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# Exploring the impact of urbanization on consumer goods distribution networks



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Received 29 December 2019
Revised 25 January 2020
Accepted 28 January 2020


## Abstract

**Purpose** – Due to the growing percentage share of urban dwellers, the physical distribution of products faces altering conditions. This research explores the effects that urbanization has on the performance of a fast-moving consumer goods distribution network. A focus is set on changes in distribution cost, the cost-minimal network design, and greenhouse gas emissions.

**Design/methodology/approach** – The analyses are based on a quantitative distribution network model of an existing manufacturer of consumer goods.

**Findings** – The results indicate that the foreseen population shift will affect the network's economic and environmental performance. Effects are, among others, due to differences in the efficiency of supplying urban and nonurban regions. The combined effects of urbanization and the development of the population size will even more affect the network's performance.

**Originality/value** – Research dealing with distribution logistics and urbanization primarily focuses on city logistics. In this paper, the object of analysis is the entire distribution system.


**Keywords** Distribution network, Distribution logistics, Urbanization, Fast-moving consumer goods

**Paper type** Research paper

## 1. Introduction

Urbanization, which may be defined as a population shift from rural to urban areas, is a major demographic trend that applies to all regions of the world (United Nations, 2014). For distribution logistics, this trend is relevant as constantly growing city regions need to be supplied where the consumer demand is geographically concentrated. On the one side and from the suppliers' perspective, this allows focusing on fewer market areas and establishing well-adapted concepts for the handling of the single markets (e.g. dedicated transportation and warehousing concepts that allow benefiting from economies of scale). On the other side, supplying urban areas is getting challenging with worsened traffic conditions and the trend of a more frequent delivery of low-volume shipments (Bretzke, 2013; Crainic *et al.*, 2009). A great share of products shipped to city regions are fast-moving consumer goods (FMCG), which need to be fine-distributed in the destination areas and which are focused on in this research.

Research focusing on distribution logistics and ongoing urbanization is especially concerned about the fine-distribution stage, the city logistics concept, the last mile issue. The entire distribution network ranging from production sites to consumer locations is less regarded. Even if the last mile is known to represent an important leverage in distribution logistics (Edwards *et al.*, 2010), neglecting the "first mile" would leave important aspects, such as cost and greenhouse gas (GHG) cutting opportunities, obscured. Thus, the investigation of the impact of urbanization on distribution networks is a relevant topic for research and for



Journal of Asian Business and Economic Studies
Emerald Publishing Limited
2515-964X
DOI 10.1108/JABES-12-2019-0127

practice. The contribution of this research is twofold: first, it presents a methodology for estimating consequences of ongoing urbanization on the economic and environmental performance of a whole distribution network. Second, the methodology is used for the analysis of the real-world distribution network of a representative German FMCG manufacturer to explore the extent to which urbanization affects the network performance. In detail, this paper analyses how an increasing share of urban population affects the cost-minimal network configuration in terms of the number of the distribution centers and how total distribution costs and GHG emissions from distribution will develop.

For decision-makers, it is important to understand the effects of changing environmental conditions on network performance as this will help to drive management attention. Especially when (re-)designing the distribution system, it is important to consider the (future) locations of the customers and demographic shifts of demand as the design of the physical distribution system is typically a strategic, long-term decision that cannot be changed easily (Crainic and Laporte, 1997; Snyder, 2006). At least, it is important to monitor the network's performance regularly. Practitioners may transfer the presented approach to their own structures to observe if ongoing urbanization risks turning current distribution networks suboptimal in the near future and to learn if it is necessary to change the network design to align to the company's economic and environmental goals.

In this research, the focus is set on the FMCG industry because this is a large-volume industry in which the distribution stage is crucial and because, in this industry sector, logistics activities are considerably affected by urbanization. In fact, for FMCG companies, it is important that their products are well-distributed and that on-shelf-availability is high because FMCG are convenience goods, that is, consumer preferences in these products are often not rigid and brand loyalty is often not very prevalent. Furthermore, many FMCG request quality standards in distribution (cooling systems, fast deliveries), which makes distribution costly. Guaranteeing fast deliveries becomes even more challenging with increasing urbanization (unfavorable traffic situations, etc.). Moreover, FMCG typically have a high stock turnover and the market is characterized by high-volume sales resulting in a high volume of distribution activities (Ihde, 1978; Majumdar, 2004). In addition, urbanization leads to a more frequent delivery of retailer shops in urban areas as a consequence of higher rental fees. To increase the shops' productivity, the sales floor is enlarged and the storage rooms are reduced, which involves a greater number of shipments with low volumes. Finally, FMCG/groceries are distributed nationwide. This allows for a nationwide analysis of the urbanization effect. The origin of the demand for groceries is expected to reflect the geographical distribution of the population.

The paper is organized as follows: Section 2 reviews the existing literature and identifies gaps in research that this paper aims to fill. Section 3 presents the methodology. This includes a description of the case company and the data set used. Furthermore, the approach of modeling the distribution network from an economic and environmental perspective is explained, as well as the approach of modeling urbanization. Section 4 presents the results of the scenario analyses and discusses the generalizability of the findings. Section 5 recaps the results and offers directions for further research.

## 2. Literature review

Distribution networks are operated to connect a given set of factories to a given set of customers (Fleischmann, 1993). Research shows that, apart from network design decisions, internal and external conditions influence a network's performance and may affect optimized configurations (Bottani and Montanari, 2010; Boutellier and Kobler, 1998; Melo *et al.*, 2009).

Literature indicates that the cost-optimal configuration and the performance of distribution networks depend largely on demand volumes and the geographical locations of the customers.

Both elements are processed in a multitude of network optimization models. However, urbanization, which affects the future location of demand, has not been studied yet with respect to its consequences for overall distribution network performance. In fact, the starting point of many research projects considering consequences of urbanization for distribution logistics is the fact that rising urbanization is closely linked to infrastructure problems (congestion), which are at the origin of multiple negative environmental and economic impacts. Starting from that point, research analyzes urban logistics systems and proposes measures to moderate the congestion problem (e.g. Allen *et al.*, 2011; Crainic *et al.*, 2009; Dablanc, 2011; Gonzalez-Feliu *et al.*, 2014; Ljungberg and Gebresenbet, 2004; Macharis and Melo, 2011; Taniguchi *et al.*, 2001; Taniguchi and Thompson, 2004, 2014). In addition, literature proves that ongoing urbanization affects the performance of distribution systems and the way how goods will/should physically be delivered henceforth (Dablanc and Rakotonarivo, 2010; Gonzalez-Feliu *et al.*, 2012; Gonzalez-Feliu *et al.*, 2014; McDermott and Robeson, 1974). However, this research primarily focuses on city logistics, that is, the last mile issue and the way how goods are/should be distributed in urban areas. Until now, no contribution takes the manufacturer perspective to observe the whole distribution network to study the effects of urbanization on the cost-minimal number of distribution centers and on the economic and environmental network performance. This paper contributes to close that gap.

Existing research on distribution network sensitivities helps to build hypothesis concerning the potential effects of urbanization on network performance. Kellner *et al.* (2013), for instance, prove that the cost-minimal distribution network design is sensitive to changes in shipment sizes and delivery frequencies. As the demand for low-volume but high-frequent deliveries opposed to high-volume but low-frequent shipments differs between urban and rural areas, it may be hypothesized that growing urbanization changes the total number of shipments and average shipment sizes, thereby transportation costs, overall distribution costs, and eventually network design. Lalwani *et al.* (2006) studied the impact of transport and inventory costs, delivery frequency, and demand volume on the distribution network structure in the automotive aftermarket industry. They confirm the crucial role of shipment sizes as they find that the optimum network design is most at risk due to the uncertainties associated with stock holding costs and delivery frequencies. Considering these findings, it may be hypothesized that a changed share of urban population will affect shipment structure in terms of the geographical locations of the customers, the number of shipments, and the shipment sizes. The altered shipment structure affects transportation cost, itself affecting the overall cost, the cost-optimal network design, and the GHG performance.

Concerning the environmental performance of distribution networks, Gross *et al.* (2012), Harris *et al.* (2011), Kellner and Igl (2012), Kohn and Brodin (2008), McKinnon and Allan (1994), Rizet *et al.* (2010), and Treitl and Werner (2014) investigated the effect of different network design parameters on GHG emissions from distribution. These articles prove that a changing shipment structure (number of shipments, average shipment sizes, vehicle utilization ratios) and a modified network design (number and locations of the warehouses/depots) affect GHG emissions in distribution systems. Urbanization affects both shipment structure and the network design. The effect of urbanization on GHG emissions through a changed network configuration is as follows: rising urbanization changes shipment structure, itself changing transportation costs; higher/lower transportation costs will eventually change the cost-minimal network design, itself affecting GHG emissions from distribution.

## 3. Methodology

This research explores effects of urbanization on distribution network performance by means of a real-world example case. This approach is in line with prior research studying sensitivities of logistic networks (cf. Harris *et al.*, 2011; Lalwani *et al.*, 2006). The example case represents an existing German FMCG manufacturer. Concerning the generalizability of the findings, the results are expected to be informative about the experiences of the "average firm" as the focal company is a typical German FMCG producer in terms of its cost structure, shipment data, network design, flow of materials, and product portfolio. To be precise, the company produces and distributes large volumes of food and kindred products in two temperature zones. Products are delivered palletized. Trucks are used to move the final products. The manufacturer does not possess any trucks but has outsourced logistics activities to logistics service providers. The German landscape concerning FMCG food distribution is well represented as the analyzed shipment data encompasses a great share of the German customer/retailer destinations (retail distribution centers and retail outlets).

The proposed distribution network model is based on the real-world data of the focal firm and reproduces the distribution network (structure and material flows) from the economic and environmental perspective. It is used to observe how variations of demand in rural and urban regions affect a) the cost-minimal network configuration in terms of the number of manufacturer distribution centers (MDC), b) total distribution costs, and c) the total amount of GHG generated for the totality of transportation activities between the manufacturer's factories and its customers. Four scenarios plus the baseline situation are studied where the scenarios are specified by the percentage share of the focal firm's distributed tonnage that is destined to supply urban and rural areas. A growth/reduction in population size in the single area types will change the demanded and delivered tonnages.

### *3.1 Setting and data*

*3.1.1 Case company and dataset.* The focal company is a major German food manufacturer (annual revenue: $1.5*10^9$ Euro) producing around 0.5 million tons of FMCG per year in six factories located in Germany. All finished products are moved from the plants to one MDC (production flows) and onward to the food/FMCG retailers, mainly supermarket chains (distribution flows). The more than 2,000 customer/retailer locations are represented by five-digit postal code areas. 10 percent of the customers are retailer distribution centers (RDC) and 90 percent are retail outlets.

The dataset used for this study is provided by the focal company and contains information on the company's distribution activities of one calendar year. It encompasses master data about all stock keeping units, inventory data, handling cost rates, and information about all shipments moved during the observed period. The shipment dataset contains details about 170,000 shipments, including information about the delivery days, customer names and locations, shipment sizes (weight, number of loading devices), cost information, and more. During the observed year, approximately 30,000 shipments with an average shipment size of 17 tons supplied the MDC out from the six factories and nearly 145,000 shipments with an average shipment size of 3.3 tons moved goods from the MDC to the retailers. Logistics service providers are engaged to carry out all distribution-related activities. Around 60 percent of all distribution costs are for transportation, 10 percent for the capital commitment for the finished goods in the MDC, and 30 percent for handling activities in the warehouse. Figure 1 shows the flow of goods in the distribution network.

*3.1.2 Urbanization in Germany.* According to the United Nations' "World urbanization prospects," the German population residing in urban areas totals 62.1 million people in 2014 and 20.6 million are living in rural areas, corresponding to an urban share of 75.1 percent. This share is expected to continue growing to reach 83 percent in 2050, but the total population living in urban areas is estimated to remain stable. This is a result of an expected population decrease: 72.6 million people are projected for 2050 (United Nations, 2014).

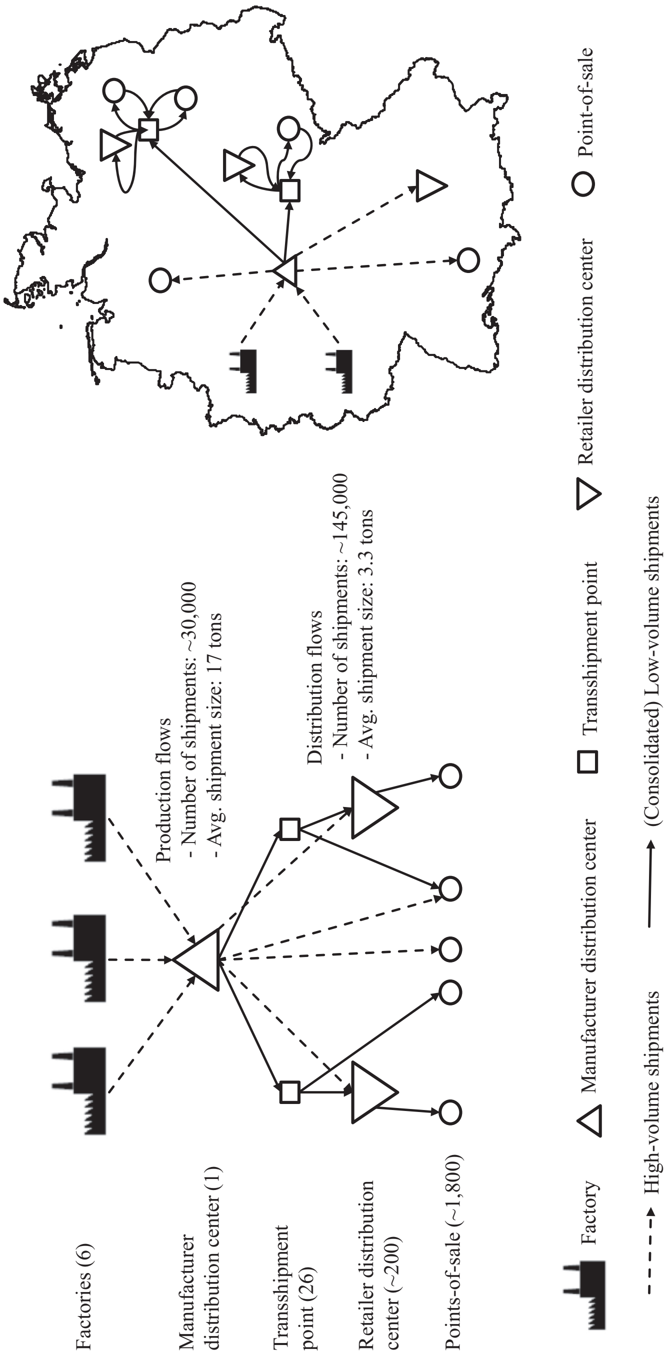



**Figure 1.**
Distribution network of the focal company

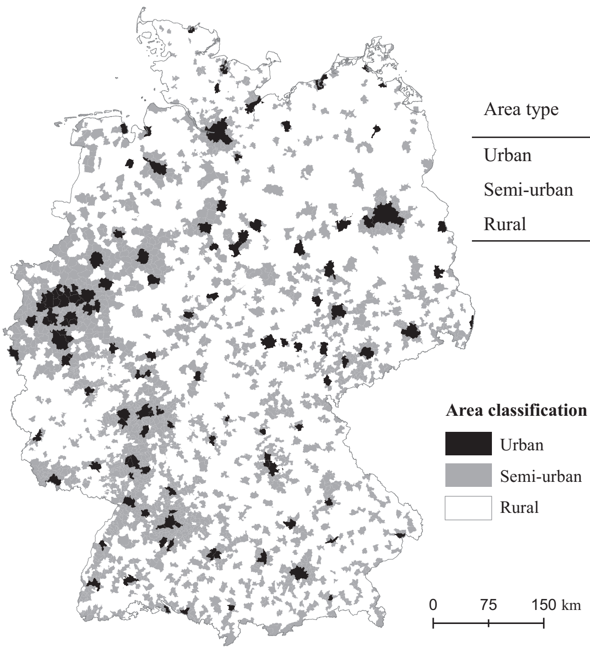
*3.2 Modeling urbanization*

First, only the effect of a *shift of demand* from rural toward urban regions is reproduced. The effect of an overall *reduction of demand* as a consequence of a population decrease will be demonstrated in a subsequent step. The first analyses are to expose the urbanization effect as a shift of population and the reduction of the total demand is not modeled to prevent from overlaying effects.

*3.2.1 Modeling the status quo.* First, a shipment profile is established for each customer location to indicate the number of shipments, the total delivered tonnages, and the average shipment sizes within the period of observation for three shipment classes: FTL (Full-Truck-Load) shipments with a tonnage per shipment above 11, LTL (Less-than-Truck-Load) shipments with a tonnage per shipment between 2 and 11, and Groupage (GRP) shipments with a tonnage below two. Differentiating between three shipment classes per costumer allows for accurate retailer profiles. Moreover, it is necessary to distinguish between theses shipment classes as different transport tariffs, consolidation strategies, and routings apply to the shipments as a function of shipment size (see further).

Next, the five-digit zip code areas are classified each into one of three urbanization classes as proposed by EUROSTAT (2011). This approach is used as it is a European-wide accepted methodology to distinguish three types of areas: urban (densely populated), semiurban (intermediate populated), and rural (thinly populated) areas. According to that approach, local administrative units (LAU) are classified taking into account population density and total population. Applying this methodology leads to the map shown in Figure 2 and to a share of the German population living in urban areas of 35.3 percent, in semiurban areas of 41.6 percent, and 23.2 percent for rural regions in 2013.

In the observed period, 42.6 percent of the total distributed tonnage was destined for retailer outlets lying in urban areas, 39.4 percent for retailers in semiurban areas, and 18.0 percent for outlets situated in rural regions. To calculate these shares, first, deliveries




| Area type | % of population | % of distributed tonnage |
|---|---|---|
| Urban | 35.3 | 42.6 |
| Semi-urban | 41.6 | 39.4 |
| Rural | 23.2 | 18.0 |

**Figure 2.**
Area classification for Germany in 2013 according to the approach of EUROSTAT (2011)

destined to supply retailer outlets and deliveries supplying RDC are separated (cf. Figure 1). Shipments that serve directly the retailer outlets correspond to the demand of the zip code area where the outlet is situated. RDC are supplied by the MDC to forward the finished products to the point-of-sale. Since the dataset used does not reveal which RDC supply which outlets, it is assumed that each RDC serves all zip code areas within a radius of 100 kilometers. The total tonnage that is moved from the MDC to the single RDC is split up as a function of the total number of inhabitants residing in urban, semiurban, and rural regions within the radius of 100 kilometers.

*3.2.2 Modeling the future development.* The demand of the single zip code regions (for customer-specific FTL, LTL, and GRP shipments) will rise/decrease as a function of the area type when more people are living in urban areas. As for the scenarios, the share of tonnages that are destined for urban, semiurban, and rural areas is varied gradually to reflect an in-/decrease of demand and population size in the corresponding area types. The demand of the customers of the original situation serves as basis for all manipulations. Demand/population growth is modeled proportional to the demand of the initial situation, that is, bigger customers will demand even more/less in the altered situation, but the relative growth of demand is for customers of a certain area type identical. Thus, the total delivered tonnage is not changed but "shifted" between the LAU as a function of the supposed degree of urbanization and the shipment profiles of the customers. The shipment profiles of the single customers in terms of the repartition of demand for high- and low-volume shipments as well as for the average shipment sizes in these shipment classes are not modified. This approach is chosen as there are various other factors and trends that determine the ordering behavior of the retailers and modeling a changed ordering behavior that is solely due to urbanization on a single retailer's basis is speculative. Differences in the ordering behavior between urban, semiurban, and rural areas are captured as the projected shipments are oriented on the shipment profiles of the initial situation. Thus, the demand of urban, semiurban, and rural areas for low-volume but high-frequent deliveries opposed to high-volume but low-frequent shipments is respected implicitly.

*3.2.3 Defining five scenarios.* Table I presents the five scenarios studied and the resulting shipment structure. Scenario 1 is the baseline scenario with the company's actual data and the real geographical population dispersion for Germany. Scenarios 1–5 assume a rising share of urban population starting from 75 percent (urban share for Germany in 2014) up to 83 percent (forecasted urban share for Germany in 2050 (United Nations, 2014)).

According to the approach of EUROSTAT (2011), 82 percent of the total distributed tonnage was destined for urban and semiurban LAU (see above). To simulate an increasing degree of urbanization, this percentage ("modelled urban share" in column 3) is incremented proportionally, assuming that both the urban and semiurban LAU will see an increase in population, whereas only the rural regions are faced with migration (columns 4–6). This corresponds to the predictions concerning the demographic development in Germany (BBSR, 2012, 2013; Kröhnert *et al.*, 2011).

### *3.3 Modeling the distribution network*

*3.3.1 Economic perspective.* Total distribution costs consist of the costs for transportation, inventory holding, and handling activities in the MDC.

As for transportation, more than 20 logistics service providers are engaged by the focal company to move goods from the plants to the MDC and onward to the RDC or outlets. Differentiating between four transportation flows and using regression analysis to estimate cost functions resulted in an acceptable model fit. The four transport cost functions indicate the estimated cost per shipment in Euro. They have been estimated using regression analysis based on the more than 170,000 shipments recorded. Each cost function has a $R^2$ value above 0.83. The relevant flows are:

| Scenario | Urban share in % of population | Modeled urban share [%] | Urban [%] | Semi-urban [%] | Rural [%] | Avg. shipment size MDC outbound [tons per shipment] | Number of MDC outbound shipments [thousands] | DSD share [%] (tonnage; number of shipments) | |
|---|---|---|---|---|---|---|---|---|---|
| Scenario 1 (orig. situation) | 75 | *82.0* | *42.6* | *39.4* | *18.0* | 3.3 | 145.0 | 35 | 73 |
| Scenario 2 | 77 | *84.1* | *43.7* | *40.4* | *15.9* | 3.2 | 147.6 | 35 | 74 |
| Scenario 3 | 79 | *86.3* | *44.8* | *41.5* | *13.7* | 3.2 | 148.3 | 35 | 74 |
| Scenario 4 | 81 | *88.4* | *45.9* | *42.5* | *11.6* | 3.2 | 148.9 | 36 | 74 |
| Scenario 5 | 83 | *90.6* | *47.1* | *43.5* | *9.4* | 3.2 | 149.7 | 36 | 74 |

**Table I.**
Set of scenarios

(1) *Production flows.* These are high-volume shipments with an average tonnage of 17. Costs per shipment depend mainly on distance. The cost per shipment $C_{fj}^{PF}$ (in Euro) between factory $f$ and MDC $j$ is estimated as a function of distance between the two locations, measured in kilometers.

$$C_{fj}^{\mathrm{PF}} = 87 + 1.13 \times \mathrm{distance}_{fj} \quad \forall f \in \mathrm{factories},\ j \in \mathrm{MDC} \tag{1}$$

(2) *Distribution flows FTL.* These shipments move goods from the MDC to the retailer locations and have a tonnage above 11. Costs are primarily driven by distance. The cost per FTL distribution shipment ($C_{ji}^{\mathrm{FTL}}$) in Euro is estimated as a function of distance between MDC $j$ and customer $i$.

$$C_{ji}^{\mathrm{FTL}} = 153 + 0.85 \times \mathrm{distance}_{ji} \quad \forall j \in \mathrm{MDC},\ i \in \mathrm{customers} \tag{2}$$

(3) Costs for *distribution flows LTL* ($C_{ji}^{\mathrm{LTL}}$), that is, MDC-outbound shipments with a tonnage between 2 and 11, are modeled as a function of the distance between MDC $j$ and customer $i$ and the tonnage load of shipment $s$ ($\mathrm{to}_s$).

$$C_{ji}^{\mathrm{LTL}} = 2.86 \times \mathrm{distance}_{ji}^{0.34} \times \mathrm{to}_s^{0.34} \quad \forall j \in \mathrm{MDC},\quad i \in \mathrm{customers},\quad s \in \mathrm{shipments} \tag{3}$$

(4) Costs for *distribution flows GRP* (tonnage below 2, $C_{ji}^{\mathrm{GRP}}$) are modeled similarly but with different coefficients.

$$C_{ji}^{\mathrm{GRP}} = 3.21 \times \mathrm{distance}_{ji}^{0.24} \times \mathrm{to}_s^{0.71} \quad \forall j \in \mathrm{MDC},\quad i \in \mathrm{customers},\quad s \in \mathrm{shipments} \tag{4}$$

The inventory holding costs are derived from the overall stock held, which is made up of cycle and inventory stocks, valued by the costs of goods. Cycle and safety stocks are calculated as a function of demand per product ($demand_{pj}$: demand for product $p$ in MDC $j$; $\sigma_{pj}$: standard deviation of demand of product $p$ in MDC $j$), the value of goods ($c_p$: stock holding costs for product $p$), ordering cycles according to the Economic Order Quantities model depending on fixed costs per order ($F$), replenishment cycle times (RCT), and service level targets ($k$):

$$\text{Cycle stock}_{pj} = \left(2 \times F \times \mathrm{demand}_{pj}/c_p\right)^{1/2} \Big/ 2 \quad \forall p \in \mathrm{products},\ j \in \mathrm{MDC} \tag{5}$$

$$\text{Safety stock}_{pj} = \mathrm{k} \times \sigma_{pj} \times (\mathrm{RCT})^{1/2} \quad \forall p \in \mathrm{products},\ j \in \mathrm{MDC} \tag{6}$$

Following the case company's practice, handling costs in MDC $j$ $C_j^H$ are calculated on a pallet basis. Different cost rates $c_h$ are applied for handling in and out and for storage activities for the pallets throughput $NbPal_j$ in MDC $j$.

$$C_j^H = \sum\nolimits_h (c_h \times \mathrm{NbPal}_j) \quad \forall j \in \mathrm{MDC} \tag{7}$$

The presented approach of modeling the distribution network achieves a high fit between actual and modeled costs (Table II).

*3.3.2 Cost-minimal network configuration.* Increasing urbanization will affect the cost-optimal network configuration as it changes demand volumes at the specific locations, shipment structure, and thus transportation costs.

A $p$-median model is used to identify the transport cost-minimal network configuration. The goal is to find the $p$ MDC – where $p$ captures the number of MDC – that minimize the overall transportation costs by allocating the customers to the MDC. This approach allows comparing the performance of different MDC strategies with regard to their relative cost advantage in different scenarios. Furthermore, it reflects the case company's current and former practice of distributing its products: customers are served by exactly one MDC. In addition, warehouse capacity restrictions are negligible as sufficient capacities are assumed for the preselected sites. Eqns 8–11 represent the $p$-median model.

Objective

$$\min \sum_{ij} (x_{ij} \times c_{ij}) \tag{8}$$

Constraints

$$\sum_j x_{ij} = 1 \qquad \forall i \in \text{customers} \tag{9}$$

$$\sum_j y_j = p \tag{10}$$

$$x_{ij} \leq y_j \qquad \forall i \in \text{customers},\ j \in \text{MDC} \tag{11}$$

$$x_{ij} \quad \text{equals 1 if customer } i \text{ is allolcated to MDC } j,\ 0 \text{ otherwise}$$

$$y_j \quad \text{equals 1 if a warehouse is installed on site } j,\ 0 \text{ otherwise}$$

The model minimizes the MDC-customer allocation costs (Eqn 8), where $c_{ij}$ captures the total transportation costs that arise when supplying customer $i$ from MDC $j$. The potential MDC sites are the 412 German administrative districts. Eqn 9 guarantees that each customer is served by exactly one MDC. Eqn 10 fixes the number of opened MDC to a predefined value. Concerning service levels, it is supposed that even for a 1-MDC configuration, the replenishment cycle time as requested by the retailers (72 hours) is met. Eqn 11 ensures that customers are only served by sites where an MDC is installed. To find the optimal number of MDC, the parameter $p$ is gradually incremented and the sums of the transportation costs, the inventory holding costs, and the handling costs are compared.

Inventory holding costs are difficult to integrate into such a model (cf. Fleischmann, 1993) and proved to have a minor effect on the optimal network design: total stocks vary slightly depending on which customers are supplied together from one and the same MDC, as a separate simulation study showed. For given numbers of MDC and different, arbitrary customer-MDC allocations, the total inventory holding costs vary at a low level as shown in Table III. Because of the low influence of customer-MDC allocation on total inventory holding costs and the minor importance of inventory holding costs in overall distribution costs (about

**Table II.**
Economic perspective: model fit

| Cost component | Cost estimation (percentage of real-world costs) |
|---|---|
| Transportation costs | 99.3% |
| Inventory holding costs | 99.7% |
| Handling costs | 102.1% |
| Total distribution costs | 99.9% |

10 percent of total costs), inventory holding costs are not integrated into the optimization model but derived from the transport cost-optimal solution found. It is assumed that the deviation of the solution that is based on transportation costs from the overall optimal solution is marginal.

To calculate the inventory holding and handling costs associated with a certain network design, the total demand and the standard deviation of demand per product in the single MDC regions are aggregated. Thus, cycle and safety stock levels are derived as well as the pallet throughput per MDC and product.

As the focal company has outsourced all distributions activities to logistics service providers, it does not possess any logistics assets, such as trucks and warehouses. Therefore, there are no additional fixed facility costs for estates, buildings, or technical equipment with an increasing number of facilities. Handling costs are charged by the logistics service providers on a pallet basis and not per provided MDC. However, the cost rates $c_h$ per pallet and the overhead costs are normally higher with an increasing number of MDC, among others, due to economies of scale (Chopra and Meindl, 2014). The model follows the focal company's experience and calculates with the costs of one man-year per MDC and year for overhead/administration and an increase of the pallet-based handling cost rates ($c_h$ in Eqn 7) of 10 percent per MDC.

*3.3.3 Environmental perspective.* The GHG boundary covers all transportation flows from the manufacturer's plants to the retailers' locations. As the manufacturer is not hold responsible for the GHG emissions from supplying the outlets out from the RDC and for the consumers' shopping trips, these emissions are not added to the GHG assessment. Emissions from operations in the warehouse(s) are excluded from the analysis for two reasons: first, research showed that the volume of GHG resulting from these activities is complex to quantify and less important in distribution networks compared to emissions caused by transportation (Edwards *et al.*, 2011; Rizet *et al.*, 2010). Second, results indicate that even in scenarios with high shares of demand originating from urban areas, the number of MDC remains constant (see further). Thus, the effect of urbanization on GHG emissions is supposed to be by far due to altered physical transportation flows. Three transportation processes are distinguished (Figure 3):

(1) *Production flows.* These are FTL shipments with an average tonnage of 17. Goods are transported directly from the plants to the MDC without being transshipped (direct shipments). For each shipment/vehicle, an approach of 40 kilometers is necessary to reach the plants.

(2) *Distribution shipments FTL*, that is, shipments supplying the retailers and that have a tonnage above 11 are moved directly from the MDC to the RDC/outlet with no transshipment in between.

(3) *Distribution shipments LTL* (tonnage below 11) are consolidated at the MDC and forwarded as consolidated shipments via transshipment points (main leg). The transshipment points correspond to the 26 transshipment point locations offered by a

| 40 simulation runs with arbitrary customer MDC-allocations... | Coefficient of variation of total inventory holding costs | Maximum deviation from average total inventory holding costs |
|---|---|---|
| ... for 2 MDC | 0.7% | 1.3% |
| ... for 3 MDC | 0.7% | 1.5% |
| ... for 4 MDC | 1.2% | 1.5% |

**Table III.** Variation of inventory holding costs for different customer-MDC allocations major German logistics service provider specialized in the FMCG segment. Distribution shipments LTL are always transported to the transshipment point that is nearest to the customer destination. Then, the goods are forwarded in delivery tours (round trips) to the retailers (Figure 1).

The methodology used corresponds to the methodology proposed by Kellner and Igl (2012), where it is explained more in detail.

For the production flows, the distribution shipments FTL, and for the main leg shipments, heavy goods vehicles (HGV) with a maximum payload of 25 tons are used; for the delivery trips, HGV with a maximum payload of 17 tons.

The volume of GHG caused by the transportation operations ($GHG_{TO}$) is approximated according to the road freight emission modeling approach unanimously recommended by Agence de l'environnement et de la maîtrise de l'énergie (2010), Department for Environment, Food and Rural Affairs (2012a, b), and Institut für Energie- und Umweltforschung Heidelberg GmbH (2011):

$$GHG_{TO} = EF \times \left( EC_{vu} + (EC_{vc} - EC_{vu}) \times \frac{\text{VehicleLoad}}{\text{Cap}_v} \right) \Big/ 100\,\text{km} \times \text{distance} \qquad (12)$$

$GHG_{TO}$ are estimated by multiplying an energy conversion factor EF, which converts a certain amount of combusted fuel into GHG emissions, and the total fuel consumption of the transportation process. The fuel consumption is approximated resorting to vehicle $v$'s specific average consumption patterns (fuel consumption when unloaded $EC_{vu}$ in liters fuel per 100 km, and $EC_{vc}$ when completely loaded), to the weight-based vehicle capacity utilization (*VehicleLoad* / $\text{Cap}_v$) of vehicle $v$, and to distance traveled. For the constants EF, $EC_{vu}$, $EC_{vc}$, and $\text{Cap}_v$ values recommended by DEFRA (2012a, 2012b) and Institut für Energie- und Umweltforschung Heidelberg GmbH (2011) are used. Vehicle load and distances are determined individually for each shipment taking into account the different transport processes.

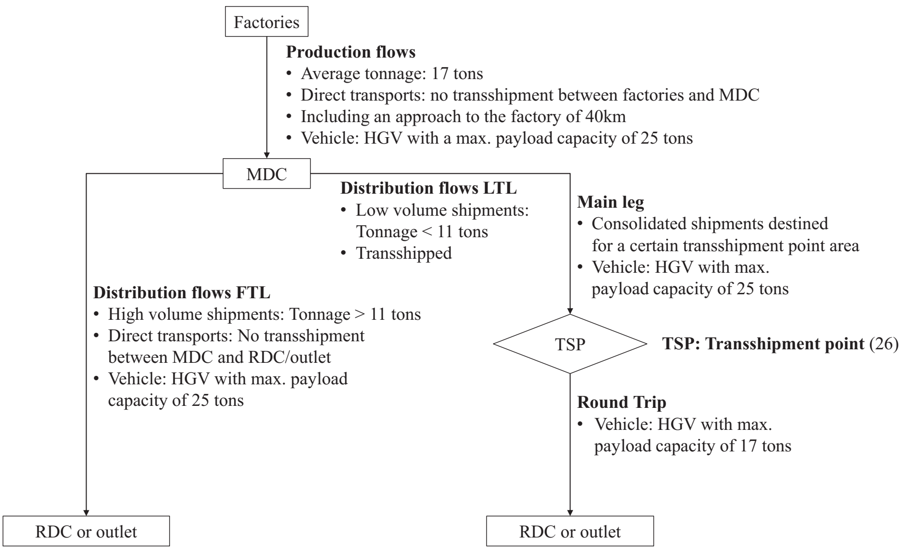



**Figure 3.**
GHG analysis: transportation flows. Model adopted from Kellner and Igl (2012)

## 4. Results

As for the example case, the cost-minimal 1-/2-/3-/4- and 5-MDC configurations are determined and the corresponding costs and GHG are recorded for the five scenarios and the five network configurations.

Concerning the baseline scenario, the model affirms the cost-optimality of the 1-MDC strategy. Table IV gives an overview of the principal findings.

### *4.1 Cost-minimal network configuration*

Using the methodology presented earlier and basing the results on the dataset provided, the analysis suggests that it is for the focal firm in each scenario cost-minimal to opt for the 1-MDC configuration. The 1-MDC configuration remains optimal as the transport cost reductions that come when installing additional MDC are in no scenario important enough to compensate the additional costs of inventory holding and handling when decentralizing the distribution network. Interestingly, the cost differences between the cost-optimal 1-MDC and 2-MDC configurations slightly decrease with a rising degree of urbanization turning the 2-MDC configuration more attractive in the future (cf. Table IV). The same is for the other MDC configurations: the cost advantage of the 1-MDC configuration compared to the other configurations decreases with rising urbanization. This may be explained by the fact that the transportation costs rise in the 1-/2-/3-/4- and 5-MDC configurations on average by 1.25 percent from scenario 1 to 5. Thus, with rising transportation costs, a multi-MDC configuration becomes more attractive as it allows to reduce total travelled distance in the MDC-outbound transport (Chopra and Meindl, 2014). Furthermore, the decreasing cost advantage of the 1-MDC configuration may be explained by the observation that the share of transportation costs in total distribution costs rises in the 1-/2-/3-/4- and 5-MDC configurations on average by 0.5 percent from scenario 1 to 5.

As the focal company's 1-MDC configuration is (from an urbanization perspective) likely to persist on the long run, the further explanations refer only to the cost-minimal 1-MDC networks observed for the five scenarios.

### *4.2 Distribution costs*

In the example case, overall distribution costs rise as transportation costs are estimated to increase with a higher degree of urbanization. Inventory holding and handling costs are slightly affected. The foreseen long-run increase of the share of urban population by 8 percentage points leads to a plus in transportation costs of about 1.4 percent and to a plus of 0.9 percent in total distribution costs. Two main reasons explain that finding: the assumed/

| | Cost-minimal network config. (number of MDC) | | Distribution costs (1-MDC config.): development when compared to scen. 1 | | | | GHG emissions (1-MDC config.): development when compared to scen. 1 |
|---|---|---|---|---|---|---|---|
| Scen. | 1st best solution | 2nd best solution (cost increase) | Transp. costs | Inv. holding costs | Handl. Costs | Total costs | Total GHG emissions [tons $CO_2$] |
| 1 | 1 | 2 (+3.1%) | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| 2 | 1 | 2 (+3.0%) | +1.0% | −0.0% | −0.0% | +0.7% | +0.3% |
| 3 | 1 | 2 (+3.0%) | +1.2% | −0.0% | −0.0% | +0.8% | +0.2% |
| 4 | 1 | 2 (+2.9%) | +1.3% | −0.0% | −0.1% | +0.8% | +0.1% |
| 5 | 1 | 2 (+2.9%) | +1.4% | −0.0% | −0.1% | +0.9% | −0.1% |

**Table IV.**
Summary of results

modeled development of population in urban, semiurban, and rural areas and the cost efficiency of supplying these regions. Table V presents performance indicators of the company's shipment data that show that there is unexpectedly little difference in the efficiency of supplying urban and rural areas in terms of the average transportation costs per shipped tonnage. However, supplying semiurban regions is done considerably less efficiently. Shipments that supply urban areas cover on average less distance than shipments destined for semiurban or rural LAU (Table V, Figure 4a). Yet, whereas shipments that supply rural areas compensate that cost-relevant disadvantage with a more efficient shipment structure in terms of tonnage per shipment and the tonnage split of FTL, LTL, and GRP shipments, shipments supplying semiurban LAU also show a less favorable shipment structure. The fact that supplying urban and rural areas is done almost equally efficiently explains why a plus of population in the one region may, from a total cost point of view, largely be compensated by a minus of the same number of population in the other region. Assuming that the population in semiurban regions will increase its share in total population explains why distribution costs are expected to increase as the tonnage volume that is least efficiently delivered will increase. Figure 4b illustrates that semiurban shipments are overrepresented in the classes of the costly low-tonnage shipments (0–2 tons)[1]. If only urban areas would see a population increase and the share of the semiurban population would remain stable or diminish, the cost situation of the company would become more favorable, given that the three area types are supplied with shipments that have the same characteristics as those of the example dataset. If the share of the semiurban shipments would decrease, overall transportation costs will decrease and the optimal network design will even more tend to a 1-MDC solution. Note that the reasons for the differences in shipment structures are various, including the ordering behavior of the customers, the manufacturer's strategy of handling the market, and more. It is an interesting track for future research to find out if the shipment profiles for the different area types differ for other companies in the same way and, if so, why.

| Performance indicator | Urban area | | | Semiurban area | | | Rural area | | |
|---|---|---|---|---|---|---|---|---|---|
| Average (median) distance per MDC-outbound shipment[a] | 320 km (318 km) | | | 360 km (360 km) | | | 340 km (330 km) | | |
| Average (median) tonnage per MDC-outbound shipment[b] | 3.6 (1.4) | | | 2.8 (0.5) | | | 4.0 (1.1) | | |
| Average tonnage per MDC-to-outlet shipment | 2.1 | | | 1.2 | | | 1.4 | | |
| Percentage delivered via RDC | 57% | | | 68% | | | 79% | | |
| Tonnage shares: FTL LTL GRP | 62% | 32% | 6% | 57% | 36% | 8% | 68% | 28% | 5% |
| Average transp. costs per tonnage MDC outbound | 38.3 euro | | | 45.3 euro | | | 38.3 euro | | |
| Average $CO_2$ emissions per tonnage MDC outbound | 15.4 kg | | | 19.3 kg | | | 18.5 kg | | |

**Note(s)**: [a]These are the cost-relevant direct distances for the origin–destination pairs, which correspond to the distances of FTL shipments. However, LTL shipments are "physically" moved from the MDC to transshipment points close to the customer to be delivered in round trips (cf. Figures 1 and 3). The average distance of the consolidated LTL main leg shipments between the MDC and the transshipment points is 330 km and the average distance per shipment between the transshipment points and the customer locations is 50 km
[b]These average MDC-outbound tonnages are quite high as 65 percent of the total delivered tonnage is shipped to RDCs where RDC deliveries are often high-volume shipments

**Table V.** Shipment structure according to area type for Scenario 1

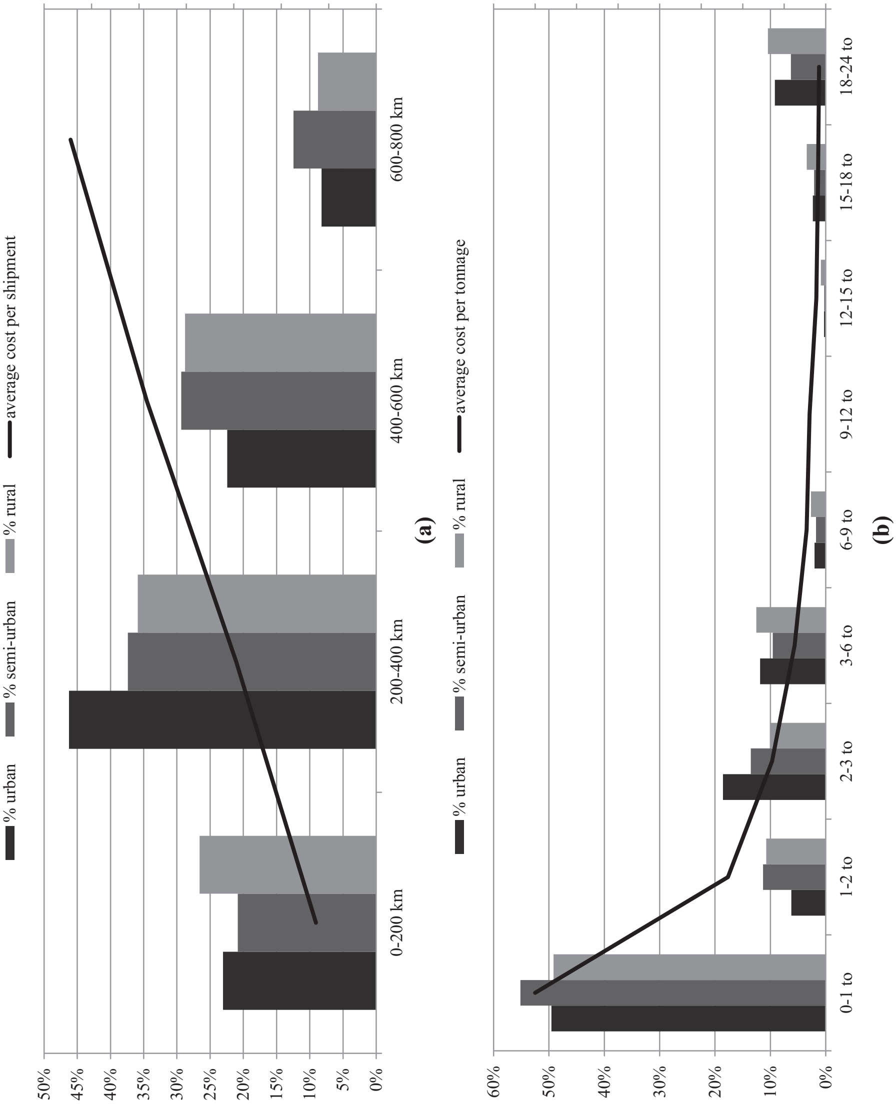



**Figure 4.**
Shares of total shipments according to (a) distance and area type and (b) shipment size and area type

*4.3 GHG emissions*

Interestingly, total emissions are estimated to remain constant. On the one side, shipments destined to satisfy urban demand are more efficient (Table V, bottom line) with respect to GHG emissions than shipments that supply rural LAU. This may be explained, among others, by the shorter distances to supply urban areas. In the case of FTL shipments, the average distance between the MDC and the customer locations is 320 kilometers for urban shipments, 360 kilometers for semiurban shipments, and 340 kilometers for rural shipments. In the case of LTL shipments, the distance advantage of urban areas is even more important as the 26 transshipment points are situated closely to city regions promoting bundling for these areas and keeping the detours of the two-leg shipments short. When all LAU are allocated to the nearest transshipment point, the average distance from a transshipment point to communities classified as "urban" is 32 kilometers, to zip code areas classified as "semi-urban" 43 kilometers, and 53 kilometers for rural LAU. On the other side, the increasing share of semiurban shipments boosts total GHG emissions as these are the least efficient shipments with 19.3 kg $CO_2$ per shipped tonnage. When the demand in the semiurban regions takes a greater share in overall demand, the share of the GHG efficient FTL shipments will decline. FTL shipments are more efficient as they are transported without detours where detours are an important driver for GHG emissions (Gross *et al.*, 2012). Moreover, vehicle capacity is used to a better extent.

*4.4 Effects of demand volume reductions*

Next, the predicted development of the total population is considered to observe how it affects the distribution costs and GHG volumes. The aim is to capture both the development of the total population size (demand volumes) and its future geographical location.

For this analysis, both effects are overlaid: the basis are the five scenarios presented in Table I; now, additionally, the total population is reduced gradually from 82.7 million in 2014 to 72.6 million (predicted situation in 2050, United Nations, 2014). This is done by reducing proportionally the demanded volumes in the single local administrative units – split up in the demand for FTL, LTL, and GRP shipments. Table VI shows the five scenarios with the assumed total population.

This analysis suggests that also for a considerable decrease of the total population, the 1-MDC solution is the cost-minimal. The long-term population decrease of about 11 percent, combined with the rising share of urban population, leads to reductions in total distribution costs of about 10 percent and to reductions of about 11 percent for GHG emissions.

*4.5 Generalizability of the findings*

The results show substantial effects of urbanization on the investigated network and allow for the estimation of the extent to which urbanization affects distribution network performance. The effect results, among others, from changes of the shipment structure as it is different for urban, semiurban, and rural LAU and from the altered customer locations. More

| Scenario | Total population (in millions) | Demand of the single LAU compared to scenario 1 in % | Urban [%] | Semiurban [%] | Rural [%] |
|---|---|---|---|---|---|
| Scenario 1 | 82 | 100.0 | 42.6 | 39.4 | 18.0 |
| Scenario 2 | 80 | 97.6 | 43.7 | 40.4 | 15.9 |
| Scenario 3 | 78 | 95.1 | 44.8 | 41.5 | 13.7 |
| Scenario 4 | 76 | 92.7 | 45.9 | 42.5 | 11.6 |
| Scenario 5 | 73 | 89.0 | 47.1 | 43.5 | 9.4 |

**Table VI.** Set of scenarios, including population development precisely, urbanization influences the destinations and the number of shipments, average shipment sizes, the consolidation and the routing of shipments (direct shipments vs transshipment). The reduced demand that results from a population decrease involves a reduced logistic activity and, hence, considerably less cost and GHG emissions. Some reasons leading to the observed results have been explained. However, the specific company and the external conditions have to be taken into account.

Case company: The generalizability of the findings requires confirmation through the investigation of more cases as the studied company and the dataset used do certainly not represent the situation of all FMCG manufacturers. However, the focal company is rated as a typical producer of FMCG and representative for many manufacturers. It is assumed that the experiences of this firm are informative for the "average firm."

Supply chain: In German FMCG distribution, the share of RDC deliveries is relatively high when compared to other countries. The role of the RDC is crucial as RDC constitute a layer in the supply chain that distorts, from a manufacturer's perspective, the growth in demand in certain areas and the corresponding distances that have to be passed to supply those areas. That means that for the manufacturer, the distance to supply the LAU is the same for all LAU that are delivered via the same RDC. Without that layer or a higher share of shipments moved directly to retailer outlets, the observed results would be amplified in magnitude. Moreover, RDC shipments move typically more tonnage per shipment than outlet shipments and reduce the total number of MDC-outbound shipments. This reduces the effect of a changed shipment structure on the economic and environmental performance of the distribution system.

## 5. Conclusion

This research studied the effect of increasing urbanization on the economic and environmental performance of an existing German FMCG distribution network. The results show that the urbanization trend and the development of the total population affect costs and GHG in distribution networks. Yet, for the case company, they do not change the cost-minimal network configuration.

Future research may focus on other industries or on the FMCG retailers. Whereas, from the manufacturer perspective, the RDC layer absorbs a great portion of the effect of urbanization on the optimal network configuration and its performance, the retailers are directly confronted with the shift of consumer demand. Furthermore, the analysis revealed that, in the studied case, LAU classified as "semi-urban" are less efficiently supplied than the other areas. Future research may analyze the single market areas more in detail to propose approaches for a more efficient supply of the single regions. This could include the analysis of cooperation between shippers or carriers to bundle their flows of material to a geographically more concentrated demand or the analysis of potential benefits and drawbacks when using different modes of transport according to the market area.

### Note

1. Two statistical tests (Kruskal–Wallis *H*-Test, Mann–Whitney *U*-Test) have been used to check whether there is a statistically significant difference ($p = 0.05$) in transport distance and shipment size between the three area types. Shipments supplying urban areas pass statistically significantly shorter distances than shipments supplying semiurban and rural areas. Furthermore, shipments supplying semiurban regions move statistically significantly less tonnage per shipment than shipments supplying urban and rural regions.

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