GoodTrip - A New Approach for Modelling and Evaluation of Urban Goods Distribution

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Abstract

The GoodTrip model estimates goods flows, urban freight traffic and its impacts. This paper discusses the theory and application of the model, that is based on logistical chains. Liveability and accessibility of urban areas are influenced by freight traffic resulting from logistical choices in the supply chain, like warehouse location, delivery frequencies, vehicle type and routing. To support decision making it is necessary to model these choices and their effects, in current and future situations.

In GoodTrip the logistical chain links activities of consumers, supermarkets, hypermarkets, distribution centres and producers. Based on consumer demand, the GoodTrip model calculates the volume per goods type in m^3 in every zone. The goods flows in the logistical chain are determined by the spatial distribution of activities and the market shares of each activity type - consumer, supermarket, hypermarket, distribution centre, etc. This attraction constraint calculation starts with consumers and ends at the producers or at the city borders. A vehicle loading algorithm then assigns the goods flows to vehicles. A shortest route algorithm assigns all tours of each transportation mode to the corresponding infrastructure networks. This results in logistical indicators, vehicle mileage, network loads, emissions and finally energy use of urban freight distribution.

GoodTrip is a tool to evaluate different concepts of freight distribution from both a societal as economical viewpoint, by using geographical, economical and logistical data. This was done in a case study for the City of Groningen The modelling approach is innovative and the first results are promising. Model output discriminates clearly between different alternative freight distribution concepts. The modelling results comply with empirical data and real life experience.

1 Introduction

Our modern urban civilisation strongly depends on freight transport systems that facilitate the massive flow of goods to, from, and within it. However, congestion, pollution, noise and vibration caused by urban freight transport reduce the livability and accessibility of cities. Due to strong competition and increasing consumer demands companies try to reduce costs while simultaneously improving efficient consumer response. This leads to centralisation of warehouses and an increase in transport distances and frequency. However, the negative effects - noise, pollution, hindrance - of the strong growth in freight traffic are being less and less accepted by society. Paradoxically society also represents the ever more demanding consumers that cause the transport increase.

To solve this paradox new distribution systems are needed that improve logistical performance and reduce external effects at the same time. The current truck transport system is not able to meet this demand because the increased shipment frequencies and smaller shipment sizes lead to a decrease in loading factors and an increase in the number of stops per tour. This results in more vehicle kilometres.

In order to assess the environmental impacts of freight transport a small number of models has been developed over the years. They are mostly based on indicators for the amount of freight movements generated per area of floor space or per employee. These models are useful to evaluate existing goods distribution systems. However, they are unable to evaluate new concepts due to the lack of empirical data and indicators for freight movement.

This paper discusses a new method to determine the logistical performance and environmental effects of alternatives for urban goods distribution, and impacts of policy measures. Due to the huge differences in distribution structure and consumer behaviour between goods categories, the focus of the research described in this paper was narrowed down to the food retail sector and bookstores. Moreover, only the inbound goods flows in cities and the environmental effects of goods transport within cities have been examined.

This paper reviews the environmental impacts of two concepts, urban distribution centres using vans, and underground distribution via pipelines. These concepts are based on concentration of goods flows, destinations and routes by using a distribution centre just outside the city. The impacts of the new concepts are compared to the current situation.

Technical problems will not play a dominant role in the decision-making process preceding the implementation of these concepts. Indications of costs, logistical performance and environmental effects will be decisive in these long-term decisions. Therefore there is a need for a method that can determine the costs, performance and effects of new concepts for urban goods distribution. The GoodTrip model is a new approach to meet this demand.

2 The GoodTrip model

2.1 State-of-the-art in modelling urban goods transport

Before 1970 little attention was paid to modelling urban goods transport (Button, 1981). Nowadays there are some specific goods transport models, but most models are integrated into the more commonly used personal transport models. Most models can be classified in three groups.

The first group of models uses the traditional four-step approach: trip generation, trip distribution, mode choice and route choice. In these models goods transport on network links is often estimated as a percentage from the other traffic. In this kind of models there is no separate modelling of freight traffic. Therefore these models are hardly able to calculate the effect of measures or developments related to freight traffic.

The second group of models is trip-based. Freight traffic flows are estimated by using indicators for trip generation. These indicators relate to the number destinations, the gross company area (in m^2) or the number of employees. After linking the trips generated to the access roads of a city, the urban freight traffic can be estimated. Good examples of this method are the Dutch handbook for freight traffic in cities (Ministerie VROM, 1996) and the work of Schwerdtfeger (1976). Eriksson (1996) discusses an empirical modelling approach that distinguishes different industrial sectors, types of trips, types of truck operators, types of origins and destinations and variations in traffic flows over years, months and days. The French contribution to the COST 321 European working group on urban goods distribution (Dufour and Patier, 1997) consists among others a large survey of urban goods traffic in Bordeaux. The results of the survey were used to build a model that calculates freight infrastructure use (both driving and parked vehicles) and vehicle mileage. This type of models is not able to evaluate new transport systems because the trip generation indicators are derived from empirical data.

The third group of models are goods-flow based simulation models. Here the goods flows are generated based on consumption indicators (of shops or consumers). A vehicle loading model then assigns the goods flows to vehicle tours, after which the tours are assigned to the traffic network. Schwerdtfeger (1976) made a rather complicated theoretical model, estimating goods flows and traffic flows based on consumer expenditure in shops. Due to the large number of steps and parameters in this model, it needed a lot of empirical data that were not available at that time. The GoodTrip model, discussed in this paper, is also part of this group of models.

A general problem in modelling goods traffic is the lack of reliable statistics. On a national level there are often datasets of reasonable quality, estimating traffic and transport performance. This kind of data is useless for estimating of parameters and calibration of urban goods traffic models. A comparison of Dutch surveys on urban freight transport (DHV, 1999) shows huge variation in delivery frequencies of shops. This is can partly be explained by regional differences, but is mostly a result of different survey methods.

From the current state-of-the-art we can conclude that most existing models are underdeveloped and/or have extensive empirical data requirements. They are hardly able to evaluate new logistical concepts and transport systems, especially when these involve changes in the logistical chain. Therefore there is a need for a new approach: the GoodTrip model.

2.2 A conceptual framework

The model has been developed on the basis of a conceptual framework that contains the relations between the four physical components of urban goods transportation (figure 1). These are: spatial organisation of activities, goods flows, traffic flows and (multimodal) infrastructure. The components are interconnected by markets with a demand and supply side.

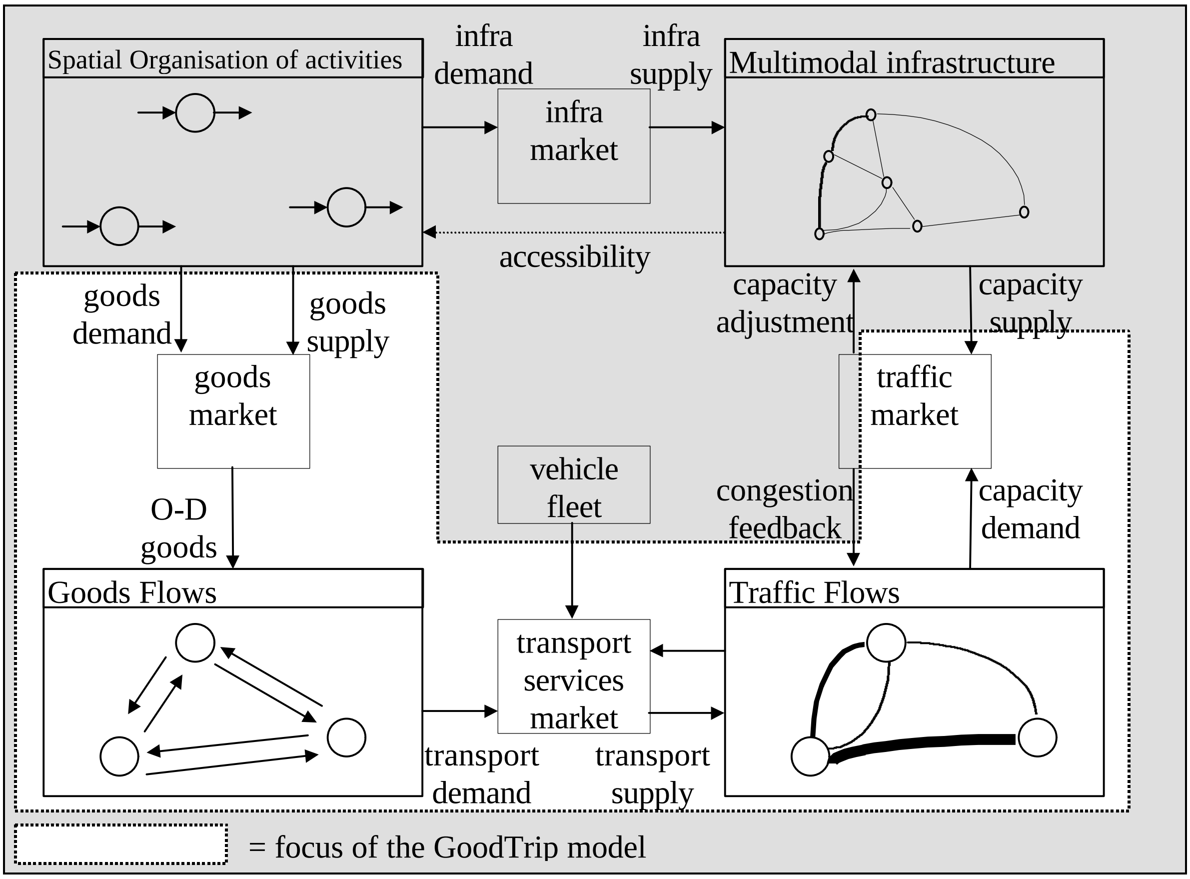

Figure 1: Conceptual framework for (urban) goods transportation

Spatial organisation describes where people live and work, where facilities are located, and where goods are produced and consumed. Spatial organisation and activity patterns result in a demand for transportation of persons and goods. Infrastructure is a basic condition to supply this demand. It consists of links and nodes, each with unique characteristics like speed and capacity.

Goods demand is derived from spatial organisation and quality of accessibility, and results in a demand for transportation. The transport market links demand and supply of transportation services. Delivery frequencies, costs, reliability and flexibility are important demand aspects, while vehicle fleet, human resources and infrastructural provisions are important supply aspects. Decisions in the transport market result in traffic flows per mode, that can be quantified as vehicle tours (round trips) per unit of time. The vehicle tours are made on the multimodal infrastructure network.

Lack of capacity can result in congestion. In turn, congestion might lead to changes in the traffic flows (e.g. route choice, departure times), and – on the long term – modification of infrastructure capacity (dynamic traffic management, more lanes, more links). The light grey area in figure 1 marks the part of the conceptual framework that is modelled by GoodTrip: starting with consumer demand, the final results are vehicle flows on infrastructure networks.

2.3 Model functionality and applicability

The decision-making process preceding the implementation of new concepts and measures for urban goods distribution requires good predictions on their effects. Indications of costs, logistical performance and environmental effects will be decisive in these long-term decisions. Therefore there is a need for a method that can determine the costs, performance and effects of new concepts for urban goods distribution. Every link in every distribution chain has very different characteristics and will therefore react differently to changes. A demand based supply chain analysis makes it possible to quantify these changes.

Future developments will change logistical efficiency and external effects of urban goods transport. GoodTrip can be used to assess the effects of the following developments:

1. changes in distribution patterns and mode choice:
    - 1a. use of other goods distribution systems, e.g. city distribution centres;
    - 1b. changes in accessibility for certain modes of transportation;
2. developments in supply chain organisation:
    - 2a. cooperation between shippers and transporters;
    - 2b. increasing possibilities to load different goods types together;
3. changes in demand patterns:
    - 3a. increasing delivery frequencies, smaller shipment sizes;
    - 3b. changes in consumer demand volumes per goods type;
    - 3c. use of other shopping locations/systems, e.g. hypermarket and teleshop;
    - 3d. changes in spatial organisation of activities, e.g. population spread;
4. environmental improvements:
    - 4a. lower fuel consumption, energy use and emissions.

2.4 Outline of the GoodTrip model

The GoodTrip model connects all aspects of urban goods distribution: economics, logistics, traffic and effects. GoodTrip is based on the structure of supply chains. Chain organisation determines parameters that influence vehicle mileage: vehicle capacity and loading factors, groupage probability, delivery frequencies and tour characteristics. The model uses one transport mode for each link in the chains.

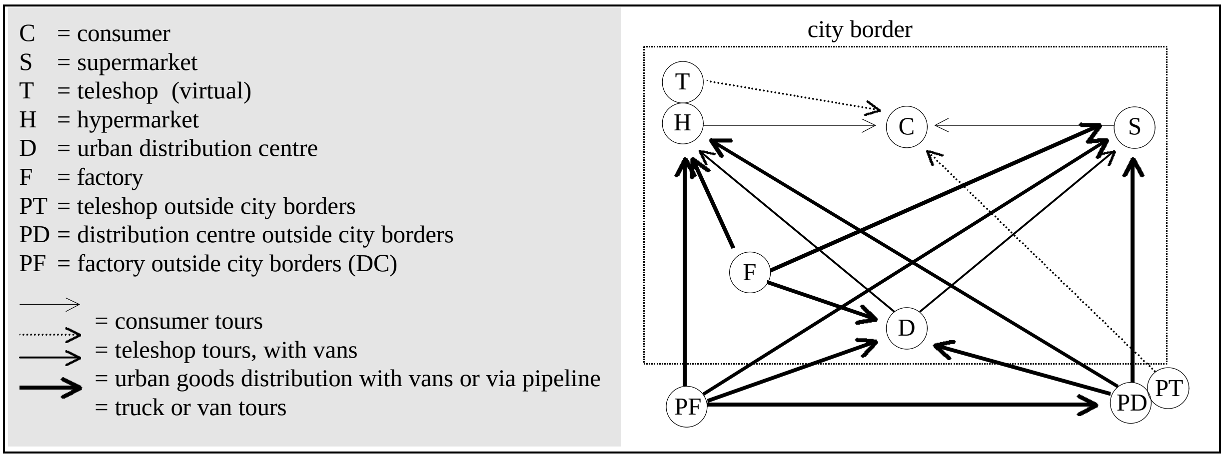

Figure 2: Example of a logistical network in the GoodTrip model

Based on consumer demand, the GoodTrip model calculates the volume per goods type in m^3 in every zone. The goods flows in the logistical chain are determined by the spatial distribution of activities and the market shares of each activity type - consumer, supermarket, hypermarket, distribution centre, etc. This goods attraction constraint calculation starts with consumers and ends at the producers or at the city borders.
Next, the goods flows of each goods type are combined by using groupage probabilities. Every combination of goods types is regarded as a different flow.

The combined goods flows are assigned to vehicle tours. The conversion is done per origin-destination pair. The origin's activity type determines the transport mode, vehicle capacity, maximum loading factor and maximum number of stops per tour. The destination's activity determines the minimal delivery frequency. The conversion results in origin destination matrices and a list of tours per mode. The model also produces indicators of tour characteristics.

The tours per mode are assigned to their infrastructure networks, resulting in network loads, per mode on each network. The network loads are then used to determine vehicle mileage per mode. Finally, the emissions and energy use per mode are calculated, based on the vehicle mileage and network loads. The modelling process is sequential; there are no feedbacks to previous phases in the process.

A logistical concept can be integrated in the model by redefining all relevant activity types in the logistical chain and the market shares of each activity type. Each zone in the model can contain several activity types. The goods flows between the activities are calculated by using the distribution channel choice probabilities between the activities, comprising of the functional choice (what kind of shop?) and the spatial choice (which shop?). Next to this the following parameters are needed: delivery frequencies, transport modes, vehicle capacities, max. loading factors and max. number of stops per delivery tour.

Due to the disaggegrate approach it is possible to validate the model for each distribution branche. This can be done by comparing the results to indicators provided by experts and by comparing with indicators derived from surveys.

3 Evaluation of urban goods distribution options

3.1 Three scenarios for urban goods distribution

GoodTrip was used to compare the logistical performance and external impacts of three types of distribution systems: the 'traditional' system, the concept of urban distribution centres with vans (UDC) and the concept of urban underground logistics systems (ULS). The latter two systems use a transhipment centre just outside the city. This section briefly describes the systems, Van Binsbergen (1999) and Boerkamps (1999) give more information on these systems and related issues.

The traditional system shows a very strong segmentation of the transport market: a large number of shippers using many different distribution channels, transporters and vehicles to deliver a large variety of goods to a wide-spread group of receivers. This segmentation leads to relatively low vehicle loading factors. To counteract this, the number of stops per tour is rather high, which results in long vehicle tours.

The concept of urban distribution centres (UDC) is based on the idea that inter-city and inner-city goods transport have a very different character. In inter-city transport large trucks are preferred, while small vehicles are more practical in the congested inner-cities. Incoming goods are consolidated and loaded into vans at a transhipment centre just outside the city. This system is used in several European cities, but often proves to be economically unfeasible due to its small market share.

The urban underground logistics system (ULS) is also based on the concept of splitting inter-city and inner-city goods transport. This concept was developed as part of a Dutch governmental programme for sustainable development (DHV/TRAIL, 1997). Goods are received just outside the city at a city logistics park (CLP). At this point there is a possibility for short-term storage. The goods are then distributed to district interchanges via a pipeline transport system, without consolidation. The concept is also well suited for reverse logistics. In the summer of 1999 feasibility studies for the implementation of this system will be completed in the cities of Utrecht, Leiden and Arnhem-Nijmegen. When the concept proves to be feasible there is a high probability that a pilot project for implementation of urban pipeline distribution will be initiated.

3.2 Model application to the city of Groningen

The alternative distribution concepts have been evaluated with GoodTrip for a case of the city of Groningen (170,000 inhabitants). In Groningen, two urban goods distribution centres of independent operators are already serving the city centre with vans. In spring 1999 the city won a national competition for its innovative approach to urban goods distribution, in which the distribution centres and general goods transport conditions are improved. An underground pipeline network was designed for evaluation purposes. It consists of three ring-lines, one city logistics park and 55 district interchanges.

Goods volumes of four goods categories and traffic volumes to all 49 supermarkets in Groningen were estimated based on average consumer shopping expenditure. This was done for three scenarios in which either traditional distribution, urban distribution centres (with vans) or underground transport were used. The model has been calibrated and validated for the food retail sector by using the case study results, data from a traditional four-step traffic model and empirical data of the traditional way of distribution. Next to analysis of the food retail sector, a quick scan was done for book stores to test the model's flexibility. Validation for other distribution channels will most likely not cause any problems. The flexible design of GoodTrip enables broader application on, for instance, a regional or even a national level.

3.3 Results

This paragraph gives an overview of the model output for the food retail sector in Groningen. This sector generates a weekly flow of about 8000 m^3 of goods. As current operations are already very efficient in the food retail sector (high vehicle loading factors and large volumes) there will be a sharp increase in the number of vehicle tours if the other systems would be used. Table 1 shows the most important distribution characteristics for each scenario.

Table 1: Characteristics of weekly goods transport in the food retail sector for each scenario

	number of vehicle tours in the city	number of stops in the city	total vehicle mileage (km)	local emissions within the *city centre*			global impacts of goods transport within *city borders*	
				SO_2 (kg)	NO_x (kg)	CO (kg)	CO_2 (kg)	Energy use (GJ)
traditional distribution (trucks)	290	990	7,590 (trucks)	0.3	3.0	1.5	8,570	116
urban distribution centres with vans (UDC)	1,660	1,920	4,760 (trucks) 17,870 (vans)	0.2	1.6	6.0	10,450	142
underground logistics system (ULS with palletsize vehicles)	4,530	4,530	4,650 (trucks) 86,310 (undergr)	0.0	0.0	0.0	7,040	93

Note that the weekly mileage (by car, bus, bike and foot) of consumers buying groceries is about 440,000 km or 98% of the total food transport in the current situation. It shows how efficient the food retail sector is operating already, and therefore it's low potential for improvement. Other distribution channels have very different characteristics, with a higher

goods transport mileage and much lower consumer mileage (due to lower shopping frequencies).
The large underground vehicle mileage is a result of the pipeline network design, assuming one-way pipelines with a length of about 18 km. For each destination the full line length has to be travelled, generating large detours. Underground vehicle mileage can be greatly decreased by building two-way pipelines and by a smarter network design.

Use of urban distribution centres with vans leads to a decrease of emissions in the city centre. Contradictionary, the emissions in the entire city increase. Underground transport eliminates all emissions inside the city centre and reduces global impacts (even despite the detours). If improvements are feasible in the currently efficient food retail distribution, there will most certainly be large improvements in most other distribution channels.

It is interesting to compare how the different elements of the distribution chain contribute to energy use within the city borders. Figure 3 shows the contribution of the different modes in each scenario for both food retail and book stores.

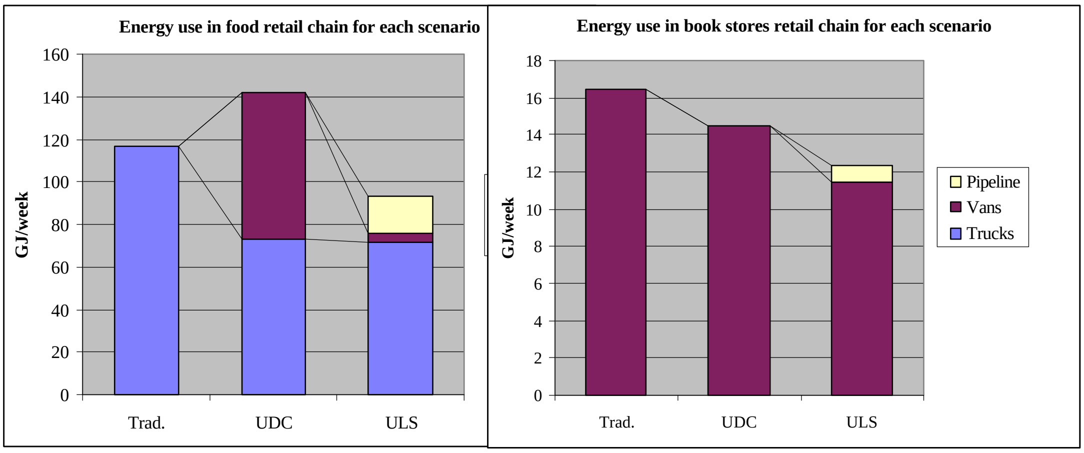

Figure 3: Weekly energy use within the city borders, per transportation mode in two distribution channels

4 Conclusions

Evaluation of the case results leads to the conclusion that pipeline distribution can generate the largest reduction of environmental impact for distribution channels with high volumes and current high efficiency - like the food sector. For this kind of channels, urban distribution centres are no good alternative as vans increase emissions. For distribution channels with low volumes and high delivery frequencies - like bookstores - both alternatives reduce the environmental impacts.

In general, urban distribution centres with vans are most suitable for small shipments. Underground distribution is suitable for any kind of shipment, except maybe for large goods that don't fit in the pipeline vehicles. It's self-evident that pipeline distribution leads to a very large reduction of the local emissions. The reduction of global emissions and energy use is smaller as expected, mostly due to the high detour factor in the pipeline network, but also due to the large share of the urban distribution centre's supply side in the emissions.

The research in this paper was focussed solely on changes of goods distribution and their effects inside the city. Future developments as described in the scenarios will also have a huge impact on intercity transport. As a matter of fact, new systems can only be successful when the total supply chain is revised, both from a logistical and an environmental point of view. As long as the distribution concepts of individual users - shippers, transporters and receivers - are not using the full potential of the new transport systems there will be no benefit to them. On the contrary, they will be faced with extra costs and decreased logistical performance. Therefore policy makers have to decide if the environmental improvements are large enough to justify financial subsidies to the new transport system in the start-up phase.

With this research the author hopes to contribute to the discussion about applicability and effects of new concepts in urban goods distribution. The GoodTrip model was developed and applied as a new instrument that enables quantification of logistical performance and effects of these improvements. It can not only be used for evaluation of large changes involving new infrastructure, but also for smaller changes like improved cooperation between transport companies or other vehicle routing strategies.

In the next years model development will continue as part of the Freight Transportation Automation and Multimodality research programme of The Netherlands TRAIL Research School for Transport, Infrastructure and Logistics.

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