Decision Support for Urban E-Grocery Operations

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Abstract

We discuss an alternative logistics concept for e-grocery operations using an urban network of refrigerated grocery lockers. Regarding the last mile delivery of food and other fast-moving consumer goods, customers either collect their orders by themselves or the products are delivered by means of electric cargo bicycles. To determine the optimal grocery locker locations and both, the routes from the lockers to the consumers as well as the routes from the depot to the grocery lockers, we propose a 2-echelon optimization model minimizing total costs. We present a Location Routing Problem (LRP) in combination with a customized Vehicle Routing Problem (VRP). With our decision support system (DSS), we react to the call of Malhotra et al. (2013) and Gholami et al. (2016) and address the lack of solution-oriented research. We contribute to the Green IS domain by extending the concept of e-grocery with an environmental and social component.

Keywords


Introduction

The growing population in cities implies an increasing demand for all kind of goods in urban areas. In addition, e-commerce is prospering accounting for a rising number of delivery activities and resulting traffic on the last mile to satisfy customer needs (Van Duin et al., 2016). The politics is called to mitigate the global warming potential by enacting appropriate laws to reduce the greenhouse gas emissions. For instance, the European Commission defines the objectives of excluding conventionally powered vehicles by 2050 and achieving “essentially CO2-free city logistics in major urban centers by 2030” (EUC, 2011). To attain clean air for all inhabitants, national emission ceilings for different pollutants (PM10, NOx, etc.) are currently discussed. If those limits are exceeded, municipal authorities might be forced to ban certain vehicles from the urban traffic. For example, driving bans can cover diesel cars (e.g., Oslo, January 2017), vehicles with even/uneven-numbered registration plates (e.g., Athens, Beijing, Mexico City), and so forth. Despite vehicle bans, urban inhabitants need to be supplied with various goods. As one result, the number of electric cars, light-duty vans, and other transport vehicles such as cargo bi- and tricycles is rising in urban areas.

In addition, the delivery of groceries to end-customers (e-grocery) is a steadily increasing market. Figure 1 shows the e-grocery market value in billion USD (United States Dollar) for selected countries in 2015 and 2020 (forecast). The predicted growth rates vary between 77.8% (France) and 300% (Netherlands), which illustrates the significant rise of the e-grocery industry in different regions worldwide. One of the biggest challenges for e-grocery activities is the food delivery and its necessary compliance with the refrigeration chain. As one result, some vendors are not delivering any refrigerated food making additional grocery shopping necessary.
Urban E-Grocery Optimization

Figure 1. Market Size of E-Grocery Industry by Country in 2015 & 2020 (Profitero, 2016)

Concurrently, our society is becoming increasingly aware of environmental and economic sustainability (Dedrick, 2010). The attention on sustainability is also recognized in information system (IS) research (Watson et al., 2010). The emerged research domain of Green IS addresses the transformative role of IS in the context of a sustainable society and business strategies, while considering the role of people and their livability. The foci in this field vary by conceptualization, analyses, design, and impact of such systems (Watson et al. 2010). Studies examining Green IS research by Malhotra et al. (2013) and Gholami et al. (2016) reveal that design and impact-oriented research is lacking. To tackle the described problems of an increasing city population and their related grocery demand with IS-methods, we formulate the following research question:

How can an IS support efficient and eco-friendly grocery deliveries in cities?

To address this question, we introduce an optimization approach using an urban network of refrigerated grocery lockers. Customers may either pick up their orders at those lockers or request deliveries by means of electric cargo bicycles (ECB). To determine the grocery locker locations and the routes from the grocery lockers to the customers as well as the routes from a depot to the grocery lockers, we propose a 2-echelon optimization model minimizing costs. We present a Location Routing Problem (LRP) and an adjusted Vehicle Routing Problem (VRP) considering multiple products, compartments, time windows, and split delivery. Both problems are implemented in modelling software GAMS to permit the application of use cases and sensitivity analyses. Benchmarks are provided for the city of Hanover (Lower Saxony, Germany) to demonstrate the functionality of the developed decision support system (DSS), which addresses (e-)grocery retailers, parcel delivery services, and city authorities. Afterwards, we discuss the proposed approach and draw a conclusion.

Optimization Approach

Logistics Concept for Urban E-Grocery Operations

Groceries include food and household items as well as other fast-moving consumer goods. To supply a demand area with those groceries, we propose a network of refrigerated grocery lockers and ECBs. We aim at determining optimal grocery locker locations, optimized routes for direct locker-to-customer deliveries, and optimized routes for the locker-supply from a central depot. This problem tackles the urban last mile which is the final section and the most cost-intensive part of the supply chain (Gevaers et al., 2009). As a simultaneous location and routing decision provides better results than a sequential decision (Salhi and Rand, 1989), we formulate a LRP for the grocery locker location optimization and the ECB route determination. To reduce the problem's complexity, the van route optimization is executed in a separate model. Figure 2 illustrates the described logistics concept and our corresponding two-stage optimization approach.

In a first step, a particular LRP based on the warehouse-LRP formulation of Perl and Daskin (1985) determines the optimal number, sizes, and locations of grocery lockers among the sets of available locker types and potential locker locations. The wide range of groceries implies different requirements concerning the cooling and dimensions of the ordered products. Hence, different locker types (e.g., temperature zones frozen, refrigerated, and dry) and sizes need to be considered. The model further allocates customers to established grocery lockers. Those customers can either pick up their ordered products themselves or request a delivery by means of ECBs. The LRP determines the ECB routes for the locker-to-customer deliveries, minimizing the sum of transport and locker operating costs. In view of an ECB's limited capacity, resulting tours must be restrictable to comply with cooling chain requirements by use of cooling boxes.
In a second step, the grocery lockers need to be supplied with the ordered products, taking the unequal product requirements and incompatibilities into account, e.g., frozen food must not be stored together with dry goods. Time windows must also be considered to ensure punctual locker-supply. For this purpose, we present an adjusted VRP, derived from the formulation of El Fallahi et al. (2008). Routing decisions for the grocery locker supply are modelled in an operational context considering compartmentalized vehicles originating from the central depot, product-compartment incompatibilities, time window constraints, and split-deliveries (SP-VRPMPCTW) to minimize transportation costs. Split deliveries can increase the optimality of the solution and seem to be a convenient feature in the given context where no customer must be present to receive goods, i.e. allowing for split deliveries does not negatively affect service quality (Archetti et al., 2006).

To provide decision support for (e-)grocery retailers, parcel delivery services, and city authorities, we formulate two consecutive mixed integer linear programs (MILP) for both, the LRP and SP-VRPMPCTW. The underlying assumptions, notations, and mathematical problem formulations for the two models are given in the following section.

2-Echelon Optimization Model

Before the notation is explained, we present the underlying assumptions of our optimization approach:

- The customer locations are given and characterized by a distinct demand level for the different product types. This demand has to be fulfilled while the product types differ in terms of cooling chain requirements, which have to be met within the whole delivery process.
- The potential locations for grocery lockers are given. Regarding their storage capacity, grocery lockers vary in terms of dimensions resulting in a set of different locker sizes. Further, these lockers are subdivided into compartments to store each product type at its appropriate bearing temperature. The proper operation is secured by an existing electricity connection and a screen for storage and collection processes. Each established grocery locker disposes of a socket outlet for ECB recharging. For the establishment of a grocery locker operating costs incur varying per location.
• If the ordered products are not picked up by the customers, the goods are delivered by a given number of ECBs with identical specifications. Each trip starts and ends at the same grocery locker. Different product types are delivered simultaneously to supply each customer only one-time. As the storage capacity of an ECB is limited, resulting trips can be restricted in terms of length to meet the cooling chain requirements by use of cooling boxes.

• The grocery lockers are supplied with the desired goods from a given depot. A trip starts and ends at the same depot where all offered groceries are stored in a sufficient amount.

• The transport vehicles for the grocery locker supply, further referred to as vans, are given and identical in its specifications. The load area is subdivided into the number of product types which are stored in special compartments complying with cooling chain restrictions. The supply of different grocery lockers might be served in different tours, as partial supply is not a critical element. For the timely delivery of groceries to customers, the grocery locker-supply is restricted through time-windows for the latest storage with requested goods.

The following Table 1 contains the underlying notation including sets, parameters, and decision variables for the LRP and the SP-VRPMPCTW.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a, b, r \in \emptyset \cup S$</td>
<td>Nodes of the SP – VRPMPCTW</td>
</tr>
<tr>
<td>$g, h, l \in N \cup M$</td>
<td>Nodes of the LRP</td>
</tr>
<tr>
<td>$j \in J$</td>
<td>Set of grocery locker sizes</td>
</tr>
<tr>
<td>$k \in K$</td>
<td>Set of available ECBs</td>
</tr>
<tr>
<td>$m \in M$</td>
<td>Set of potential locker locations</td>
</tr>
<tr>
<td>$n \in N$</td>
<td>Set of customer nodes</td>
</tr>
<tr>
<td>$p \in P$</td>
<td>Set of product types</td>
</tr>
<tr>
<td>$s \in S \subseteq M$</td>
<td>Set of opened grocery lockers</td>
</tr>
<tr>
<td>$v \in V$</td>
<td>Set of available vans</td>
</tr>
<tr>
<td>$\emptyset$</td>
<td>Depot</td>
</tr>
</tbody>
</table>

- $c^{eb}$: Average travelling cost per distance unit of an ECB
- $c^{van}$: Average travelling cost per distance unit of a van
- $d_{np}$: Demand at customer node $n$ for product type $p$
- $F_{jm}$: Costs for operating a grocery locker with size $j$ at potential location $m$
- $M$: Sufficiently large number
- $Q^{eb}$: Capacity of an ECB
- $Q_{j}^{pl}$: Capacity of grocery locker size $j$
- $Q_{p}^{van}$: Capacity of a van's compartment for product type $p$
- $r_{sp}$: Required quantity of product type $p$ at opened grocery locker $s$
- $s_{max}$: Start of time window for stowing at opened grocery locker $s$
- $t_{min}$: End of time window for stowing at opened grocery locker $s$
- $\alpha$: Maximum distance between a grocery locker and its assigned customers
- $\Delta_{gh}^{eb}$: Travel distance between nodes $g$ and $h$ of an ECB
- $\Delta_{ab}^{van}$: Travel distance between nodes $a$ and $b$ of a van
- $\Delta_{ab}^{max}$: Maximum allowed travel distance of a van
- $\theta_{ab}$: Travel time between nodes $a$ and $b$ of a van
- $\lambda$: Average handling time per product type per unit for locker stowing
- $a_{jm}$: 1, if locker size $j$ is opened at locker location $m$; 0, otherwise
- $t_{av}$: $P$, Arrival time at node $a$ by van $v$
\begin{table}
\centering
\begin{tabular}{|c|p{0.7\textwidth}|}
\hline
\textbf{$u_l$} & $l \in N$; Auxiliary variable \\
\hline
\textbf{$u_{rv}$} & $r \in S$; Auxiliary variable \\
\hline
\textbf{$x_{ghk}$} & 1, if node $g$ precedes node $h$ with ECB $k$; 0, otherwise \\
\hline
\textbf{$x_{abv}$} & 1, if node $a$ precedes node $b$ with van $v$; 0, otherwise \\
\hline
\textbf{$y_{nm}$} & 1, if customer $n$ is assigned to locker location $m$; 0, otherwise \\
\hline
\textbf{$z_{svp}$} & 1, if product type $p$ is delivered to opened locker $s$ by van $v$; 0, otherwise \\
\hline
\end{tabular}

\caption{Applied Indices, Parameters, and Decision Variables.}
\end{table}

\textbf{Location Routing Problem (LRP)}

\begin{align*}
\text{Min.} & \sum_j \sum_m F_{jm} \cdot o_{jm} + \sum_g \sum_h \sum_k \Delta_{gkh}^{e_{cb}} \cdot c_{e_{cb}} \cdot x_{ghk} \\
& \sum_h \sum_k x_{nhk} = 1 \quad \forall n \\
& \sum_g x_{ghk} - \sum_g x_{ghk} = 0 \quad \forall h, k \\
& \sum_n \sum_m x_{nmk} \leq 1 \quad \forall k \\
& u_l - u_n + |N| \cdot x_{ink} \leq |N| - 1 \quad \forall l \in N, n, k \\
& \sum_n \sum_h \sum_p d_{np} \cdot x_{nhk} \leq Q^{e_{cb}} \quad \forall k \\
& \Delta_{gkh}^{e_{cb}} \cdot y_{nm} \leq \alpha \quad \forall k \\
& \sum_n \sum_h d_{np} \cdot y_{nm} \leq \sum_j Q_{f}^{g_{i}} \cdot o_{jm} \quad \forall m \\
& \sum_h (x_{nhk} + x_{mhk}) - y_{nm} \leq 1 \quad \forall n, m, k \\
& \sum_m y_{nm} = 1 \quad \forall n \\
& \sum_j o_{jm} \leq 1 \quad \forall m \\
& o_{jm} \in \{0, 1\} \quad \forall j, m \\
& x_{ghk} \in \{0, 1\} \quad \forall g, h, k \\
& y_{nm} \in \{0, 1\} \quad \forall n, m
\end{align*}

The objective function in (1) minimizes the accumulated costs of operating grocery lockers and transport costs for grocery delivery to customers. The trade-off between operating grocery lockers and traveling a certain distance combines location decisions with routing decisions. Thus, it is necessary to preprocess the input data such that all cost parameters are aligned in their occurring time horizons. Regarding the model’s operational context, all parameters must be indicated concerning short-term decision making. Constraint (2) ensures that every customer has to be visited exactly once across all vehicles. Constraint (3) represents...
the flow conservation constraint which imposes the arrival and the department at a customer node for each vehicle. Constraint (4) ensures the assignment of a trip to any locker at most once. Subtours are eliminated in (5) using the Miller-Tucker-Zemlin (MTZ) constraint (Kara et al. 2004). Constraint (6) guarantees that the capacity limit of each ECB is fulfilled by restricting the total quantity transported. In (7), the distance between an opened grocery locker and its assigned customers is restricted to be smaller than a predetermined distance. This formulation serves two purposes: For the case of self-collection by customers, the space that is spanned around an opened locker by \(a\) represents the area of customer responsibility, constituting the service level. For the case of delivery, \(a\) is used to restrict the ECB-trip length to meet the cooling chain requirements by use of cooling boxes. Constraint (8) is useful for several issues: First, the cumulated demand of customers must not exceed the capacity of their assigned grocery locker; Second, it ensures that no customer is assigned to a non-existent locker; Third, the grocery locker location and its size are chosen based on the existing demand values. Constraint (9) requires the assignment of a customer and a grocery locker to a trip. Constraint (10) ensures that each customer is assigned to exactly one opened grocery locker. Constraint (11) imposes the establishment of only one locker per potential grocery locker location across all possible locker sizes. Equations (12) - (14) define the variables’ value ranges.

**Split Delivery Vehicle Routing Problem with Multiple Products, Compartments, and Time-Windows (SP-VRPMPCTW)**

\[
\text{Min.} \quad \sum_{a} \sum_{b} \sum_{v} \Delta_{ab}^{van} \cdot c_{van} \cdot x_{abv}' \\
\sum_{h} x_{hsv}' \leq 1 \quad \forall s, v \quad (15) \\
\sum_{a} x_{asv}' - \sum_{a} x_{asv}' = 0 \quad \forall s, v \quad (16) \\
\max - u_{rv} + |S| \cdot x_{sv}' \leq |S| - 1 \quad \forall r \in S, s, v \quad (17) \\
z_{svp} \leq \sum_{a} x_{asv}' \quad \forall s, v, p \quad (18) \\
\sum_{v} z_{svp} = 1 \quad \forall s, p \quad (19) \\
\sum_{s} z_{svp} \cdot r_{sp} \leq Q_{p}^{van} \quad \forall v, p \quad (20) \\
\sum_{a} \sum_{b} \Delta_{ab}^{van} \cdot x_{abv}' \leq \Delta_{max} \quad \forall v \quad (21) \\
t_{sv} \geq t_{s}^{\min} \quad \forall s, v \quad (22) \\
t_{sv} + \sum_{p} q_{sp} \cdot z_{svp} \cdot \lambda \leq t_{s}^{\max} \quad \forall s, v \quad (23) \\
t_{sv} + \sum_{p} q_{ap} \cdot z_{svp} \cdot \lambda + \delta_{asv}' \cdot \bar{M} \leq t_{sv} \quad \forall a, s, v; a \neq s \quad (24) \\
x_{abv}' \in \{0,1\} \quad \forall a, b, v \quad (25) \\
z_{svp} \in \{0,1\} \quad \forall s, v, p \quad (26)
\]

The objective function (15) minimizes the total transport costs which incur for the supply of the opened grocery lockers by means of vans. Constraint (16) states that every locker is visited at most once within a vehicle’s tour. However, a locker can be visited by more than one vehicle, which represents the necessary condition for split-deliveries. Constraint (17) ensures the typical tour flow (a vehicle visiting a locker...
location must also leave it) and constraint (18) represents the MTZ subtour elimination to prevent short-trips. Constraint (19) ensures the delivery of products in existing tours. Every product type required at a locker must be delivered within a single tour according to constraint (20). Here, we implicitly assume that a compartment’s capacity is sufficiently large to provide a full replenishment of the associated product type at any grocery locker. Constraint (21) imposes that the vehicle’s load of a particular product type must not exceed the associated compartment’s capacity. Due to physical vehicle characteristics, the distance a vehicle may cover in its tour is restricted by (22). Constraints (23) – (25) secure the time-window compliance of the grocery lockers. The earliest arrival time of a locker is secured by constraint (23) and the latest departure time including the handling time for grocery storage is set by constraint (24). The arrival time at a grocery locker has to exceed the arrival time at a previous locker plus the handling time and the driving time between both lockers. Equations (26) – (27) define the decision variables’ value ranges.

**Computational Study**

To evaluate our developed two-stage optimization approach for one exemplary day, we provide benchmarks using the German city of Hanover (Lower Saxony) as an investigation example. Hanover represents a mid-sized city with a population of more than 500,000 inhabitants living across an area of approximately 20,413 hectares (≥ 50,442 acres). Regarding transport-relevant infrastructures, the number of public car charging stations (currently approximately 30) and parcel pickup points (currently approximately 50) is continuously increasing, reflecting the rising acceptance for electric vehicles and alternative last mile delivery concepts. To execute benchmark calculations for two crucial model parameters, it is necessary to set all other parameter values at the beginning. For this purpose, we define an exemplary demand of 15 customers per day who are allocated in the city area and who order three product types (e.g., frozen, refrigerated, and dry products). As usual in grocery delivery, the food is packed in standardized transport cases like boxes or bags. Hence, the capacity specifications of the transport vehicles and the different locker sizes are indicated as upper limit of storable bags. In terms of grocery locker concepts, there already exist several systems and suppliers of compartmentalized pick up points, like enmasbox or BentoBox (Dell’Amico et al., 2011). We assume three locker sizes with the associated operating costs: small (35 bags; 8 €/day), medium (50 bags; 11.5 €/day), and large (65 bags; 15 €/day). Depending on the demand level of the three product types, the LRP determines the size of each compartment type at each locker location. In this example, each customer demands 1 to 10 bags, differing in terms of product type. The actual grocery locker locations are chosen from a set of 11 potential locker locations which are allocated within the urban demand area. The utilized ECBs are expected to transport up to 20 bags per trip and cause variable costs of 0.1 €/km (kilometer). To calculate the travel times as well as the driving distances between each potential grocery locker location and each customer site, we use the Google Maps Distance Matrix API (application programming interface).

As explained, the number, sizes, and locations of grocery lockers as well as the locker-to-customer assignments are determined in the first optimization step. Since the described parameter \( \alpha \) (maximum distance between a grocery locker and its assigned customers) is a crucial factor, we ceteris paribus calculated benchmark results for several specifications of it. Figure 3 illustrates the resulting decision variable outputs for the applied \( \alpha \)-values from 0.5 to 2.5 kilometers. The maximum distance between a grocery locker and its assigned customers can be interpreted as service level. The lower the parameter value, the closer the grocery locker to its assigned customers. Regarding customer self-collection, this service level might be a decisive factor in terms of consumer acceptance. Small distances to grocery lockers encourage customers to pick up their products by bicycle or by foot, relieving the related road traffic. Those small distances also promote the utilization of ECBs, as the travel distances to customers are comparatively low. Benchmark results show that lower maximum distances increase the number of opened grocery lockers, the number ECB tours, and the total costs. At the lowest implied \( \alpha \)-value (0.5 km), total costs of 56.74 €/day result, demonstrating that the number of opened grocery lockers must be minimized from an economic perspective. On the other hand, the total travel distance is reduced by opening more grocery lockers, contributing to a traffic reduction. However, the resulting costs hardly change above a certain \( \alpha \)-value (≥ 1 km). When opening seven grocery lockers (\( \alpha = 0.5 \) km), only small lockers are utilized. Having just two grocery lockers (\( \alpha ≥ 1.5 \) km), a mixed set up of one medium and one large version is recommended. The benchmarks reveal the \( \alpha \)-value’s impact on the resulting decision variables. In any case, the DSS-user must be aware that the optimization problem can become infeasible, if the \( \alpha \)-value is set too low. For instance, this can occur because one or more customers are placed out of the potential locker locations’ range.

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In the second optimization step, the van-routes for grocery locker-supply are determined using the described SP-VRPMPCTW. The utilized vans are identical in terms of operating costs (0.17 €/km), capacity (150 bags), and range (300 km/day). Further, the determined grocery locker locations and their assigned product demands from the first optimization stage now serve as input data. At this second stage, we provide benchmarks for different time window extents at the grocery lockers. Figure 4 illustrates the resulting decision variable outputs for time frames between one and ten hours.

The time window variation shows that smaller time frames result in more van tours, higher travel distances, and therefore higher expenses. For instance, when the time windows are halved from two hours to one hour, the total travel distance increases from 50.74 km/day to 94.23 km/day (+85.7 %) and the related costs rise by 85.5 %. For this example size, extending the time windows over three hours has no further influence on the model variables, as the results remain unchanged. Again, the DSS-user must be aware that the optimization problem can become infeasible also at this stage, if the time windows are set too narrow. This risk is depending on the respective application case, using the given depot and the potential grocery locker locations.

**Figure 3. Benchmark Results for Different Grocery Locker-to-Customer Distances.**

**Figure 4. Benchmark Results for Different Time Windows.**
Combining the results of both optimization models, the grocery locker operation depicts the main cost element (27.5 €/day with $\alpha = 1$ km, 73.78 % of total costs), whereas the van costs are of secondary importance (8.63 €/day with 1.5 h time window, 23.5 %), and the ECB-costs are almost negligible (1.15 €/day with $\alpha = 1$ km, 3.08 %) in the presented application case. Solving the described problem instance on a standard computer (Intel Core i5-6200U CPU 2.30 GHz, 8 GB RAM, Windows 10, 64-bit) with the modelling software GAMS 24.5.6 and IBM ILOG CPLEX 12.6, computing times vary between seven minutes and four hours, depending on the optimization gap and the parameter settings (especially $\alpha$). Comparatively long computing times result, because both, the LRP and the VRP, are np-hard (non-deterministic polynomial-time) combinatorial optimization problems (Prodhon and Prins, 2014).

Contributions and Limitations

With the developed 2-echelon optimization model and DSS, we assist an efficient implementation of the proposed logistics concept. Hence, increasing urban e-grocery operations can be executed considering economic, social, and environmental aspects simultaneously. As market competition is mainly cost-driven, sustainable means of transport are hardly used at the moment. With our DSS, an efficient ECB utilization can be ensured promoting an environmentally friendly goods transport. As no driving license is required, the use of bicycles enlarges the set of potential employees. The DSS promotes the establishment of grocery lockers to allow for customer pick-ups besides the ECB-deliveries. Placing the lockers at strategically favorable locations, road traffic can be reduced when customers pick up their products by bicycle or by foot. City authorities can support this logistics concept by setting up special purpose areas to promote the use of pick-up locations. We contribute to the Green IS domain as our article addresses relevant issues regarding the supply of goods within urban areas. We developed a DSS which assists emission reductions in the urban last mile delivery by using eco-friendly vehicles. With our IS research on the three areas of sustainability, we reacted to the call of Malhotra et al. (2013) and Gholami et al. (2016), who point out the overrepresentation of conceptualization and analyses compared to solution-oriented research. We combined transportation and Green IS research to promote the transformative role of IS in contributing to enhanced economic, social, and environmental sustainability. With the help of the DSS, we enable better decision-making through an easy usability for (e-)grocery retailers, parcel delivery services, and city authorities in finding appropriate solutions for the urban delivery of goods to meet forthcoming regulations.

Nevertheless, there are limitations and enhancement opportunities to be considered. The optimization approach is based on several assumptions to simplify real-world conditions. Minimizing costs constitutes the objective of both models. Alternatively, routing can be optimized in terms of travel distance or emission minimization (Figliozzi, 2010). As both models represent hard combinatorial optimization problems and the computation time is already considerable for the relatively small application example, a heuristic algorithm is needed for very large instances. Further research on e-grocery distribution problems using a network of intermediate pickup stations and electric vehicles must concentrate on the location decisions regarding economic aspects. Beyond that, the tool’s appropriate time horizon should be evaluated in detail. Depending on spatial demand fluctuations, it must be examined whether it is preferable to change the actual grocery locker locations on a monthly, weekly, or daily basis. To finally analyze the tool’s added value, the DSS should be used in a field test, comparing the resulting costs and user acceptance with the present approach.

Conclusions and Outlook

We present a solution-oriented DSS in the domain of Green IS. Our approach comprises a 2-echelon optimization model to enable recommendations for optimal grocery locker positioning in urban areas as well as the corresponding transport vehicle deployment. On the one hand, the refrigerated grocery lockers serve as pick up points for customers to collect their ordered products. On the other hand, the lockers enable customer deliveries by means of ECBs as the distance of the last mile is significantly reduced. Thus, the proposed logistics concept integrates environmental sustainability with the main objective of cost minimization. As a result, road traffic is relieved and emissions are reduced in both cases. To enable easy utilization for relevant decision makers, the model is implemented into a DSS. (E-)Grocery retailers, parcel delivery services, and city authorities can simulate scenarios with varying parameter values to analyze the respective influences on the outcome. Benchmarks are presented to evaluate the created DSS. Our results demonstrate the tool’s applicability and indicate that increasing the service level (decreasing the grocery
locker radius) leads to higher costs, whereby the grocery locker operation constitutes the main cost element. Future research will focus on a refinement of the DSS and the related mathematical model in the discussed ways. We propose real-world investigations of the presented logistics concept to ensure further validation. If the approach proves to be advantageous compared to current business practices, it should be fine-tuned and applied on large scale. Irrespective of the application scale, our DSS contributes to Green IS domain and fosters the society’s shift towards sustainable operating modes as well as eco-friendly city logistics. Thereby, it integrates economic, social, and environmental aspects.

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