

THE DEVELOPMENT OF A COMPLEX CITY LOGISTICS COST MODEL USING URBAN CONSOLIDATION CENTRES AND INNOVATIVE TECHNOLOGY

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Abstract: This article aims to describe a strategic model of the operation of the goods supply of an arbitrarily structured city, and to evaluate results from its operation. It introduces the structure of the model and elaborates its operation. The model consists of a graph as the topography, and generates the demand of various destinations e.g. shops. It then calculates the capacity necessary to fulfil the demand, and system parameters. The nodes of the graph serve as consolidation centres and relay stations for the inbound goods. The determination of the number and location of these nodes are imperative for the optimization of the transport costs. The edges of the graph consist of the road network, railway lines and waterways. The city logistics notion, that the advantages of the consolidation of the goods due the city centre outweigh the disadvantages that of, is examined. Alternative scenarios are compared using total cost functions; including transport, loading and storage costs. The decision-making of the stakeholders is supported by objective evaluation of several scenarios.

Keywords: CITY LOGISTICS, DECISION-MAKING, MODELLING, SUPPLY CHAIN, URBAN DISTRIBUTION

1. Introduction

By definition, city logistics is the technically, economically, organizationally efficient and environmentally friendly synchronization of goods distribution (and reverse logistics) tasks generated mainly by the secondary and tertiary sectors, and mostly retailers in downtown areas and historical city centres [1]. There are many best practices to be found worldwide, that have already been identified and classified. Different city logistics system solutions affect the goods distribution of a city in various ways and magnitude, thus a model is desirable that helps the decision-making of stakeholders.

Lacking city logistics projects, the problem is that the points of demand (e.g. shops) scattered throughout the city are not visited by their suppliers in a coordinated fashion. That way, they would take advantage of the common capacity, but rather they compete. Satisfying the demand takes place with presumably sub-optimal logistics-related costs, since the different suppliers transport same types of goods to the same destinations with different – redundant – infrastructure. Moreover, the attributes of the supply chains are adjusted to the regulation of the given municipality, but these urban supply chains seldom take advantage of certain possibilities (e.g. rivers, railways), and do not utilize integrated solutions, preferring road to multimodal transportation [2].

In order to assess the possibilities, a model is developed that can compare various scenarios.

2. The structure and behaviour of the model

The fundamentals of the model are: it maps an area with a graph, generates variable demand, and compares total costs.

The model is basically static in structure: the different alternatives are constituted by nodes, and the transport system between each of these nodes. The demand is stochastic: the destinations and their daily demand (quantity of goods ordered) is a random variable. The total demand has to be satisfied with an *a priori* unknown number of vehicles.

The common elements of the solutions are the location of the suppliers (LSS), the urban consolidation centres (UCC), the urban relay stations (URS), and the urban loading points (ULP). The number and location of these varies with each alternative. Further variable elements are the local and regional transport systems, with different vehicles and tracks. Accordingly, the model consists of a network, modelled as a graph (see Table 1). This structure of the model is suitable for planned city logistics systems, and cities without one, if the intermediate nodes are omitted, so they can be compared.

Table 1: Elements of a city logistics network.

Element	Abbreviation	Type	Function
Location of suppliers	LSS	Node	Source of goods
Long-distance transport paths	LDTP	Regional vehicles	Large-scale, homogeneous goods transport
Urban consolidation centres	UCC	Node	Consolidation
Main urban transport paths	MUTP	Local vehicles	Large-scale, heterogeneous goods transport
Urban relay stations	URS	Node	Fast transshipment
Feeder urban transport paths	FUTP	Last mile vehicles	Small-scale, heterogeneous goods transport
Urban loading points	ULP	Node	Sink, points of sale

The comparison of the impact of the individual alternatives is done by calculating the factors that significantly affect the supply of a city. The model concentrates on the logistics costs, which are functions of the logistics performance. Later it will be possible to include other costs as well (e.g. external costs). For the time being, transport, loading and storage costs are identified. Investment costs are excluded here, only the costs related to the continuous operation are included. These are fixed and variable costs of the operation of the infrastructure and the execution of the daily tasks. The costs in Table 2 and Equation (1) are deduced from these.

Table 2: Cost components of a city logistics network.

Element	Loading	Transport	Storage
Location of suppliers	C_h^L	--	C_h^S
Long-distance transport paths	--	C_{hi}^T	--
Urban consolidation centres	C_i^L	--	C_i^S
Main urban transport paths	--	C_{ij}^T	--
Urban relay stations	C_j^L	--	C_j^S
Feeder urban transport paths	--	C_{jk}^T	--
Urban loading points	C_k^L	--	--

$$(1) \quad C = \sum_{h=1}^A X_h (C_h^L + C_h^S) + \sum_{h=1}^A \sum_{i=1}^B X_{hi} C_{hi}^T + \sum_{i=1}^B X_i (C_i^L + C_i^S) + \sum_{i=1}^B \sum_{j=1}^C X_{ij} C_{ij}^T + \sum_{j=1}^C X_j (C_j^L +$$

$$C_j^S) + \sum_{j=1}^C \sum_{k=1}^D X_{jk} C_{jk}^T + \sum_{k=1}^D X_k C_k^L,$$

where X_α and $X_{\beta\gamma}$
 $= \begin{cases} 1, & \text{if the given node or edge is a part of the network} \\ 0, & \text{if not.} \end{cases}$

During the execution of the daily tasks, transport performances are generated on the edges of the network. Beside these, external costs of transport and other fixed and variable (function of distance travelled or number of vehicles) costs related to the maintenance of the vehicles, road pricing and environmental impact can be taken into consideration. The transport costs are calculated in €/km.

The needed performance for the execution of the tasks on the nodes can be attributed to the:

- consolidation (the picking of the goods by destinations and product categories),
- creation of unit-loads,
- loading of the vehicles,
- cross-docking,
- transshipment,
- unloading at the destinations, and
- reverse logistics.

During the calculation of the loading and storage costs, it is recommended to begin with the fixed and variable costs of these, and from the usage of the infrastructure. The loading costs are calculated in €/unit, and the storage costs in €/(unit · day).

Apart from all the above costs, indicators can be attributed to transit times, investment needs (number of vehicles, consolidation centres, relay stations etc.), inventory, reliability. Only estimates are present as to the expected results and impacts. The rationalization of the transport system suggests e.g. the reduction of the transport performance and thus the transport and external costs. However, the complex loading and storage tasks can implicate mounting loading and storage costs. This model was created so a scenario can be developed where the total costs are lesser than that of the present level at each examined city.

3. Scenarios and simulation

The following alternative scenarios were investigated:

- 1.) distribution on road, without UCCs
- 2.) distribution on road, with UCC
- 3.) distribution partially by railway, UCC
- 4.) distribution partially by barge, UCC

The first scenario displays the so-called ‘present state’, in which the distributors use their own heavy goods vehicle fleet to individually supply the demand. From the second one, the alternative scenarios include a single UCC that consolidates the inbound goods, thus improving transport costs through cooperation. The third and fourth scenarios have another trait in common: they use a second transport mode (railway and waterway, respectively) from the UCC to the centre of the target area – by train or bulk freighter. From the suppliers’ sites towards the UCC, and from the destination of the other mode to the ULPs, the goods are transported on road, but the strain on the road network is lessened.

The calculation of the total distance travelled is based on estimates, and includes no optimization. The estimation is based on the following data:

- N: the number of destinations,
- h: the average distance between the destinations and the UCC,

- The location of the destinations is an even random variable inside the service area (in this case an ellipse),
- C: the maximum number of stops a vehicle can make depending on the loading and transport times,
- A: the size of the service area,
- δ : the density of the destinations, $\delta=N/A$,
- L: the total distance travelled by the vehicles, to be calculated,
- n: the number of vehicles originally used for the goods supply of a city.

The transport-related costs in the first scenario are derived from these [3], as described in Equation (2), and in the other three scenarios [4], in Equation (3).

$$(2) \quad L = n \cdot 0.75 \cdot (C \cdot A)^{\frac{1}{2}}$$

The costs of storage and handling are calculated from the specific costs of these operations in Central-Eastern Europe, and the inventory and throughput generated during that time.

$$(3) \quad L = 2 \cdot h \cdot \frac{N}{C} + 0.57 \cdot N \cdot \delta^{-\frac{1}{2}}$$

Table 3 shows the main parameters of a simulation modelling a pilot project.

Table 3: Parameters of the simulation.

Parameter	Value	Dimension
Number of points of demand	variable	pieces
Number of suppliers	3	pieces
Variety of goods	10	kinds
Number of goods categories	3	pieces
Capacity of a vehicle	2	units
Loading cost of suppliers	1.25	EUR/unit
Storage cost of suppliers	1.25	EUR/unit/day
Transport cost	0.5	EUR/km
Loading cost of ULPs	1.5	EUR/unit
Length of time period	30	days
Shape of target area	Ellipse	(a=3 km; b=1 km)

The total distance covered can be seen in Figure 1. The road transportation becomes the least efficient one from 240 points of demand out of these four categories, if we only look at the transportation parameters.

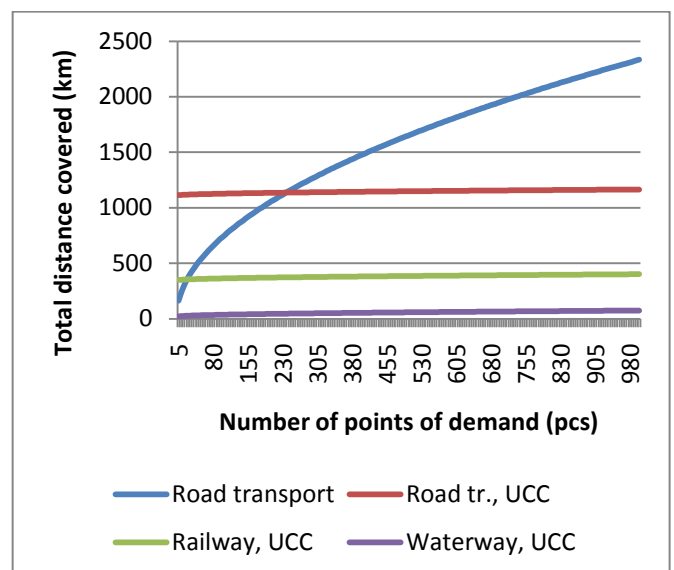


Fig. 1 Total distance covered as a function of the number of points of sale

If we look at the total costs, which can be seen in Figure 2, we can see that the additional storage- and handling-related costs increase the total costs of every UCC-based scenario, so much so that road transportation becomes the least attractive only from 945 points of demand. However, the waterway-based scenario becomes better than the original one from 345 points of demand.

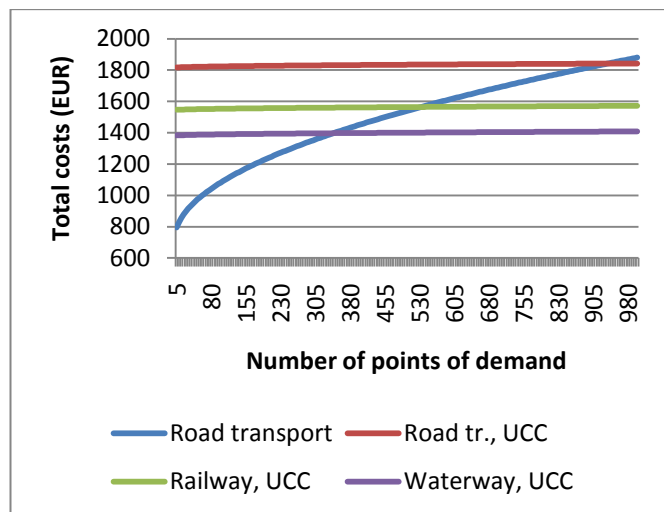


Fig. 2 Total cost as a function of the number of points of sale

Table 4 shows the simulation results, where the number of points of sale is set to slightly higher than what was previously mentioned as the dividing point. The total distance covered is evidently a smaller value in the fourth scenario, where the full demand can be hauled in one trip by barge almost to the ULPs. The total costs are diminished, too, by 25% in the fourth scenario, that is the best one in terms of total costs.

Table 4: Results of the simulation with 1000 points of demand.

Scenario	Total distance covered (km)	%	Total costs (EUR)	%
Road transportation	2333	100	1879	100
Road tr., UCC	1165	50	1842	98
Railway, UCC	402	17	1572	84
Waterway, UCC	75	3	1408	75

4. Conclusion

By varying the number of points of demand, I was able to define the dividing point where it is more efficient to use a UCC-based scenario instead of the original method. It is clear that a consolidation centre is worth using when the volume of goods is high, even more so when the investment costs are taken into account as well. It yields results if other modes are included, not just road transportation. Changing the other parameters of the model can result in more conclusions as to the efficiency interval of UCCs.

Optimization of the location and number of UCCs and URSS were excluded from this examination, but are going to be under scrutiny. With that, more savings can be achieved with these scenarios, hopefully.

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6. References

- [1] Bakos, A., in: A Modern Freight Distribution Model for Urban Areas, 2011. 09.01-03., Bratislava, Proceedings of International Conference on Innovative Technologies, pp. 726-727.
- [2] Bóna, K., A. Bakos, Sz. Foltin: Átfogó model Budapest city logisztikai fejlesztés előkészítésére – MLE Logisztikai Évkönyv 2012. pp. 36-42., Budapest, Hungary, 2011
- [3] Stein: An asymptotic probabilistic analysis of a routing problem. Math. Ops Res. 3. pp. 89-101., Harvard University, U.S.A., 1978
- [4] Robuste, Daganzo, Souleyrette: Implementing vehicle routing models. Transportation Res. B 24B. pp. 263-286., University of California, Berkeley, U.S.A., 1990