure 2). The distribution centre is supplied by a 32-40t lorry, carrying 36 pallets (full load) and travelling 600km from the supplier to the distribution centre in long-distance traffic.[ii] Here, the lorry's return trip was not taken into consideration as it is normally used for other purposes. After the operation of picking up the goods in the distribution centre (DC) they are taken to the outlets in small lorries (maximum permissible weight 7.5t). A loading factor of 60 per cent is assumed here so that the actual load carried amounts to around 1.5 tonnes. In order to distribute the load of 24 tonnes to the outlets, 16 round trips are required. Each distribution vehicle supplies 15 outlets on its 27km tour (IÖW 2000, p. 76), with a distance of 5km between the DC and the first outlet and between the last outlet and the DC respectively.

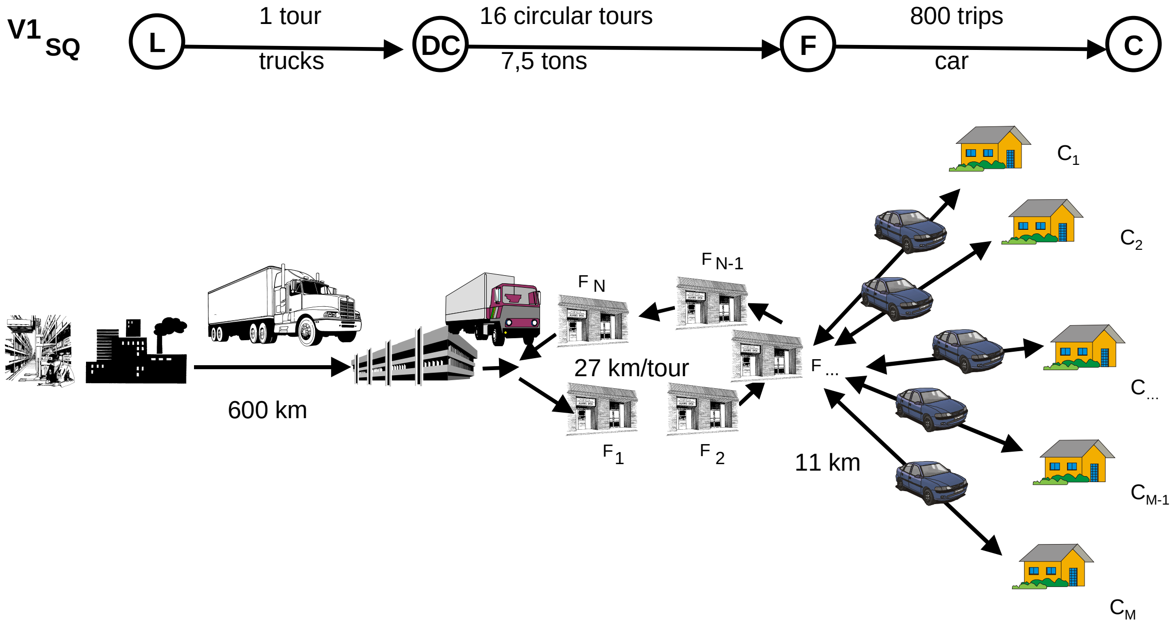

Figure 2:Scenario $V1_{SQ}$: Status quo – Shopping in a stationary shop

The average shopping load of an individual customer amounts to 30kg, therefore 800 car trips are necessary to distribute the 24t of goods to the customers' homes. Within the reference area, each consumer covers an average distance of 5.5km (Kessel + Partner 1993, p. 15). In the urban area, this distance was assumed to be 1.5km (Holz-Rau 1991, p. 302; Holz-Rau/Kutter 1995, p. 38) and in the rural area 7.8km (Frehn 1997, p. 36; BIP/IÖW 2000, p. 109).

Scenario $V2_{F\text{-}HH}$: Home delivery

In scenario $V2_{F\text{-}HH}$, which describes a classic home delivery service, all assumptions up to the supply of outlets are identical with those of the initial scenario $V1_{SQ}$. But in this case the delivery of groceries to the end consumers is done by van delivering the complete load capacity of 150kg (cf. Figure 3). With an average online order of 30kg, 5 customers can be supplied per tour. The delivery tour in the reference area covers a distance of 20km, whereas the distance from the outlet to the first customer and from the last customer back to the outlet is assumed to be 3km each. The assumed distance to be covered by the delivery van is 6km in the urban area and 25km in the rural area.

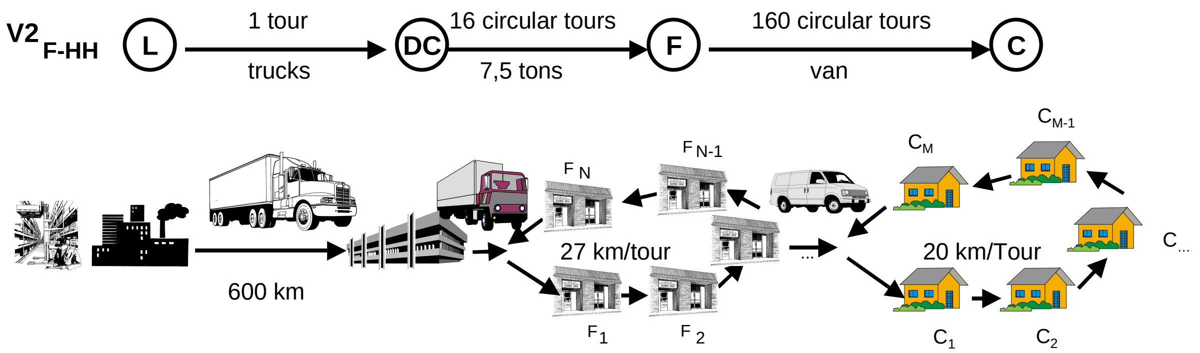

Figure 3: Scenario $V2_{F\text{-}HH}$: Conventional delivery of groceries

Scenarios V3(…): Provision in a convenience store

The goods can also be provided in a convenience store. In the scenarios V3a(…) it is assumed that the customers *walk* from their home to the shop to pick up the goods they ordered. In Scenario $V3a_{F\text{-}CS}$ identical processes for the delivery to outlets as in scenario $V1_{SQ}$ are adopted. However, the goods are handed over in a convenience store, e. g. a video store, which is close to the customers' home so they can collect the goods on foot.
In the stationary purchasing the average weight is assumed to be 10kg, because customers have to carry the goods themselves. Relating to the lower weight, 2,400 shipments are delivered since one of the basic conditions was that every kilometre covered by the transport chain would be apportioned equally to the weight of the shipments.
The supply of the convenience stores by the outlet is in turn managed by a van. The distance between the outlet and the convenience store is assumed to be 5.5km in the reference scenario - this corresponds with today's average distance to the shopping outlet (cf. scenario $V1_{SQ}$). This appears to be relatively close to reality and ensures that not too many parameters are varied simultaneously since comparability is supposed to be maintained. For the urban area 1.5km and for the rural area 7.8km are assumed.
In the scenario $V3a_{F\text{-}CS}$ the distance between DC and the most remote convenience store amounted to around 17.5km: of which 5km accounted for the round trip between DC and outlet, 7km for the circular tour and 5.5km for the distance between the outlet and the convenience store.
In scenario $V3a_{DC\text{-}CS}$ for the direct delivery from the DC to the convenience stores and back 35km are assumed. In the same manner the distances between the other area types were identified. For the urban area these assumptions result in 27km and for the rural area in 39.6km. As in the previous scenario, goods are delivered using a van with identical utilisation of capacity.
In scenario $V3a_{DC\text{-}TS}$, the supply of convenience stores does not take place separately. Instead of many round trips, only a few circular tours accrue. For this reason, a larger delivery vehicle has to be used. It has to assume that this tour will be conducted with a vehicle of 7.5t maximum permissible weight. During one tour 15 transfer stations will be supplied. In order to supply these convenience stores, the tour length amounts to around 45km, corresponding to 32km in the urban area and 51km in the rural area.
The three scenarios V3b(…) are mostly identical with the three aforementioned scenarios V3a(…). The only difference lies in the assumption that the customers collect their goods by *car* on their way home from work and not on foot. For this, independent of the type of area, a detour of 300m per car trip was included in the calculation.

Scenarios V4(…): Provision in large box systems

In the scenarios V4(…) it was assumed that the transfer stations are situated where the customers park their cars – e.g. on their way to work. For example, Tower24 (www.tower24.de) are planned at parking places. The scenarios are modelled by varying the vehicle type and the kind of tour (circular tour or round trip) used for supplying goods to the transfer stations.

In the scenario $V4_{F\text{-}T24}$ the supply of a large box system begins at an outlet. The supplying transport chain of the outlet corresponds with the initial scenario $V1_{SQ}$. For the reference area, calculations are base on a distance of 3km between outlet and transfer station. For the supply to large box systems in urban areas, a distance of 1.5km is assumed per tour, whereas in rural areas this distance amounts to 5km. For the supply vans are used, starting their route at the outlets and having the same utilisation as in the previous scenarios.

In the scenario $V4_{DC\text{-}T24a}$, a direct delivery from the distribution centre to a Tower24 takes place. As in scenario $V4_{F\text{-}T24}$, the distance in each direction is 15km in the reference area, 13.5km in the urban area and 17km in the rural area. Supply is managed by a van at the same degree of utilisation.

The difference between scenario $V4_{DC\text{-}T24b}$ and scenario $V4_{DC\text{-}T24a}$ distinguishes in the use of a 7.5t lorry. This assumption is realistic as well, as large box systems have a high capacity with room for up to 600 orders. The delivery vehicle has the same utilisation level as the distribution vehicle. In this scenario, the influence of a different vehicle type with a higher capacity was considered.

In the scenario $V4_{DC\text{-}TS}$, the supply of the Tower24 is managed in a similar way as the one described for the supply of outlets. The delivery tour in the reference area is assumed to be 36km (32km in the urban area and 43km in the rural area), slightly longer than the pure outlet tour, as it is assumed that the network of transfer stations is less dense than the network of outlets. So the distance between the outlet and the large box has been added. The loading capacity of vehicles remains the same.

Scenarios V5(…): Provision in small and medium-sized box systems

The scenarios V5(…) simulate the delivery to small and large box systems as well as the delivery to the workplace. It is presumed that regarding the possibility to have goods delivered to the workplace, the use of the car increases as the goods have to be transported home. In all four scenarios V5(…) an increased car usage of 5 per cent has been taken into account. The average distance between home and work was assumed to be 5km (cf. Schöppe, Knobel 1998, p. 18) with 3km in the urban area and 8km in the rural area. For the other logistics parameter the same assumptions as in the four scenarios V4(…) have been used.

TRAFFIC-RELATED AND ENVIRONMENTAL EFFECTS OF DIFFERENT DELIVERY CONCEPTS

For a more detailed analysis of logistics and environmental issues the relevant scenarios and their environmental impacts were evaluated for each area type. Looking at the number of kilometres per shipment we can see that within the reference area the number of kilometres is between 12.3km per shipment in the status quo scenario $V1_{SQ}$ and 1.35km per shipment in the scenario $V4_{DC-T24b}$ (direct supply of a Tower24 from a distribution centre). The situation in the rural area is similar. Here the highest values of 16.89km are generated per shipment when all customers use their own car for their shopping (scenario $V1_{SQ}$). The urban rural scenario $V4_{DC-T24b}$ results in the fewest kilometres per shipment with 1.29km. This is also true in the area, where scenario $V4_{DC-T24b}$ creates 1.43km per shipment. Here, though, the delivery scenario $V5_{DC-Sba}$, i. e. the direct delivery from a distribution centre to a shopping-box with a van, generates 7.05km and therefore the highest number of kilometres per shipment.

Over all scenarios the mileage per shipment decreased between 33 and 89 per cent in the reference area and between 41 and 92 per cent in the rural area referring to the status quo (scenario $V1_{SQ}$). For the urban area, the results are ambivalent. In scenario $V4_{DC-T24b}$, for example, the number of kilometres per shipment can be reduced to 70 per cent. At the same time, other scenarios ($V3a_{DC-CS}$, $V3b_{DC-CS}$, $V4_{DC-T24a}$, $V5_{Dc-SBa}$) lead to a noticeable increase in mileage of between 43 and 64 per cent, too.

From an ecological point of view, in the status quo scenario $V1_{QS}$ of the reference area in which customers drive to the shop themselves, all delivery concepts have to be evaluated as more ecologically favourable under the influence of the chosen input parameters. If the kilometres driven per shipment are taken as a measure, especially those scenarios are ecologically less harmful assuming a direct supply to transfer stations from distribution centre with large vehicles. CO_2 can potentially be reduced in a range between 7 per cent ($V3b_{DC-CS}$) and 57 per cent ($V4_{DC-T24b}$), compared to stationary shopping.

In the urban area the environmental saving potentials do not vary as much as in the reference area or in the rural area. Because of the short distances to the shopping locations in the urban area, many delivery scenarios have to be considered worse than the status quo scenario $V1_{SQ}$ under ecological aspects. In contrast to the rural area this occurs in those scenarios in which the goods are delivered from the distribution centre to the transfer station where the customer collects them by car. In the urban area an increase in CO_2 emissions of up to 43 per cent ($V5_{Dc-SBa}$) and a decrease of CO_2 emissions of up to 28 per cent ($V4_{DC-T24b}$) are possible, compared to stationary shopping.

The analysis for the rural area confirms these conclusions, because in this case the long trips with small vehicles make up a noticeable factor in the emissions calculation. In rural areas, delivery scenarios with large box systems seem to be the best environmental solution. Based on these simulations, CO_2 emissions in rural areas could be cut by between 18 per cent ($V5b_{Dc-SBa}$) and 64 per cent ($V4_{DC-T24b}$), compared to stationary shopping.

For the emission categories NO_x and particles, the ranking is almost identical to the main indicator CO_2. Still, this ranking shows different figures for the benzene values. In all three area types, half of the scenarios would lead to increased benzene emissions.

Comparing the emission scenarios of the three area types, it becomes clear that an approximate halving of the average distance of car trips (urban area), compared to the basic assumption of 5.5km per route, bears only minor additional ecological saving-potentials. An approximate doubling of car trip distances (rural area) leads to noticeably lower ecological saving-potentials. This result can be explained by the fact that the mileage of the vehicles is spread over all loaded shipments, but the additional individual trip potentially generated individual traffic must be assigned directly to one shipment. This is confirmed by the evaluation of the results in rural areas, where the emissions are caused mostly by the long-distance trips of small delivery vehicles.

CONSIDERATION OF THE MAXIMUM POTENTIAL OF SUBSTITUTION

Estimating the consequences of different delivery concepts does not allow conclusions concerning the change in general traffic demand. Given that for the impact estimate it was assumed that in each of the status quo scenarios $V1_{SQ}$ 100 per cent of the customers go to the stationary outlet by car, a more precise estimate of the changes in air pollution due to the different delivery concepts can be made, using the assumption that the maximum substitution potential is fulfilled.

Since a precise estimate is not possible under current conditions (especially regarding the volume of e-commerce and the changes of mobility patterns), the maximum substitution potential is estimated as an abstract concept with real data from statistics and surveys.[iii] This is done by evaluating the number of shopping events, the resulting number of shopping trips and the distances covered in different shopping locations (urban neighbourhood, city centre, greenfield), as well as the choice of transport mode (private car, public transport, bicycle, walking) and the occupation level of cars. The number of shopping events can be derived from the total number of shopping trips per year. Each shopping trip equals one shipment in this calculation.[iv]

Considering that only pure shopping trips can be substituted, which are not embedded into trip chains[v], and the trips to each different shopping location have different characteristics (level of occupancy, modal split, distance and shopping frequency at the location), the maximum substitution potential of individual motorised traffic (person km) through the use of delivery traffic is 69 per cent of the traffic volume for shopping on Saturdays (100 per cent share of e-commerce). This could be further reduce if only the food shopping trips are considered. Food sales amount to a share of around 30 per cent of total retail sales (EHI 2000, p. 82). Unlike other product ranges, food is offered in different areas: in the neighbourhood, in the city centre and in non-integrated locations.[vi] Depending on the shopping location, different distances are covered. Because of this fact, the maximum substitution potential of the individually motorised shopping traffic is reduced by delivery traffic from 69 per cent to 42 per cent (i. e. 7 per cent of shopping trips into the city centre, 24 per cent in the borough and 46 per cent in non-integrated locations) by a share of e-commerce of 100 per cent.

Assuming a substitution potential of 42 per cent in all three area types and a 100 per cent share of e-commerce, the CO_2 emissions could be reduced through delivery concepts compared to stationary shopping by 14 per cent in the urban area and by a maximum of 41 per cent in the rural area.

DISCUSSION AND SUMMARY

Over the past years various logistic solutions have been developed for the delivery of goods to the customer. They differ especially with respect to *type* and *location* of transfer points at which goods are handed over to the customer (customer-fulfilment-point). These two features determine the logistic process and the level of traffic generation with consequences for the environment. In this context, spatial structure is highly important. Depending on the type of area, reductions in mileage per shipment are possible in a range between 33 and 92 per cent; still, some scenarios in the urban area lead to an increased number of kilometres per shipment up to 70 per cent (under the assumption of 100 per cent substitution potential and 100 per cent share of e-commerce). Similar changes were calculated for air pollution.

Referring to the status quo in the reference area, the comparison of the 15 different delivery scenarios shows that there are noticeable saving-potentials regarding traffic as well as pollutants. Scenarios are most beneficial which are based on a direct supply to the transfer stations from a distribution centre with large vehicles.

In rural areas, almost all delivery scenarios offer saving-potentials compared to shopping by private car. In the urban area some delivery concepts are ecologically inferior to stationary shopping, since the route to the nearest outlet is mostly short and rarely covered by a vehicle. In all area types, we find the largest saving-potentials in scenario $V4_{DC\text{-}T24b}$ in which a large transfer station is supplied by a 7.5t truck. The most beneficial values of this scenario can be found in the rural area.

The potential for CO_2 reduction is between 7 per cent ($V3b_{DC\text{-}CS}$) and 57 per cent ($V4_{DC\text{-}T24b}$) in the reference area and between 18 per cent ($V5b_{Dc\text{-}SBa}$) and 64 per cent ($V4_{DC\text{-}T24b}$) in the rural area, compared to stationary shopping. In the urban area we find both an increase of CO_2 emissions of 43 per cent ($V5_{Dc\text{-}SBa}$) and a decrease of CO_2 of up to 28 per cent ($V4_{DC\text{-}T24b}$). These figures assume a 100 per cent substitution potential of personal car trips (mileage). However, considering that the maximum substitution potential of personal trips is actually only around 42 per cent (own calculations) around half of the delivery scenarios modelled would reduce the CO_2 emissions by more than a quarter - if e-commerce had a 100-per-cent-share of the total food sales volume.

But considering the expectation of a maximum e-commerce share of 10 per cent in the food sector in Germany on the long-run (e. g. Riehm et al. 2003, p. 27), the maximum reduction range of CO_2 emissions through delivery concepts is only between 1.4 per cent in urban areas and 4.1 per cent in rural areas.

Referring to the home delivery service (scenario V2) which is already available today and assuming a 100 per cent substitution, the reduction potential of CO_2 would amount to 9 per cent in the urban area and 31 per cent in the rural area. As only 42 per cent of all shopping journeys are made by car, the substitution of shopping journeys by delivery tours would lead to an increase of the CO_2 emissions of 8 per cent in urban areas and of 12 per cent in rural areas, referring to all shopping journeys. With a 10 per cent share of e-commerce in the food sector, the home delivery service results in an increase of CO_2 emissions in all area types.

The simulation results show that particular variables are main aspects to the logistic process chain. Those variables have to be regarded with priority. They include the different levels of the distribution system and the distance between the individual stages (producer – fulfilment centre – wholesaler – order picking warehouse – outlet – transfer point [e. g. transfer station, workplace, convenience store] – home), the choice of vehicle and their capacity utilisation, the percentage of motorised shopping trips not embedded into journeys, etc.

The results of this study show that the potential of internet-based technologies for reversing current shopping trends by „keeping the people within the city“ and „serving rural areas“ through (home) delivery and at the same time reducing environmental impacts, is limited from the supply side only. It is also necessary to consider the demand side, since shopping is more than just buying. Hence, changes in shopping behaviour, a re-organised shopping mobility due to e-commerce (e. g. when the goods are being delivered to the workplace and thus customers use their cars to get to work) or new demands for other motorised activities taken into account as well.

It is also important to address the question, who acts as a driving force in current transformations: new technologies or trade and logistics? The growing importance of logistics in the supply chain (including its „extension“ in connection to the growing importance of re-distribution), the embedding of logistic market places into vertical ones, new models for the delivery to final customer as well as the question of optimal distribution locations and storing structures may also have uncertain impacts.

Up to now, no detailed empirical research has been done to evaluate the complexity, scope and impacts of the growing distance trade, from both the companies' and the customers' point of view. Last but not least: Against the background of current forecast of further growth of shipments and traffic volume, certain transport and economy policies are required to ensure long-term quality of life in city centres.

Appendix

Reference area	32-40 tons	7,5 tons	Van	Car	km/ shipment	change	NO_x	Particle	Benzene	CO_2
V1 SQ	600 km	432 km		3696 km	5,91					
V2 F-HH	600 km	432 km	3200 km		5,29	10%	**-2,0%**	**-0,8%**	**-5,1%**	**-1,6%**
V3a F-CS	600 km	432 km	1760 km		3,49	41%	**-0,2%**	1,4%	**-2,1%**	0,8%
V3a DC-CS	600 km		5600 km		7,75	**-31%**	**-2,9%**	**-1,9%**	**-5,8%**	**-3,8%**
V3a DC-TS	600 km	720 km			1,65	72%	0,6%	2,4%	**-1,3%**	2,5%
V3b F-CS	600 km	432 km	1760 km	240 km	3,79	36%	**-0,3%**	1,1%	**-2,2%**	0,5%
V3b DC-CS	600 km		5600 km	240 km	8,05	**-36%**	**-3,0%**	-2,2%	**-5,9%**	**-4,1%**
V3b DC-TS	600 km	720 km		240 km	1,95	67%	0,5%	2,2%	**-1,4%**	2,3%
V4 F-T24	600 km	432 km	960 km		2,49	58%	0,8%	2,6%	**-0,5%**	2,1%
V4 DC-T24a	600 km		4800 km		6,75	**-14%**	**-1,9%**	**-0,7%**	**-4,2%**	**-2,5%**
V4 DC-T24b	600 km	480 km			**1,35**	**77%**	1,8%	3,8%	1,0%	**3,5%**
V4 DC-TS	600 km	576 km			1,47	75%	1,3%	3,2%	0,1%	3,1%
V5 F-SB	600 km	432 km	960 km	1200 km	3,99	32%	0,2%	1,3%	**-1,0%**	0,9%
V5 DC-SBa	600 km		4800 km	1200 km	**8,25**	**-40%**	**-2,6%**	**-2,1%**	**-4,7%**	**-3,7%**
V5 DC-SBb	600 km	480 km		1200 km	2,85	52%	1,1%	2,5%	0,5%	2,3%
V5 DC-TS	600 km	576 km		1200 km	2,97	50%	0,7%	1,9%	**-0,4%**	1,9%
Urban area	32-40 tons	7,5 tons	Van	Car	km/ shipment	change	NO_x	Particle	Benzene	CO_2
V1 SQ	600 km	432 km		1008 km	2,55					
V2 F-HH	600 km	432 km	960 km		2,49	2%	**-0,8%**	**-0,5%**	**-1,7%**	**-0,8%**
V3a F-CS	600 km	432 km	480 km		1,89	26%	**-0,1%**	0,5%	**-0,7%**	0,3%
V3a DC-CS	600 km		4320 km		6,15	**-141%**	**-3,2%**	**-4,2%**	**-4,8%**	**-6,0%**
V3a DC-TS	600 km	512 km			1,39	45%	0,2%	0,9%	**-0,4%**	0,9%
V3b F-CS	600 km	432 km	480 km	240 km	2,19	14%	**-0,2%**	0,2%	**-0,8%**	0,0%
V3b DC-CS	600 km		4320 km	240 km	6,45	**-153%**	**-3,4%**	**-4,6%**	**-4,9%**	**-6,3%**
V3b DC-TS	600 km	512 km		240 km	1,69	34%	0,0%	0,6%	**-0,5%**	0,6%
V4 F-T24	600 km	432 km	480 km		1,89	26%	**-0,1%**	0,5%	**-0,7%**	0,3%
V4 DC-T24a	600 km		4320 km		6,15	**-141%**	**-3,2%**	**-4,2%**	**-4,8%**	**-6,0%**
V4 DC-T24b	600 km	432 km			**1,29**	**49%**	0,6%	1,6%	0,4%	**1,4%**
V4 DC-TS	600 km	512 km			1,39	45%	0,2%	0,9%	**-0,4%**	0,9%
V5 F-SB	600 km	432 km	640 km	720 km	2,99	**-17%**	**-0,7%**	**-0,9%**	**-1,3%**	**-1,1%**
V5 DC-SBa	600 km		4320 km	720 km km km	**7,05**	**-176%**	**-3,7%**	**-5,3%**	**-5,1%**	**-7,0%**
V5 DC-SBb	600 km	432 km		720 km	2,19	14%	0,2%	0,4%	0,1%	0,4%
V5 DC-TS	600 km	512 km		720 km	2,29	10%	**-0,3%**	**-0,2%**	**-0,7%**	**-0,1%**
Rural area	32-40 tons	7,5 tons	Van	Car	km/ shipment	change	NO_x	Particle	Benzene	CO_2
V1 SQ	600 km	432 km		5242 km	7,84					
V2 F-HH	600 km	432 km	4000 km		6,29	20%	**-2,0%**	**-0,2%**	**-5,7%**	**-1,2%**
V3a F-CS	600 km	432 km	2496 km		4,41	44%	**-0,2%**	1,7%	**-2,9%**	0,9%

V3a DC-CS	600 km		6336 km		8,67	**-11%**	**-2,7%**	**-1,2%**	**-6,4%**	**-3,1%**
V3a DC-TS	600 km	816 km			1,77	77%	0,9%	3,1%	**-1,5%**	3,2%
V3b F-CS	600 km	432 km	2496 km	240 km	4,71	40%	**-0,4%**	1,5%	**-2,9%**	0,7%
V3b DC-CS	600 km		6336 km	240 km	8,97	**-14%**	**-2,9%**	**-1,4%**	**-6,4%**	**-3,3%**
V3b DC-TS	600 km	816 km	0 km	240 km	2,07	74%	0,8%	2,8%	**-1,6%**	3,0%
V4 F-T24	600 km	432 km	1600 km		3,29	58%	0,8%	2,8%	**-1,1%**	2,2%
V4 DC-T24a	600 km		5440 km		7,55	4%	**-1,7%**	0,0%	**-4,6%**	**-1,8%**
V4 DC-T24b	600 km	544 km			**1,43**	**82%**	2,1%	4,4%	0,9%	**4,1%**
V4 DC-TS	600 km	688 km			1,61	79%	1,5%	3,7%	-0,4%	3,6%
V5 F-SB	600 km	432 km	1600 km	1920 km	5,69	27%	**-0,2%**	1,1%	**-1,8%**	0,6%
V5 DC-SBa	600 km		5440 km	1920 km	**9,95**	**-27%**	**-2,7%**	**-1,8%**	**-5,3%**	**-3,4%**
V5 DC-SBb	600 km	544 km		1920 km	3,83	51%	1,2%	2,6%	0,2%	2,5%
V5 DC-TS	600 km	688 km		1920 km	4,01	49%	0,5%	1,9%	**-1,1%**	2,0%

Source: Assumption based on interviews and investigations as well as own calculations.
Table 1: Vehicle and shipment kilometres and emissions saving potential (with substitution of 42 per cent and E-commerce share of 10 percent)

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[i] Convenience stores include those retail stores that are located at central places with a high frequency of customers and posses long opening hours. Examples are konbinis in Japan or petrol stations in Germany.

[ii] According to interviews of truck drivers, trucks with a maximum permissible weight of 32 to 40 t are used in long-distance traffic. In the combined load trips, each truck carries 36 pallets in double layers. This results in almost 100 per cent payload efficiency. According to EHI (European Trade Institute in Germany) for large-scale distribution, vehicles normally have an average load capacity of 17,1 tons, being used to 92 per cent (of the loading space) (EHI 2001, p. 280).

[iii] For more details of calculation and data see Flämig 2002b.

[iv] In Germany, there were 25 billion shopping trips in 1998 (BMV 2000, p. 222).

[v] Thus trips whose purpose is not only shopping but during which shopping is connected to other e. g. leisure or working activities. This is the case whenever the “home – shopping location – home” chain exists.

[vi] The sensitivity calculation showed that this shift in the spatial distribution of shopping leads to an over- rather than an underestimation of the substitution potential.