

Concept for a simulation-optimization procedure model for automated parcel lockers as a last-mile delivery scheme: a case study in the city of Dortmund

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Purpose of the communication: More than half of the world's population live in urban areas, with the density increasing. Cities require goods and related logistics services, which fact has economic, environmental, and social implications. The usage of automated parcel locker (APL) systems such as packstations or locker boxes is one of the most promising initiatives to improve urban logistics (UL) activities. The APL has electronic locks with variable opening codes and can be used by different consumers, whenever it is convenient for them. Some studies confirm that online shoppers will use APLs more frequently in the future. We develop a procedure model for APL adoption as a last-mile delivery scheme, to reduce the risk of failures in their implementation. A case study in the city of Dortmund is presented.

Research design, methodological approach: The procedure model combines a system dynamics simulation model (SDSM) with a facility location problem (FLP) optimization model in a specific case of study.

Results obtained: The procedure model includes five main steps to combine an SDSM with an FLP. We use the SDSM to understand the components' behavior of the APL systems in terms of the market size, potential e-customers, APL users, purchases per month, number of deliveries, and the number of APLs. We develop a multi-period capacitated FLP as an optimization model to determine the optimal location of the APLs in every district of Dortmund. The model considers three principal scenarios – pessimistic (S1), realistic (S2), and optimistic (S3) – through a planning horizon of 60 months. The initial results of the number of deliveries (units) at the first month are: 51,381 for S1, 154,147 for S2, and 256,907 for S3; at the 60th month: 224,022 for S1, 672,067 for S2, and 1,120,110 for S3. The number of APLs that the city of Dortmund needs at the first month is: 8 for S1, 24 for S2, and 41 for S3; at the 60th month: 37 for S1, 112 for S2, and 186 for S3. We use the total cost results for applying a standard formulation of the net present value (NPV). The NPV determines the investment needed to implement each scenario.

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The investment amount in the three proposed scenarios is: 325,300 for S1, 987,600 for S2, and 1,643,900 for S3. Based on these investment amounts, third-party logistics providers could decide to implement APLs as delivery scheme.

Theoretical contributions of communication: The emphasis lies on an SDSM in the UL field, enriching existing simulation applications of APLs as a last-mile delivery scheme. Furthermore, the novel model combines an SDSM with an FLP model to increase the representation of the details of real-life APL delivery systems.

Managerial contributions of communication: In real-life FLPs, the variables such as population or customer demand are changing over time. Some models incorporate dynamics by just adding a time function. However, there are causal relationships between the key variables, which the SDSM can exploit to determine the behavior of these variables in the FLP. The SDSM is used to understand the components' behavior of the APL systems for every month. The FLP optimization model is then used to determine in which district of the city the APLs will be located, and how many APLs have to be installed in each district. Summarizing, the models perform an ex-ante behavioral analysis of the dynamic variables of possible future scenarios and their effects on the APL locations.

Limitations of the work done: The performance of the procedure model is limited by the existence and the quality of input data.

Keywords: Procedure Model, Last, Mile Logistics, Automated Parcel Lockers, System Dynamics, Facility Location Problem

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“Work in Progress”

ABSTRACT

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1 INTRODUCTION

Last-mile logistics (LML) are often characterized as the most expensive and complicated part of the supply chain, featuring negative impacts on pollution and congestion in densely populated areas (Gonzalez-Feliu, 2017). The arrival of e-commerce has accentuated the number of individual home deliveries, increasing the LML flows. Investigating how to improve the efficiency of LML in urban areas is a significant driver for the success of e-commerce, and contributes to alleviating the negative externalities of urban logistics (UL) derived from it.

Concerning decision support in UL, various methods can be used (Gonzalez-Feliu, 2017, 2019), such as empirical approaches, statistical analyses, or integrated computer science models and algorithms, among others. Concerning the last category of methods, researchers use simulation and optimization (SO) techniques as separate or alternative approaches in the operational research fields to solve complex problems (Figueira & Almada-Lobo, 2014). On the one hand, exploring the behavior of systems and estimating their response to various environmental changes is a main purpose of the use of simulation (Crainic, Perboli, & Rosano, 2018). On the other hand, the optimization tries to solve logistic problems, minimizing the total operational cost or maximizing profits. We combine SO models in UL systems to facilitate the response representation of different scenarios for changing policies and environmental regulations, enabling better accommodation of logistics schemes.

In our current work, we analyze the use of automated parcel locker (APL) systems such as packstations or locker boxes as one of the most promising initiatives to improve the UL activities (Boudoin, Morel, & Gardat, 2013). The APL has electronic locks with variable opening codes and can be used by different consumers, whenever it is convenient for them. The APLs group several lockers, sited in apartment blocks, workplaces, and railway stations. The costs of delivery using the APL are lower than home deliveries, and the risk of missed deliveries is avoided. Some studies confirm that online shoppers will use APLs more frequently in the future (Moroz & Polkowski, 2016).

APLs can be found around the world. Boudoin et al. (2013) and Zurel, van Hoyweghen, Braes, and Seghers (2018) presented a general overview of different experiences. For example, German ‘Packstations’ have been in action since 2001, with Deutsche Post DHL Group starting this business 20 years ago. The company now runs more than 3,700 APLs in Germany alone. The roll-out of the French APLs began in 2014, and at the end of 2015, 200 APLs were operational in busy areas of the five largest cities in France (Paris and the Paris region, Lyon, Marseille, and Bordeaux). InPost now has more than 2,000 APLs in service nation-wide. New locations (tramway stations, post offices, universities, hospitals, and large retail stores) are currently being tested. Around 6,500 e-retailers in France now offer parcel delivery through Chronopost or Colissimo to an APL. In turn, Amazon installed its first Amazon locker facility in France in 2015, which has been set up at a shopping mall in Levallois-Perret, near Paris. The total installations in that year were 55 new APLs. In 2018, Amazon reportedly signed an agreement with the French rail company SNCF to install APLs in around 1,000 train stations over the next five years. Some APL initiatives in Latin America through companies such as Pudo and Boxeway are present in Argentina, Brazil, Chile, and Mexico with a meager market share but growing in the region. Despite limitations to the concept, many third-party logistics providers (InPost, Norway Post, PostDanmark, UPS, Cubee, and others) continue to invest more to gain a competitive advantage (Moroz & Polkowski, 2016). Figure 1 presents some examples of APLs currently operated respectively by DHL in Germany (a) and Amazon in France (b).



Figure 1: Illustration of current APL by DHL (Beemelmans, 2016) in (a) and Amazon locker (Post&Parcel, 2015) in (b)

Verlinde, Rojas, Buldeo Rai, Kin, and Macharis (2018) remark that an APL has multiple benefits in comparison to home deliveries as less traffic in city centers, no double parking in front of customers' homes, and reduction of failed home deliveries, which gains time, fewer kilometers, stops, and off-hour deliveries, as well as a cost reduction for e-retailers and delivery operators. Environmental benefits are less pollutant emissions and less noise because of the possible reduction of delivery vehicles in the city. Social benefits are expected as an improved quality of life. The e-customers are free to choose the delivery time (24/7 availability) and select the most convenient APL location to pick up or send their parcels. Moreover, the APL could be a focal point for the local community. However, the APL has some disadvantages as low ease of use, depending on the company software interface and the payment flexibility possibilities. Also, storage feasibilities are limited and the APL is sensitive to crime or vandalism (Vakulenko, Hellström, & Hjort, 2018).

The system behavior and the possible locations are fundamental aspects for understanding the APL solution's potential impacts before the implementation. Moreover, the logistics organizations behind APL management, mainly in cases where parcel lockers are mobile or modular, can lead to a planning situation where the demand (and the following planning objectives and steps) need to take into account the cities and consumption dynamics. According to scientific literature, planning and optimization approaches are either purely static or consider traffic dynamics (mainly by discretizing them into a set of categories of traffic). However, managing the demand dynamics and the interactions between stakeholders in planning and optimization can lead to better use of resources and then to a more resilient and reactive configuration, without losing efficiency. To the best of our knowledge, no works deal with integrated dynamic planning methods. Thus, it can be interesting to show the advantages and interests of that dynamic planning. For this propose, suitable simulation approaches (that combine simulation to assess the dynamics of the system) and optimization (used not as a one-shot problem-solving method but iteratively and interactively) should be considered.

Jlassi, Tamayo, and Gaudron (2017) highlight the almost absence of system dynamics (SD) simulation applied in the UL field. Moreover, no SD applications investigate the APL system components as well as their interactions. Guerrero and Díaz-Ramírez (2017) state that the APL strategy has not been discussed in the scientific literature, but observed in practice. These studies did not

look at the APL installation costs, as well as the required capacity for seasonal e-commerce peaks. However, one of the most critical expectations of APL users is the close location from home or the way to work, and the availability of parking spaces (Iwan, Kijewska, & Lemke, 2016).

In this paper, we propose a novel model that combines an SD simulation model (SDSM) with a facility location problem (FLP) optimization model. The SDSM serves to understand the components' behavior of the APL systems. At the same time, the FLP is applied to determine where and how many standard APLs to install in each site in different periods to minimize the total operational cost. The paper is organized as follows. First, we present the main background issues related to simulation and optimization methods able to be applied to the targeted issues. Second, we explain the general methodology, i.e., the global procedural model. Third, we develop each step of the procedure model in a case study in the city of Dortmund. Finally, the conclusions address the potential future works and applications.

2 RELATED WORK

2.1 System Dynamics Modeling

The System Dynamics (SD) discipline emerged in the late fifties, as an attempt to address dynamic, long-term policy issues, both in the public and corporate domains. Jay W. Forrester (1998) proposed a methodology for the simulation of dynamic models, which is the origin of SD. The first application area of the methodology was the strategic management of industrial problems. Industrial dynamics is a quantitative approach that studies the characteristics of the information feedback of industrial systems to understand how the organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the company's success. In general, the main objective of SD is to understand the structural causes that define the behavior of a system (Sterman, 2000). In that field, modeling is seen as a feedback process, not a linear sequence of steps. Models go through constant interaction, continuous questioning, testing, and refinement. For developing an SD model, Sterman (2000) presented a modeling process with the following steps: (i) problem articulation, (ii) dynamic hypothesis, (iii) formulation, (iv) testing, and (v) policy formulation and evaluation.

The SD methodology is based on feedback concepts of control theory, and a causal loop is a convenient way to represent the feedback loop structure of systems (Bala, Arshad, & Noh, 2017). The causal loop diagrams (CLD) are used to describe feedback loop systems diagrammatically, which generates the dynamic behavior of the related model. The CLDs identify the main feedback loops of the systems. The CLDs are used to describe underlying causal mechanisms hypothesized to generate the reference mode of behavior of the system over time. A feedback loop contains two or more causality-related variables that close back on themselves. The relationship between one variable and the next one in the loop can be either positive or negative. A positive relationship means that if one variable increases, the other also increases. In a negative relationship, the two variables change inversely.

The stock and flow diagram (SFD) is the underlying physical structure of the system. The SFD is usually constructed after the CLD. The stock (level) represents the state or condition of the system, and the flow (rate) is changed by decisions based on the condition of the system. The SFD is essentially the physical structure of the system and can be simulated to generate the dynamic behavior of the system. The SFD or the system of the differential equations representing the feedback structure of systems capture the hypotheses about the causes of dynamics and the essential feedbacks. The system structure is defined by stocks, flows, and connections between them. The stock and flow structure (including feedbacks) of a system determine the qualitative behavior modes that the system can take on. In other words, stocks are the present variable values, i.e., values that have resulted from an accumulated difference between inflows and outflows (Forrester, 1968).

In this context, Villa, Gonçalves, and Arango (2015) presented an SD model that already analyzed the decisions and interdependencies between customers, retailers, and suppliers from an economic research perspective. Thaller, Niemann, Dahmen, Clausen, and Leerkamp (2017) presented a specific application of SD in UL operations. La Torre, Gruchmann, Kamath, Melkonyan, and Krumme (2018) showed an SD model that studied customer behavior from a last-mile context perspective.

2.2 Facility Location Problem

Facility location is one of the first and most prominent strategic decisions having a profound effect on tactical and operational decisions in any organization. Location decisions are frequently made at all levels of human organizations, from individuals and households to firms, government agencies, and even international agencies. The study of facility location decisions has a long history in the literature. The facility location problem (FLP) was introduced in the operations research field in the sixties (Balinski, 1965), initially referred to as plant location problem.

The FLPs are classical optimization problems for determining the sites for facilities. These consist of determining the “best” location for one or several facilities to serve a set of demand points. The meaning of “best” depends on the nature of the problem under study, namely in terms of the constraints and of the optimality criteria considered (Laporte, Nickel, & Saldanha da Gama, 2015). The FLPs are useful to anything which needs to be located, such as hospitals, fire stations, bus stops, train stations, truck terminals, fuel stations, blood banking centers, retail outlets, urban districts, libraries, parks, post offices, airports, and waste disposal sites. The FLP can be thought of as a generalization of the transportation problem, with fixed costs for opening supply facilities. Melo, Nickel, and Saldanha-da-Gama (2009) provide a comprehensive review and discussion of FLPs.

In a basic formulation, the FLP consists of a set of potential facility sites where a facility can be opened and a set of demand points that must be serviced. The goal is to determine which subset of facilities to open for minimizing the total cost of delivery of goods to the customers plus the sum of opening costs of the facilities. A simple example of a classical FLP instance is shown in Figure 2, where each customer (circle) is assigned via an active connection to its closest open facility (dark square).

The uncapacitated facility location problem (UFLP) is one of the most-widely studied discrete location problems. The UFLP stands for the problem of determining the best location for a given facility (or the best locations for a given set of facilities), given some constraints about the environment where it can be placed. The term uncapacitated is used in opposition to the capacitated

FLP, where the facilities limit the number of customers they can serve. In the uncapacitated version, such a constraint does not exist.

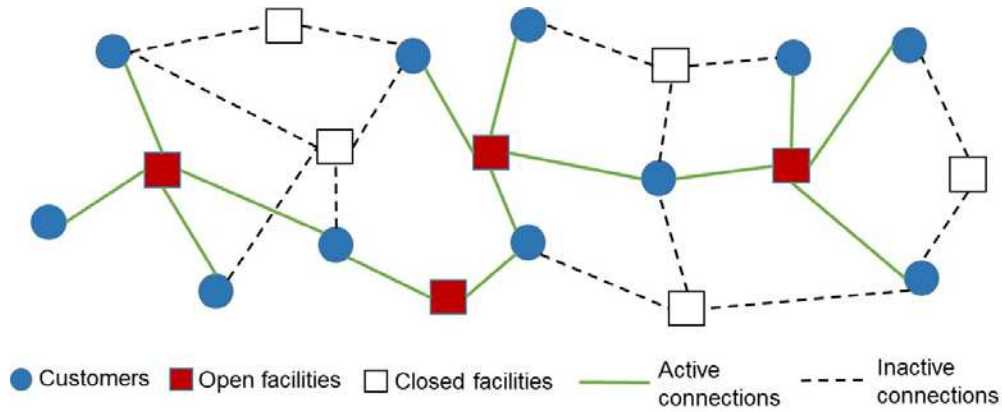


Figure 2: Illustrative example of the classical FLP based on de Armas, Juan, Marquès, and Pedroso (2017)

Eiselt and Marianov (2011) highlight the three primary forms of FLPs according to the type of objective function: mini-max, min-sum, and covering. Farahani, Fallah, Ruiz, Hosseini, and Asgari (2019) remark that various objective functions have been used including minimizing the total setup cost, the longest distance from the existing facilities, fixed cost, total annual operating cost, average time or distance traveled, maximum time or distance traveled, the number of facilities or maximizing service, and responsiveness. FLPs include but are not limited to locating a single facility versus multiple facilities, locating on a plane without any restriction in terms of the number of candidate points versus on a network with a limited number of points, assuming capacitated versus non-capacitated facilities, assuming deterministic versus stochastic parameters, and assuming static versus dynamic parameters.

Farahani et al. (2019) present an exhaustive review of applications of urban service facility location and future developments in the field. Deutsch and Golany (2017) introduced, for the first time, a concrete application of FLP in APL, in a static situation. They have basically ignored the dynamic aspects of the problem, e.g., the variability of customers' willingness to use the service, the variability of customers' willingness to use the service, the variability of operational set up prices, and others. In this paper, we emphasize the dynamic components' behavior of the APL

systems through the SDSM formulation. Furthermore, we use these dynamic parameters in the FLP optimization model formulation as well.

3 SIMULATION-OPTIMIZATION PROCEDURE MODEL

One of the main challenges of simulation and optimization techniques is reacting to uncertainty. The possibilities of the combination are vast, and their appropriate design highly depends on the problem characteristics. Figueira and Almada-Lobo (2014) describe in detail the main classification of different possible combinations. Furthermore, the VDI guideline 3633.12 (VDI 2016) provides a classification for different combinations of simulation and optimization in terms of sequential and hierarchical combination. A sequential combination assumes that either simulation or optimization are completed before the other one can be executed. Within a hierarchical combined approach, the simulation or optimization is introduced as a subclass, which can be called several times during the overall execution. We propose the combination using a sequential approach when the output values of the SDSM are used as input values of the FLP. Figure 3 illustrates the scheme of the combined simulation-optimization process.

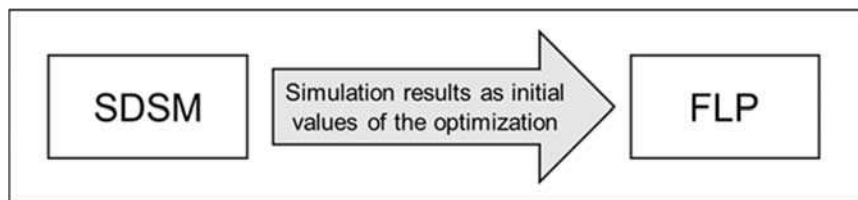


Figure 3. The simulation-optimization combination scheme

In this context, the SDSM evaluates the components' behavior of the APL systems and simulates them under a broad range of scenarios. The FLP model is to provide the optimal location of the APLs, considering the users' expectations.

In a real-life FLP, the variables such as population or customer demand are subject to changes over time (Farahani et al., 2019). Some FLP models incorporate dynamics by adding a subscript “t” to the variables. However, this is usually insufficient to gain the causal relations between key variables (Vos & Akkermans, 1996). For this reason, the SD is an appropriate methodology to determine the behavior of the key variables in an FLP.

Based on these arguments, we propose a procedure model to link an SDSM with an FLP optimization model through an iterative process for the APL implementations. The procedure model includes five principal steps presented in Figure 4. A vertical step refers to the verification and validation of data and models.

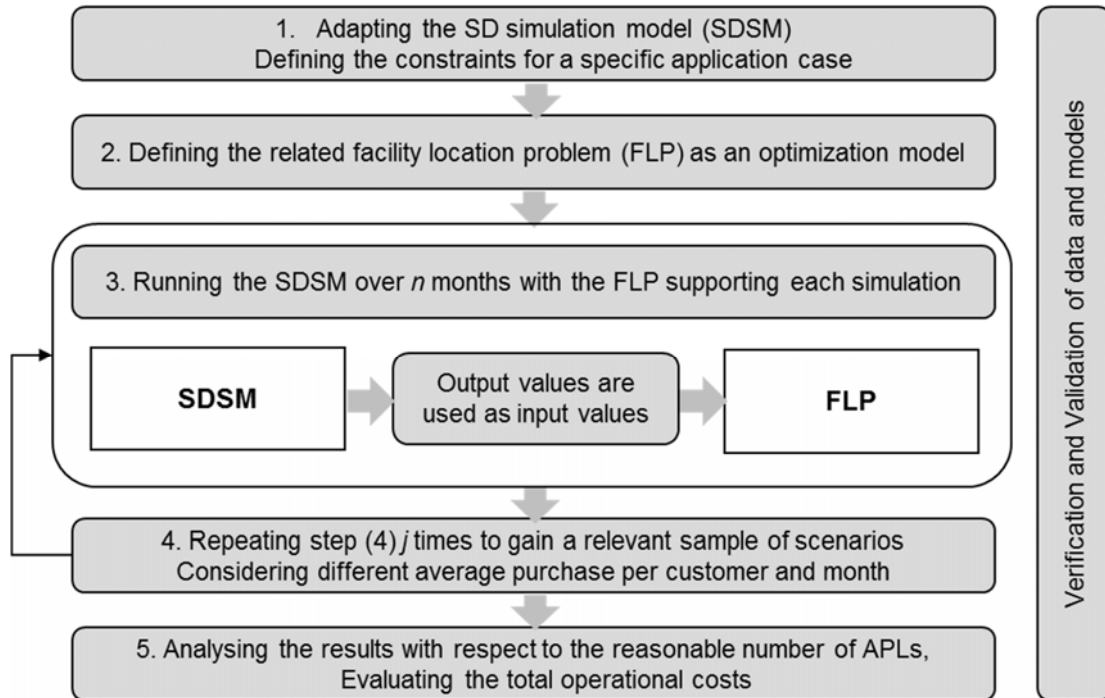


Figure 4. The procedure model for combining an SDSM with an FLP model

4 THE PROCEDURE MODEL APPLICATION

This work addresses the case of Dortmund city, which is located in the Land of North Rhine-Westphalia, Germany. Its population of about 600,000 people makes it the seventh-largest city in Germany and the 34th largest in the European Union. The city is divided into 62 districts, codified from 000 to 960. Figure 5 illustrates the map of Dortmund city with its respective districts.



Figure 5. The map of Dortmund city with its codified districts

4.1 The System Dynamics Simulation Model for a Specific Case

We use an SDSM to understand the components' behavior of the APL systems and their interdependencies. We use Vensim as a software tool that allows us to build a number of different types of diagrams, including causal-loop and stock-flow diagrams. We built these diagrams according to SD standard procedures (Sterman, 2000).

4.1.1 Causal-Loop Diagram

We present the qualitative description of the components' behavior of the APL systems. Figure 6, based on Hernández, Jiménez, and Martín (2010) and Vakulenko et al. (2018), shows the principal components and their interactions. The CLD describes that the market size is positively influenced by the population and the population growth rate. The potential number of e-customers is positively influenced by the market size and positively reinforced by the e-shoppers rate and by the number

of APL users. The number of APL users is also positively reinforced by the APL market share, APL market growth rate, and by the number of deliveries. In turn, the number of deliveries is positively reinforced by purchases per month and by the number of APLs. In turn, the purchases per month are positively reinforced by the average purchases per month and by the on-line purchase rate. The number of APLs are positively reinforced by the number of deliveries and by the average parcels per APL per month. The number of APLs are positively reinforced by the number of deliveries and by the average parcels per APL per month.

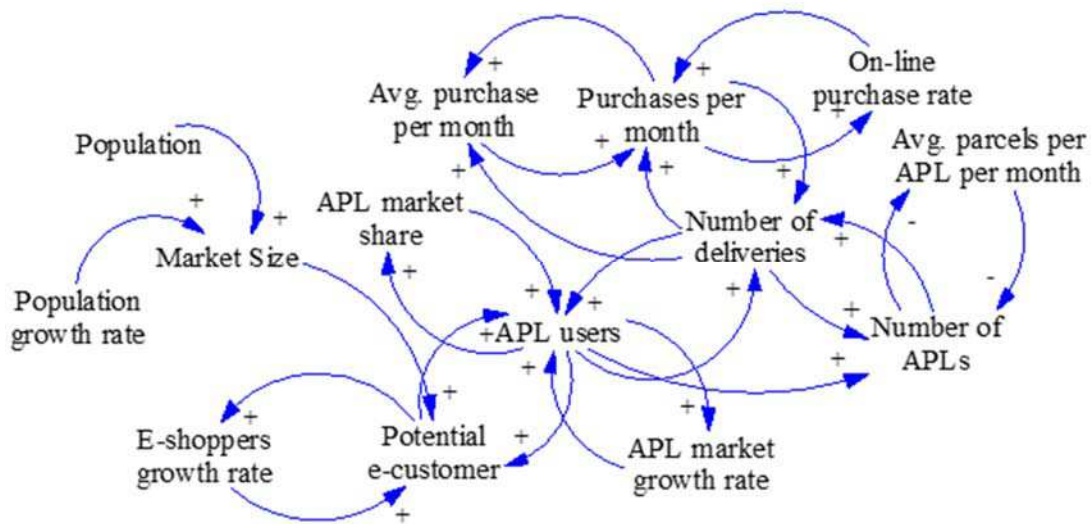


Figure 6. The APL systems causal-loop diagram

4.1.2 Stock-Flow Diagram

Figure 7 indicates the stock-flow diagram, based on the respective causal loop as the quantitative description of the rates, auxiliary, and level variables in the APL systems. To exemplify the model, we use generic information of the city of Dortmund as well as generic information of APL services.

4.2 The Related Facility Location Problem

We consider the problem of designing a network of APLs as one solution to the UL problems, where we assume that the APLs are used by several e-customers. The FLP is defined to deciding where to locate them, and how many standard APLs to install in each site, so as to minimize the total cost in different periods of time.

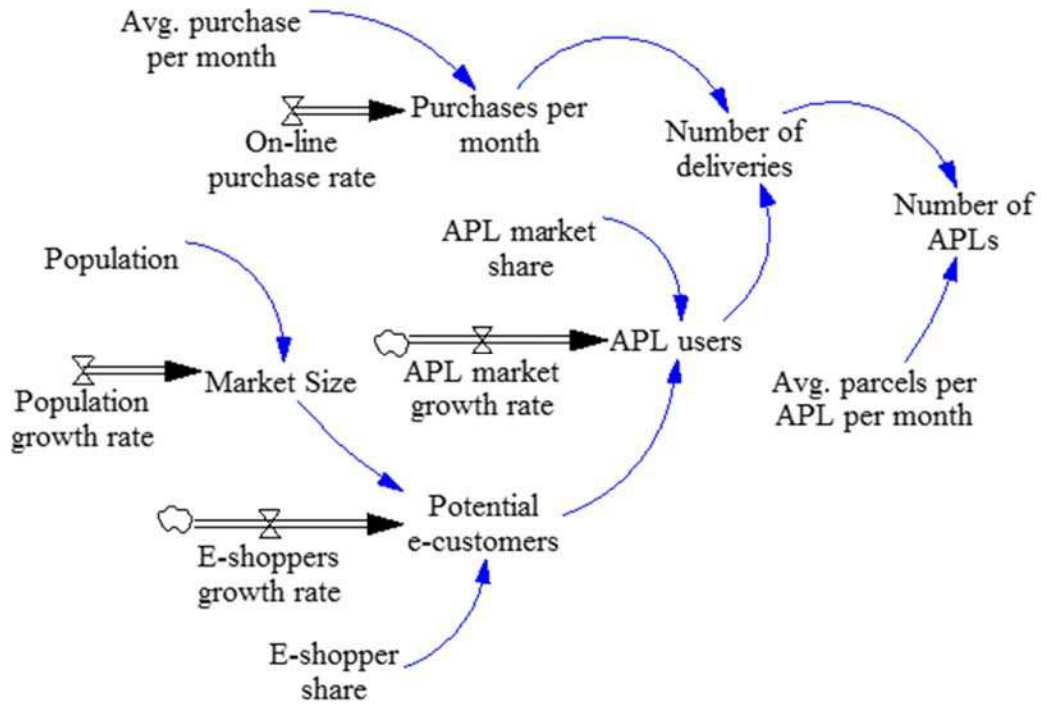


Figure 7. The APL systems stock-flow diagram

4.2.1 Model Formulation

In the city of Dortmund case, we consider a multi-period capacitated FLP (CFLP). The sets are represented by $i \in I$ as the potential locations of the APL, $j \in I$ as the districts of the potential APL users, and $k \in K$ as the different periods of the planning horizon. The parameters in the formulation are represented by d_{jk} as the demand of the district $j \in I$ during period $k \in K$, c_{ij} the unitary cost of assigning an APL located in location i to district j , f_{ik} the cost of installation of the APL in location $i \in I$ during period $k \in K$, h_{ik} the maintenance cost of the APL in location $i \in I$ during period $k \in K$, and a_i the known APL capacity. In this context, the binary variable x_{ijk} takes the value 1 if customers in district $j \in I$ are assigned to an APL in location $i \in I$ during the period $k \in k$, being 0 otherwise. Similarly, the integer variable y_{ik} represents the number of APLs that are installed in location $i \in I$ and period $k \in K$. Then, our multi-period CFLP model is formulated as follows:

$$\text{Minimize } \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} c_{ij} d_{jk} x_{ijk} + \sum_{i \in I} \sum_{k \in K} f_{ik} (y_{ik} - y_{ik-1}) + h_{ik} (y_{ik}) \quad (1)$$

Subject to:

$$\sum_{i \in I} x_{ijk} = 1, \quad \forall j \in J, \forall k \in K, \quad (2)$$

$$y_{ik} \leq y_{ik-1} \quad \forall i \in I, \forall k > 0 \in K, \quad (3)$$

$$\sum_{i \in I} y_{ik} = p_k, \quad (4)$$

$$\sum_{j \in I} d_{jik} x_{jik} \leq a_i y_{ik} \quad \forall i \in I, \forall k \in K, \quad (5)$$

$$x_{ijk} \in \{0,1\}, \quad i \in I, j \in J, k \in K, \quad (6)$$

$$y_{ik} \in \mathbb{Z}^+ \quad \forall i \in I, \forall k \in K \quad (7)$$

$$\sum_{j \in I} d_{jk} \geq m \sum_{i \in I} a_i y_{ik} \quad \forall k \in K, \quad (8)$$

Expression (1) displays the objective function, which minimizes the total cost: the first term indicates the APLs' service cost, while the second one represents the fixed cost of installing and maintenance of new APLs during the time horizon. Constraints (2) ensure that, for each period $k \in K$, each district $j \in I$ is assigned to exactly one APL. Constraints (3) guarantee that once an APL is installed, it remains in that status until the end of the time horizon. Constraints (4) ensure that, for each period $k \in K$, for each district $i \in I$ exactly the number of APLs p_k will be installed that has been determined by the SDSM model. Constraints (5) ensure that, for each APL in location $i \in I$ and period $k \in k$, the demand serviced by that APL does not exceed its capacity. Constraints (6) and (7) indicate the ranges of the decision variables.

Decisions taken in a particular period affect future periods over a time horizon K . In particular, since demand is expected to grow during the next periods, we will assume that whenever an APL is installed inside a period $k \in K$, it has to remain installed until the end of the time horizon, i.e., for all $k' \in K: k' > k$. Similarly, third-party logistics providers state that a minimum percentage m

$\in (0, 1)$ of the total installed capacity has to be utilized. Therefore, Constraints (8) guarantee, for each period $k \in K$, this minimum utilization percentage.

4.2.2 FLP Model Solution

As a mixed-integer programming problem, the multi-period CFLP was implemented in IBM® ILOG CPLEX Optimization Studio 12.9. Additionally, to solve the multi period CFLP the modeler could be used any solution algorithms for these kind of problems, e.g., Eiselt and Marianov (2011), Laporte et al. (2015), or de Armas et al. (2017).

4.3 Running the SDSM with the FLP Supporting the Simulation

In face of the respective stock-flow diagram described before, Table 1 presents the variables, equations, and their initial values used in the SDSM for the APL application in city of Dortmund.

Observing the volatility of e-commerce, the SDSM assesses the APL systems for five years as a planning horizon (divided into 60 months). Table 2 presents the results of the SDSM in the first and the last three months of the planning horizon, using the initial set of values.

4.4 Relevant Sample of Scenarios

Table 3 indicates the principal changes in the average purchase per e-customer per month to build the scenarios. We consider a pessimistic (S1), realistic (S2), and optimistic (S3) scenario. Based on Table 3, we change the average purchases per month in the SDSM. Table 4 shows the results of the number of deliveries (units) at the first month: 51,381 for S1, 154,147 for S2, and 256,907 for S3; at the 60th month: 224,022 for S1, 672,067 for S2, and 1,120,110 for S3. The number of APLs that the city of Dortmund needs at the first month is: 8 for S1, 24 for S2, and 41 for S3; at the 60th month: 37 for S1, 112 for S2, and 186 for S3. Figure 8 illustrates the scenario comparison of the number of deliveries (a) and the number of APLs (b).

Name	Definition	Initial values	Type of variable	Units
Population	Number of inhabitants in the city	602,566	Auxiliary	Inhabitants
Population growth rate	Percentage	(0.2)/12	Rate	% per month
Market size	Population * Population growth rate	Population	Level	Inhabitants
E-shopper share	Percentage	55	Auxiliary	%
E-shopper growth rate	Percentage	(20)/12	Rate	% per month
Potential e-customers	Market Size * E-shopper share * E-shopper growth rate	Market Size * E-shopper share	Level	Inhabitants
APL market share	Percentage	15	Auxiliary	%
APL market growth rate	Percentage	20/12	Rate	% per month
APL users	Potential e-customers * APL market share * APL market growth rate	Potential e-customers * APL market share	Level	E-customers
Avg. purchase per month	Number of deliveries per e-customer	3	Auxiliary	Units
On-line purchase rate	Percentage	20/12	Rate	%
Purchase per month	Avg. purchase per year * On-line purchase rate	Avg. purchase per month	Level	Units
Number of deliveries per month	APL users * Purchases per month	0	Auxiliary	Units
Avg. parcels per APL per month	Number of parcels per APL per month	6,000	Auxiliary	Units
Number of APLs	Number of deliveries / Avg. parcels per APL per month	0	Auxiliary	Units

Table 1. List and initial values of variables for the SDSM.

Variable	Months						
	1	2	3	...	58	59	60
Market size	602,666	602,767	602,867	...	608,391	608,492	608,592
Potential e-customers	334,173	336,935	339,698	...	492,354	495,143	497,932
APL users	50,539	51,374	52,216	...	109,186	110,416	111,653
Purchases per month	3	3	3	...	6	6	6
Num. of deliveries	154,143	159,259	164,480	...	644,198	656,975	669,918
Number of APLs	8	8	9	...	107	109	112

Table 2. Initial results of the SDSM.

Variable	S1	S2	S3
Avg. purchase per month per APL user	1 unit	3 units	5 units

Table 3. Value changes to develop the scenarios.

Variable		Months						
		1	2	3	...	58	59	60
Number of Deliveries	S1	51,381	53,087	54,827	...	215,366	219,666	224,022
	S2	154,143	159,259	164,480	...	644,198	656,975	669,918
	S3	256,907	265,432	274,134	...	1,076,830	1,098,330	1,120,110
Number of APLs	S1	8	8	9	...	35	36	37
	S2	25	26	27	...	107	109	112
	S3	42	44	45	...	179	183	186

Table 4. The scenarios' results regarding number of deliveries and number of APLs.

From the multi-period CFLP model perspective, for each district $j \in I$ and period $k \in K$, we use the SDSM to generate an estimate of the expected number of deliveries (demand) d_{jk} and the number of APLs p . The variable cost c_{ij} is proportional to the distance between each pair of districts. We estimate this distance using a web mapping service. The fixed cost is $f_{ik} = 5,500$ € and the maintenance cost is $h_{ik} = 100$ €. These costs will increase according to the average inflation of

1.5 % every year in the German context. The capacity of each APL in a district $i \in I$ is $a_i = 6,000$ units per month, and the minimum utilization percentage is $m = 40\%$. Then, our multi-period CFLP model is solved in each period using CPLEX, one per scenario. Figure 9 represents the multi-period CFLP results of the spatial location of the APLs in Dortmund for the first and 60th month in Scenario 1. The location symbol has a specific color according to the number of APLs assigned in the respective district. Figure 10 represents the spatial location of the APLs for the first and 60th month in Scenario 2. Figure 11 shows the spatial location of the APLs in Dortmund for the first and 60th month in Scenario 3.

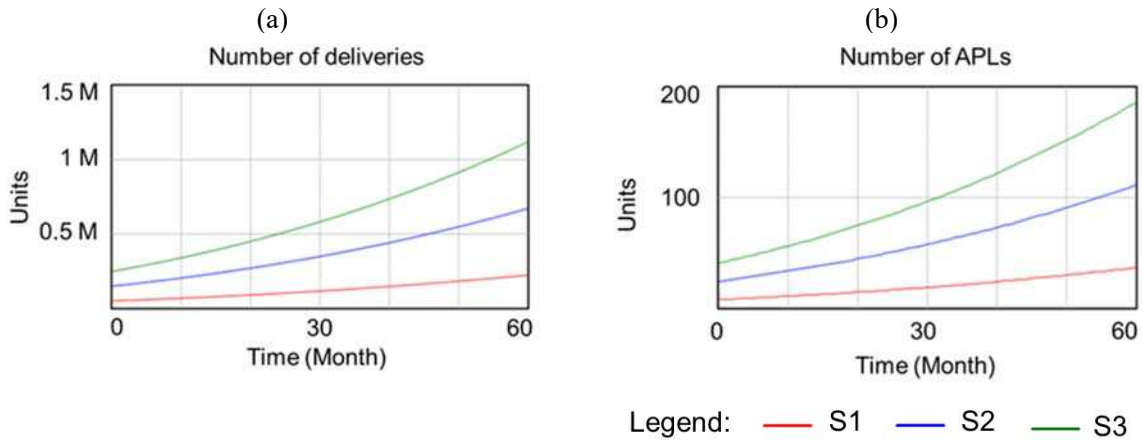


Figure 8: Scenario comparisons: number of deliveries (a) and number of APLs (b)

4.5 Analyzing the Results

As the base average, the number of deliveries (demand) d_{jk} increases over time according to the SDSM results. The same is true for the number of APLs. However, the total number of installed APLs differs significantly from one scenario to another, e.g., 8 for S1, 25 for S2, and 42 for S3 in the first month. The eight APLs in the S1 represent 21 % and 8 % of the demand and geographic covering respectively, with total costs of 44,875 €. The analysis continues considering the results in the different periods in each scenario. Table 5 displays a sample of the total results about the number of APLs, the demand covering, the geographic covering, and the total costs per month and scenario through the planning horizon. On the one hand, the demand coverage is calculated by the number of APLs that cover the respective demand concerning the total demand. On the other hand, the geographic coverage is calculated by the number of locations of APLs respect to the total of 62 districts.



(a)

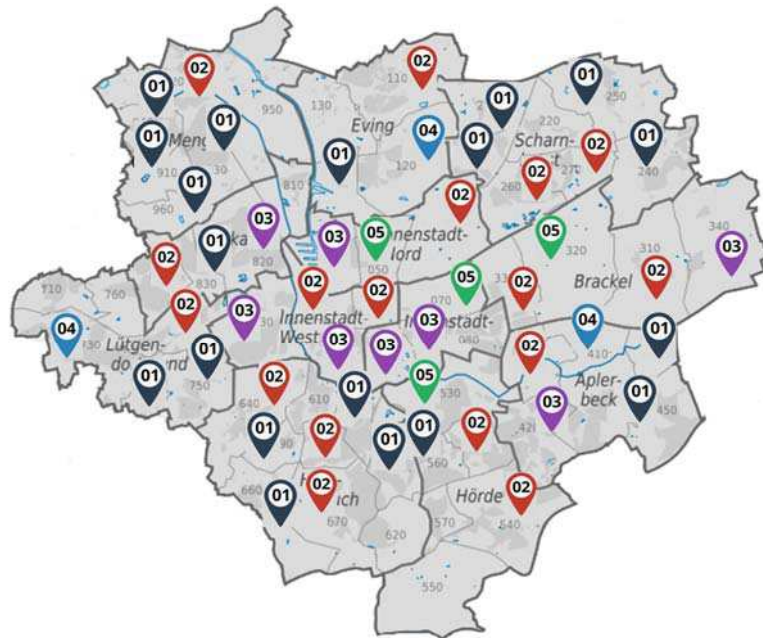


(b)

Figure 9: The Scenario 1 multi-period CFLP results representation: month 1 (a) and month 60 (b)



(a)



(b)

Figure 10: The Scenario 2 multi-period CFLP results representation: month 1 (a) and month 60 (b)



(a)



(b)

Figure 11: The Scenario 3 multi-period CFLP results representation: month 1 (a) and month 60 (b)

Variable		Months						
		1	2	3	...	58	59	60
Number of APLs	S1	8	8	9	...	35	36	37
	S2	25	26	27	...	107	109	112
	S3	42	44	45	...	179	183	186
Demand Covering	S1	21 %	21 %	22 %	...	69 %	70 %	71 %
	S2	45 %	45 %	46 %	...	80 %	81 %	83 %
	S3	71 %	72 %	72 %	...	96 %	96 %	97 %
Geographic Covering	S1	8 %	8 %	9 %	...	43 %	43 %	44 %
	S2	21 %	21 %	22 %	...	60 %	61 %	63 %
	S3	44 %	44 %	45 %	...	82 %	83 %	85 %
Total Costs	S1	44,875 €	802 €	6,432 €	...	3,855 €	10,039 €	10,167 €
	S2	140,233 €	8,127 €	8,241 €	...	23,900 €	24,161 €	30,611 €
	S3	235,592 €	15,451 €	10,050 €	...	43,946 €	44,461 €	38,788 €

Table 5. The scenarios' results of number of APLs, demand covering, geographic covering, and total costs

We use the total cost results for applying a standard formulation of the net present value (NPV). The NPV determines the actual investment needed to implement each scenario. The investment amounts in the three scenarios are: 325,300 € for S1, 987,600 € for S2, and 1,643,900 € for S3.

5 CONCLUSIONS

In this paper, we have emphasized the conceptualization of a procedure model that seeks to link an SDSM with an FLP optimization model. The conceptualization includes five major steps: (i) Adapting an SDSM, defining the constraints for a specific application case; (ii) Defining the related FLP as an optimization model, (iii) Running the SDSM over n months with the FLP supporting each simulation step, using an initial data set, (iv) Repeating step (iii) j times to gain a relevant sample of scenarios; with different average purchase per e-customer and month, and (v) Analyzing the results with respect to the reasonable number of APLs, considering the total operational costs. A vertical step refers to the verification and validation of data and models.

On the one hand, the SDSM describes the causal-loop and stock-flow diagrams. Its diagrams show the main components and their interactions in terms of positive reinforcing or balance loops. On the other hand, the mathematical formulation of a multi-period CFLP model has been developed

to determine where to locate the standard APLs in each district and minimize the total cost in different periods. In this context, an SDSM offers a suitable methodology to determine the behavior of the parameters in our multi-period CFLP model. Then, this model provides an optimal location for the APLs considering expectations on APL users' demands.

The analysis is based on the city of Dortmund as a case study, where we consider servicing demands in each district. Firstly, we design an SDSM to determine the behavior of parameters such as the number of deliveries and the number of APLs. Furthermore, we develop a multi-period capacitated FLP. The model provides an optimal location for the APLs considering expectations on users' demands in each district. We have considered three scenarios to cover pessimistic (S1), realistic (S2), and optimistic (S3) developments. The planning horizon has always been 60 months.

The results for the number of deliveries (units) after 60 months show a wide spread from around 220,000 in the pessimistic case to more than a million in the optimistic case. Obviously, there is a strong impact on the number of APLs that the city needs. In the first month, this figure varies from eight in a pessimistic scenario (21 % and 8 % of the demand and city geography covering respectively) to 42 in an optimistic scenario (71 % and 44 % of the demand and city geography covering respectively). After 60 months, the number of APLs grows to 37 in the pessimistic scenario (71 % and 44 % of the demand and city geography covering respectively) and 186 in the optimistic scenario (97 % and 85 % of the demand and city geography covering respectively). Interestingly, the “realistic” scenario leads to a number of APLs required that lies just in the middle of the other two scenarios, i.e., the effect on the APLs appears linear with respect to the e-consumers without obvious scale effects.

Considering the total costs, we apply a standard formulation of the net present value (NPV). The NPV determines the investment needed to implement each scenario. The investment amounts in the three proposed scenarios are: 325,300 € for S1, 987,600 € for S2, and 1,643,900 € for S3. Based on these investment amounts, third-party logistics providers could decide to implement the APL as delivery scheme.

The procedure model is a decision-making tool for APL adoption as a last-mile delivery scheme, reducing the risk of failures in their implementations. For the future, observing the uncertainty of the demand could be modeled and simulated as a random variable. Furthermore, the procedure model could be applied in any city around the world, especially in cities in emerging markets, considering the APL schemes' few applications in these kinds of markets.

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