Contributions to Sustainable Urban Transport: Decision Support for Alternative Mobility and Logistics Concepts

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Für Justus, Minou und Theodor

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I. Abstract

Increasing transport activities in cities are a substantial driver for congestion and pollution, influencing urban populations' health and quality of life. These effects are consequences of ongoing urbanization in combination with rising individual demand for mobility, goods, and services. With the goal of increased environmental sustainability in urban areas, city authorities and politics aim for reduced traffic and minimized transport emissions.

To support more efficient and sustainable urban transport, this cumulative dissertation focuses on alternative transport concepts. For this purpose, scientific methods and models of the interdisciplinary information systems domain combined with elements of operations research, transportation, and logistics are developed and investigated in multiple research contributions. Different transport concepts are examined in terms of optimization and acceptance to provide decision support for relevant stakeholders. In more detail, the overarching topic of urban transport in this dissertation is divided into the complexes *urban mobility* (part A) in terms of passenger transport and *urban logistics* (part B) with a focus on the delivery of goods and services. Within part A, approaches to carsharing optimization are presented at various planning levels. Furthermore, the user acceptance of ridepooling is investigated. Part B outlines several optimization models for alternative urban parcel and e-grocery delivery concepts by proposing different network structures and transport vehicles. Conducted surveys on intentional use of urban logistics concepts give valuable hints to providers and decision makers.

The introduced approaches with their corresponding results provide target-oriented support to facilitate decision making based on quantitative data. Due to the continuous growth of urban transport, the relevance of decision support in this regard, but also the understanding of the key drivers for people to use certain services will further increase in the future. By providing decision support for urban mobility as well as urban logistics concepts, this dissertation contributes to enhanced economic, social, and environmental sustainability in urban areas.

Keywords: Information Systems Research, Decision Support, Operations Research, Acceptance Research, Urban Transport, Urban Mobility, Urban Logistics, Sustainability.

Abstrakt

Zunehmende Verkehrsaktivitäten in Städten verursachen Staus und Umweltverschmutzung, welche die Gesundheit und Lebensqualität der Stadtbevölkerung beeinflussen. Diese Problematik ist eine Folge fortschreitender Urbanisierung sowie einer steigenden individuellen Nachfrage nach Mobilität, Gütern und Dienstleistungen. Mit dem Ziel die ökologische Nachhaltigkeit in Städten zu gewährleisten, streben Stadtverwaltungen und Politik eine Verkehrsreduzierung sowie eine Senkung der Verkehrsemissionen an.

Um einen effizienteren und umweltfreundlicheren Stadtverkehr zu fördern, konzentriert sich die vorliegende kumulative Dissertation auf alternative Transportkonzepte. Dazu werden wissenschaftliche Methoden und Modelle aus dem interdisziplinären Forschungsfeld der Wirtschaftsinformatik genutzt, mit Operations Research-, Transport- und Logistikansätzen kombiniert und in verschiedenen Fachbeiträgen analysiert. In diesem Zusammenhang werden verschiedene Verkehrskonzepte hinsichtlich Optimierung und Akzeptanz untersucht, um relevante Akteure in ihrer Entscheidungsfindung zu unterstützen. Das übergeordnete Thema des Stadtverkehrs wird in dieser Dissertation in die Themenkomplexe *urbane Mobilität* (Teil A) im Hinblick auf den Personenverkehr, sowie *urbane Logistik* (Teil B) mit dem Schwerpunkt auf der Lieferung von Gütern und Dienstleistungen unterteilt. Im Rahmen von Teil A werden Ansätze zur Carsharing-Optimierung auf verschiedenen Planungsebenen vorgestellt. Darüber hinaus wird die Nutzerakzeptanz von Ridepooling untersucht. Teil B präsentiert mehrere Optimierungsmodelle für alternative urbane Paket- und E-Grocery-Zustellkonzepte und empfiehlt dabei verschiedene Netzwerkstrukturen und Transportfahrzeuge. Durchgeführte kundenseitige Erhebungen zur beabsichtigten Nutzung verschiedener Logistikkonzepte geben Logistikdienstleistern und Entscheidungsträger wertvolle Handlungsempfehlungen.

Die vorgestellten Ansätze mit ihren jeweiligen Ergebnissen ermöglichen eine zielgerichtete Unterstützung hinsichtlich der Entscheidungsfindung auf Grundlage quantitativer Daten. Aufgrund des kontinuierlichen urbanen Verkehrsanstiegs wird die Bedeutung entsprechender Entscheidungsunterstützung, ebenso wie das Verständnis der wichtigsten Motive für die Nutzung bestimmter Dienstleistungen in Zukunft weiter zunehmen. Durch die zur Verfügung gestellten urbanen Mobilität- und Logistikkonzepte trägt diese Dissertation zur Verbesserung der wirtschaftlichen, sozialen und ökologischen Nachhaltigkeit in Städten bei.

Schlagworte: Wirtschaftsinformatikforschung, Entscheidungsunterstützung, Operations Research, Akzeptanzforschung, Urbaner Transport, Urbane Mobilität, Urbane Logistik, Nachhaltigkeit.

II. Management Summary

In an era dominated by ongoing urbanization, rising individual mobility needs, continuous growth of e-commerce, as well as rising demand for all types of goods and services, the efficient transport within cities becomes a major challenge. Resulting transport activities lead to increased traffic, congested road networks, and different kinds of pollution. To reduce these negative externalities on urban inhabitants' health and quality of life, politics and city authorities are interested in optimizing urban transport activities. Action is required to alleviate the problems described, while maintaining city dwellers' needs. As standalone measures, such as the introduction of emission ceilings or the sole use of eco-friendly vehicles do not overcome the entirety of the problems mentioned, alternative transport concepts have to be developed. These concepts in combination with regulations may be able to drastically affect urban road networks, but at the same time city dwellers' and companies' daily transportation routines and costs. Alternative ways of transport and respective acceptance of these concepts by both stakeholders is therefore indispensable. In this regard, it may have beneficial effects that our population is increasingly aware of economic, social, and environmental sustainability (Dedrick, 2010).

The methods and models of the interdisciplinary information systems (IS) domain can be applied to derive solutions for transport related issues by information usage and processing to enable appropriate decisions on sustainable actions (Watson et al., 2010). Development and interpretation of optimization models as well as quantitative surveys provides decision support to identify best possible solutions and recommendations regarding the investigated transport concepts.

In this cumulative dissertation, the overarching topic of urban transport is divided into urban mobility (part A) and urban logistics (part B), which are both based on related research articles. Part A focuses on new mobility services (NMS) related to the concept of sharing, which are facilitated through modern information and communication technologies (ICT). In more detail, carsharing is analyzed in terms of optimization potential, while ridepooling is examined regarding its customer acceptance. Part B mainly focuses on transport processes of courier, express, and parcel (CEP) service and e-grocery providers with investigations in terms of optimization and acceptance.

In the following, a brief summary of addressed solution approaches is presented.

The initial focus in *part A* is on carsharing optimization approaches. Carsharing is a mobility concept for individuals to use a car without owning it. The contained research contributions deal with station-based carsharing concepts. Users pay fees based on the period of use and/or distance for renting a company-owned car at fixed locations. Regarding optimization purposes, strategic network planning is divided from tactical fleet assignment and operative revenue and pricing decisions. All planning stages are addressed as subject of different optimization approaches and described in the following.

The accessibility of carsharing stations is described as most relevant factor for the long-term success of a carsharing organization. The placement of stations is a challenging task and should be as close as possible to the demand locations of customers to best satisfy existing customer demand. The developed approach is based on a definable service level, which allows to exclude areas with lower demand from network planning. The respective optimization model maximizes the annual profit of a station-based two-way carsharing organization concerning the strategic station and tactical fleet planning. Besides other features, the model allows to permit the establishment of a heterogeneous fleet, take account for a preset maximum CO_2-threshold, and limit the distance between stations and customer to optimally satisfy demand. Based on a mathematical model, a decision support system (DSS) is introduced (see Figure 1).

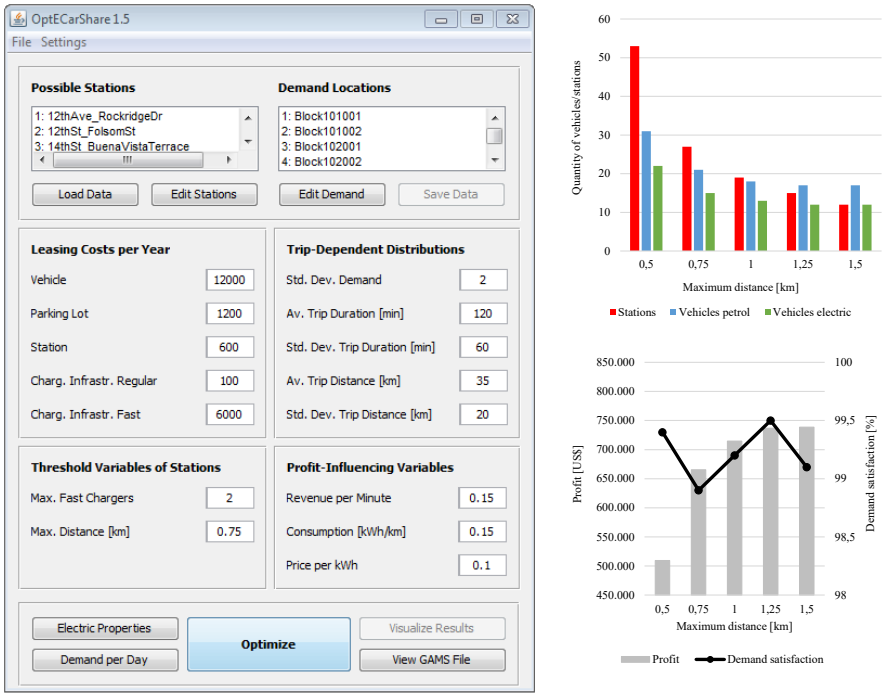

Figure 1. Strategic Carsharing Optimization: Decision Support System and Results; Based on Sonneberg et al. (2015; 2020).

The DSS allows the setting of desired parameters and enables decision makers to solve their own scenarios without optimization knowledge. Irrespective of the investigation area chosen, the maximum distance between customers and assigned stations depicts one of the most crucial factors for network generation, corresponding vehicle deployment, and resulting profit (see Figure 1). Likewise, the choice and size of the investigation area with its underlying demand has a major influence on network design and resulting costs. The preset emission limit mainly influences the vehicle selection, but not the station network itself. Based on further generalizations, carsharing providers are supported in strategic and tactical planning of stations and fleet assignment for a more profitable operation (section 2).

The next introduced concept focuses on the tactical decision level of carsharing. The accessibility and availability of vehicles in station-based two-way carsharing is described as one of the most significant factors to meeting customers' demands. With locations of carsharing stations defined, the developed optimization model enables tactical vehicle distribution based on fluctuating demands while considering emission limits. The model and performed benchmarks permit decision support for carsharing providers in response to monthly demand fluctuations while taking into account customer satisfaction, sustainability, and profitability (section 3).

The last optimization approach of part A focuses on carsharing revenue management at operative level. While considering different vehicle types, the mathematical model performs demand-side management preferring profitable journeys over of less profitable short-term reservations. The approach provides assistance for carsharing providers in terms of revenue management for a more efficient vehicle utilization (section 4).

Part A is completed by an investigation on the customer acceptance of ridepooling, which applies and evaluates a survey-based IS approach. In ridepooling, users hail a shuttle to designated pick-up points near their location; passengers are matched and transported together in company-owned vehicles. While theoretical calculations suggest positive impact on traffic and emissions, the service is currently not widely utilized. Therefore, the approach focuses on the exploration of factors that influence the customers' acceptance of ridepooling to derive recommendations for ridepooling providers (Figure 2). As practical implications, ridepooling providers should highlight the usefulness of the service,

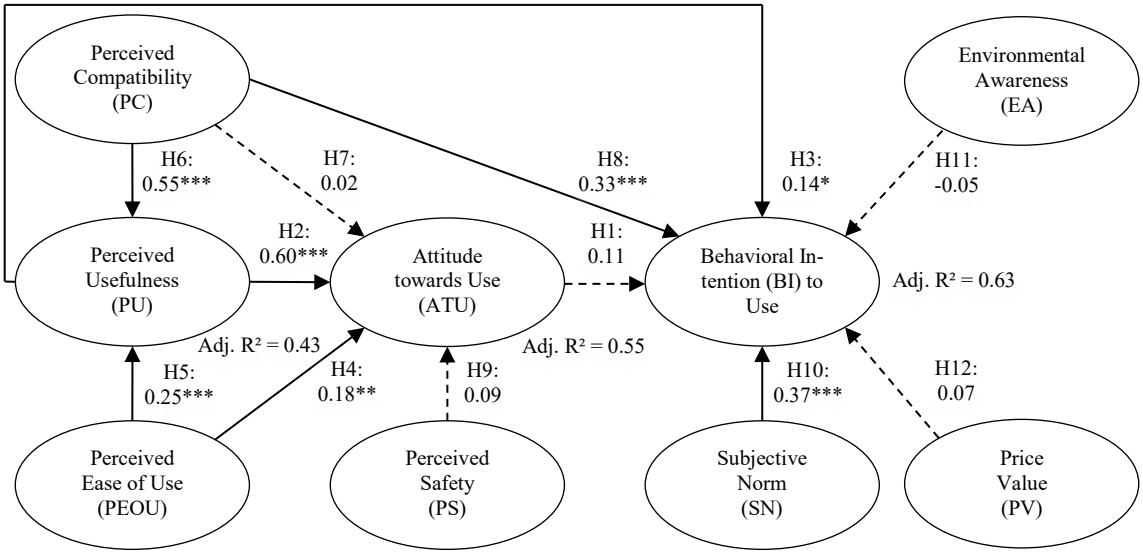

Figure 2. Results of the Path Analysis; Based on Werth et al. (2020).

offer an easy booking process, and convince early adopters to gain higher usage rates. Environmental benefits, prices, and safety issues are in customers' view not relevant due to the typical irregular use for occasional trips (section 5).

Part B of this dissertation focuses on urban logistics. Rising individual demand for goods and services, driven and supported by the growth of e-commerce, require efficient and sustainable transport solutions. Today, transport providers perform their logistics activities mostly with conventional powered vans and trucks. To reduce congestion and pollution, the implementation of regulatory or incentive measures is necessary and needs to be combined with sustainable logistics concepts and strategies making use of new technologies and additional infrastructures. One respective idea is the installation of transshipment points in combination with alternative delivery vehicles. However, current pilot projects in this regard mostly focus on solutions tailored to CEP service providers and further investigations are required to support a sustainable way of urban life through less urban road transport.

The first introduced concept does therefore not exclusively focus on CEP service providers; it permits a generic optimization of routing for various kinds of urban goods and service transporters. With optimized routes, the company can save costs, while the environment benefits from reduced emissions. Based on a heuristic solution approach covering a bandwidth of possible routing specifics, a DSS is developed. In Figure 3, the user interaction and the system architecture of the DSS is illustrated. Users without optimization knowledge or programming skills are able to optimize their customized business

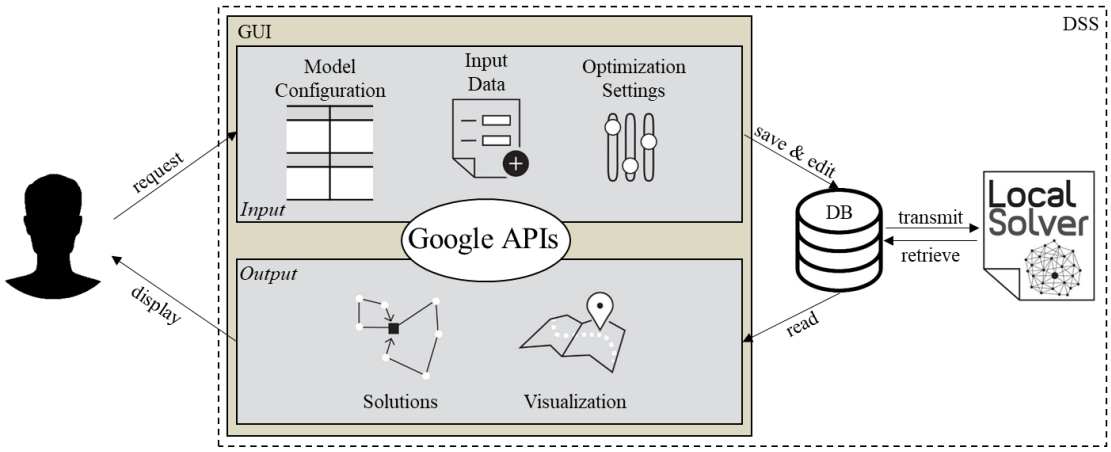

Figure 3. User Interaction and System Architecture of the DSS; Based on Leyerer et al. (2019a).

cases. The tool is evaluated by a proof-of-concept. Two real-world application examples highlight the efficient solution performance as well as resulting savings in terms of distance and emission (section 6).

The remaining sections of the part urban logistics account for the rising percentage of parcels forecasted in next years and focus on e-grocery and CEP service providers.

The first respective concept supports simultaneous optimization of urban micro-depot locations, vehicle fleet assignment, and routes. The consideration of urban micro-depots reduces the last mile to customers' homes and allows for the implementation of alternative delivery vehicles. The developed mathematical model minimizes the monthly operating costs while deploying heterogeneous fleets and emission limits. The following Table 1 visualizes exemplary results of the conducted benchmarks. When incorporating hub operation, (fixed and variable) vehicle, and personnel costs, a CO_2-neutral delivery (tank-to-wheel emissions) only amounts to additional cost of about 6%. In this case, a heterogeneous fleet consisting of electric cargo bicycles (eCB), electric cargo tricycles (eCT), and electric powered vans (eVan) is suggested to be deployed. Based on further scenario

Table 1. Benchmarks for Different CO_2-Emission Levels for A2; Based on Leyerer et al. (2019b).

Max. CO_2-level [gCO_2/km]	Total costs [€/month]	Used hubs [#]	Used vehicles [#]							Approx. distance covered [km/day]			Total emissions [gCO_2/day]	Average emissions of vehicle fleet [gCO_2/km]
			eCB	*eCT*	*Car*	*eCar*	*Van*	*eVan*	Σ	Diesel driven	Electric driven	Σ		
200	187,465	37	2	-	-	-	60	-	62	300.2	11.9	312.1	60,038	192.3
150	189,156	36	19	-	-	-	48	-	67	240.0	121.0	361.0	48,000	133.0
100	191,242	27	37	-	-	-	36	-	73	180.1	187.5	367.6	36,027	98.0
50	195,819	33	51	-	2	-	18	6	77	115.2	341.3	456.5	20,820	45.6
0	199,091	21	54	2	-	-	-	22	78	-	467.4	467.4	0	0.0

analyses, a heterogeneous delivery fleet in combination with micro-depots is more cost-efficient than a homogeneous fleet due to the vehicles' varying (dis-)advantages. The model is incorporated into a user-friendly DSS, which supports decision makers in finding appropriate solutions for a more sustainable urban delivery of goods (section 7).

The subsequently introduced model focuses on delivery by means of autonomous unmanned ground vehicles (AUGV). These robots move autonomously within public space on footpaths, relieve stressed road networks, and are predominantly used for small-sized same-day or instant deliveries. The developed mathematical model optimizes station selection in terms of number and location, related customer assignment, number of AUGV, as well as corresponding routes. An application example based on different scenarios allows to derive implications and recommendations in terms of efficient parcel delivery for CEP service providers and AUGV manufacturers (section 8).

The delivery of online-ordered groceries (e-grocery) is part of next investigation. Compared to conventional operation with vans, a novel concept for e-grocery delivery is introduced that employs refrigerated grocery lockers. These are spread throughout the city and allow for self-collection by customers or delivery via ECB. Figure 4 visualizes the concept and the calculation stages of the 3-echelon optimization model. With the overall

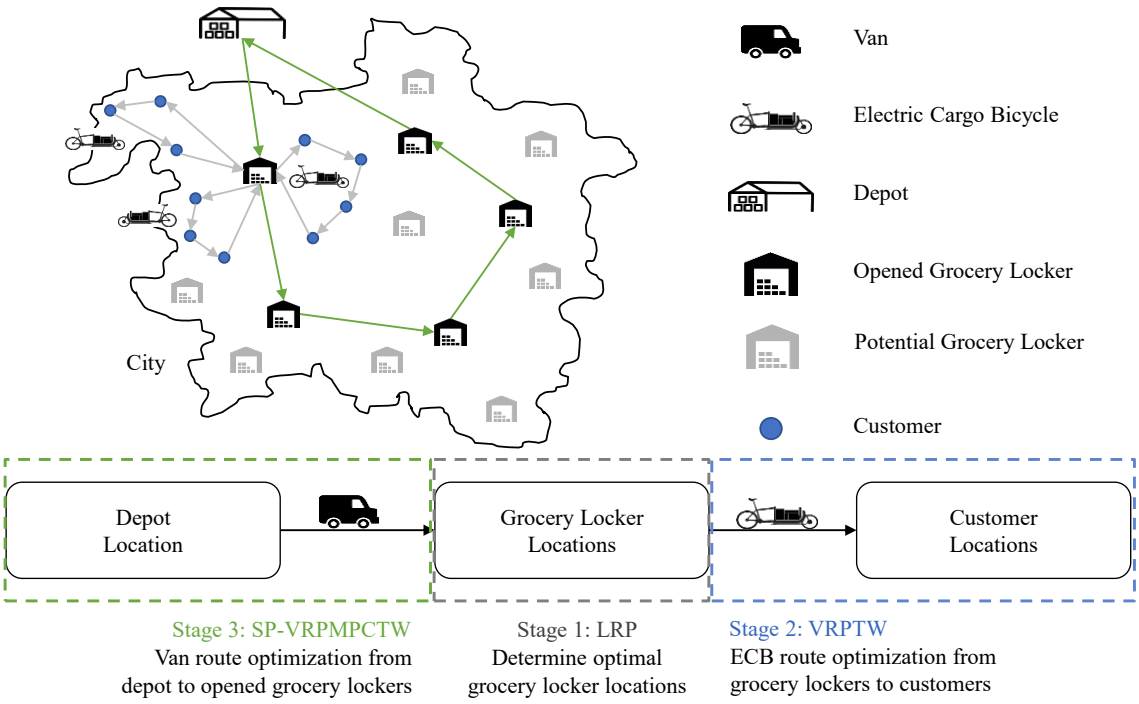

Figure 4. Overview of the Proposed E-Grocery Logistics Concept; Based on Leyerer (2020).

goal of costs minimization, grocery lockers are established, ECBs are assigned, and routes for grocery locker and home deliveries planned. Sensitivity analyses include varying ratios of home delivery and self-collection customers, the maximum distance between grocery lockers and assigned customers, as well as a comparison to the conventional delivery. Results highlight the impacts on distance travelled, emitted emissions, required space, and resulting costs. Decision makers are supported in planning and implementing a more sustainable and urban road relieving delivery concept for e-groceries (section 9).

End customer acceptance regarding 14 different delivery alternatives of the CEP service and e-grocery industry is investigated in the final article of this dissertation. With the logistics concepts previously examined in terms of optimization, their successful implementation heavily depends on the acceptance and application of end customers. To provide decision support in this regard, factors for the acceptance were analyzed and interpreted by conducting survey-based IS research on different concepts. The 14 concepts range from various forms of self-collection and unattended access for various types of properties to delivery via alternative transport vehicles. Elaborated factors for most concepts are perceived efficiency, social influence, and habit. In terms of recommendations, CEP service and e-grocery providers should focus on punctual delivery in offered short timeframes with tracking opportunities, advertising measures, provision of positive customer feedback, and promotional videos to highlight the advantages of the concepts, as well as the easy implementation in daily behavioral patterns and the provision of incentives (section 10).

After presenting the related research articles as core elements of the cumulative dissertation, an overall discussion critically reviews these contributions in context of the overarching topic of urban transport. Resulting contributions derived during the time as research assistant, limitations regarding the topics as well as the research methods of IS, and future research on urban transport are presented (section 11).

In summary, this dissertation presents optimization and acceptance approaches to address the problems of ongoing urbanization, rising individual needs, and resulting externalities on urban road networks and city dwellers. Thus, the dissertation contributes to increased economic, social, and environmental sustainability by applying different theoretical IS methods as foundation for the suggested practical solutions.

III. Table of Contents