Tactical and Operative Optimization of the Last Mile in Urban Logistics

Masterarbeit

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1 Introduction

1.1 Motivation and Objective

In today's competitive and highly demanding environment, there is a growing recognition that cost reduction and customer service are achieved on the basis of efficient logistics. An efficient distribution of goods and services is crucial for many companies since transportation is an important cost factor, and hence they constitute a considerable component of final purchase prices. In this regard, vehicle routing is considered an important source for potential savings in a company's distribution system (Drexl, 2012, p.47; Crainic and Laporte, 1998, pp.6-7). Studies have demonstrated that optimized routing plans can lead to significant economic savings ranging between 5-30% (Hasle and Kloster, 2007, p.398) or 5-20% (Toth and Vigo, 2002, p.1) on average. Besides the economic importance for the companies themselves, the macroeconomic relevance of efficient routing plans must not be overlooked. The avoidance of unnecessary long routes with low degrees of capacity utilization contributes to the reduction of harmful emissions and reduces congestion by removing pressure from road infrastructure (Cattaruzza et al., 2017, p.52).

The Vehicle Routing Problem (VRP) in its many variants has been widely studied for more than 50 years (Laporte, 2009, p.408). The VRP calls for the determination of the optimal set of routes to be performed by a fleet of vehicles to serve a given set of customers (Toth and Vigo, 2002, p.1). Typically, routing models are developed to support operational as well as tactical decision-making processes in transport and logistics (Lahyani et al., 2015, p.2).
While a human planner may often be able to conceive a feasible routing schedule within reasonable time for small problem sets, such manual solutions are usually far from optimality when the specific business context requires the consideration of structural constraints such as time windows and capacity restrictions (Rademeyer and Lubinsky, 2017, pp.57-58). In this sense, it is advisable to rely upon scientific approaches to address such combinatorial optimization problems that are notoriously hard to solve. While academic researchers have devoted much effort to developing new variants and solutions methods for the VRP, much of this work has been criticized of "being too focused on idealized models with non-realistic assumptions for practical applications" (Hartl et al., 2006, p.103). Therefore, in order to make vehicle routing an appealing option for companies catering to customer needs in different business contexts, it is necessary to incorporate more intricate constraints and objectives into VRP models and to adapt Decision Support Systems (DSS) capable of handling a variety of structurally different problems (Sörensen et al., 2008, p.243; Lahyani et al., 2014, p.1).

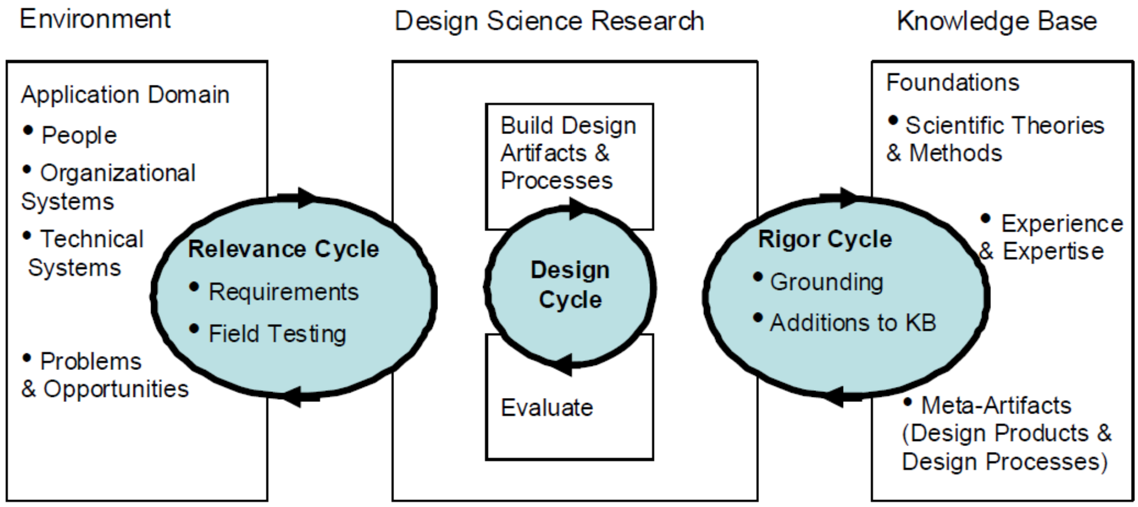
Taking a modeling standpoint, this thesis investigates how typical distribution problems faced by companies dealing with routing issues in their business operations can be addressed effectively and efficiently by means of a DSS. Because it cannot be an option to develop and implement a problem-specific routing model for each business context, the goal is to develop a versatile routing model capable of handling a variety of different practical problems. This model is integrated in a user-friendly software system that can assist managerial decision-making on the tactical and operational level.

Yet, existing solution methods are mostly unable to handle the multiplicity of possible constraints and objective combinations and the development of a new problem-tailored method is a time-consuming process. Therefore, this thesis relies upon the innovative general-purpose heuristic LocalSolver for modeling and solving the routing problem. LocalSolver is a math-programming solver following the model-and-run paradigm that allows one to focus on the modeling of the problem and to defer its resolution to a black-box solver based on local-search techniques (Benoist et al., 2011, p.299). With respect to the advertised versatility of the routing model developed in this thesis, the application of a generic solution method offers great prospects to tackle a large class of different problems without requiring extensive user expertise on algorithmic implementation.

1.2 Research Methodology

This thesis bases on the methodological approach of design science research (DSR) as conceptualized by Hevner et al. (2004) and Hevner (2007), which is widely used in Information Systems research (Fischer, 2011, p.5). DSR is a pragmatic research paradigm promoting the creation of innovative and valuable artifacts to solve real-world problems. Hevner describes a framework for researchers and practitioners to understand and address the problem domain. He depicts three cycles that must be present and identifiable in every DSR project, namely the Relevance Cycle, the Design Cycle and the Rigor Cycle. Figure 1 illustrates the DSR framework overlaid by the three cycles as found in Hevner et al. (2007).

Figure 1: Design Science Research Cycles (Hevner, 2007, p.88)



A DSR research process typically starts with the identification of problems and opportunities in an application environment. This thesis is motivated by the observation that companies can have large efficiency reserves in transportation processes due to a lack of optimized routing considerations. Furthermore, many academic approaches to solving routing problems are too problem-specific to be applicable in the various business contexts, in which routing problems generally occur. On this basis, the relevance cycle represents the formulation of requirements for the design of a meaningful artifact to improve the current situation.

The rigor cycle represents a researcher's selection and application of appropriate theories and methods as sources for all design activities. A literature review on VRPs is conducted within the broader context of tactical and operational decision-making (chapter 3.1). In order to ensure an appropriate focus on the application domain, the scope of the VRP review is narrowed to real-world application cases and their respective modeling approaches. As Iivari (2007) points out, if DSR is solely based on scientifically validated knowledge, there is a risk of merely reproducing existing artifacts (meta-artifacts), which may have been constructed outside of the research community (Iivari, 2007, p.50). Therefore, a brief overview of existing vehicle routing software systems in practice is documented in chapter 2.1. The rigor cycle ideally concludes with a research contribution to the knowledge base (Hevner, 2007, p.90). Subsequent to the conducted literature review, this thesis proposes a classification scheme for VRPs (chapter 3.2), which may be used as a reference framework for the structurally different VRP models encountered in VRP literature. In this thesis, the classification scheme provides the basis for the developed model and serves as a navigating structure for the user interface in the software system.

The purpose of this thesis is to create a vehicle routing software system that can be applied by practitioners from various business contexts. In a first step, this requires the formulation of a routing model, which is adaptable to a given business context (chapter 4), and the application of an appropriate solution method. In a second step, the routing model and its resolution mechanism must be integrated in a user-friendly software system (chapter 5).
As stated by Hevner et al. (2004), "the goal of design science research is utility" (S.80). Besides activities of constructing an artifact, the design cycle calls for continuous evaluation of resulting work to ensure its adequacy to improve the environment. On one side, the functionality and efficiency of the routing model is monitored continuously throughout the development process. On the other side, the evaluation of the artifact must be based on scientific theories and engineering methods drawn from the knowledge base. For this purpose, the artifact is tested on different well-known academic VRP benchmarks to ensure validity and functionality (chapter 6.1).

8 Conclusion and Outlook

This thesis presents a set-based formulation of a routing model based on identified VRP model attributes in literature and introduces a decision support tool relying on a component-based design. The DSS provides a user-friendly interface and supports the full customization of a routing model by offering a pool of various model attributes. This allows practitioners from different business contexts to describe a practical routing problem using a single optimization tool. The possibilities of using the resulting artifact for tactical and operational decision-making are highlighted.

For modeling the routing problem and for its resolution, this thesis makes use of LocalSolver, which is the first math programming solver integrating pure and direct local search techniques for combinatorial and continuous optimization in a model-and-run fashion. The creators of LocalSolver advertise the method's efficiency when applied on routing and scheduling problems, for which a solution can be represented in form of an ordered set (Darlay, 2017). The results of applying LocalSolver on different well-known VRP benchmark instances are revealing in this regard. However, it is pointed out that a more thorough testing procedure must be carried out to ensure that reasonable results are obtained not only for idealized problems variants but also for the various attribute combinations a user of the DSS can choose. In addition, an empirical evaluation in the field is suggested in the context of the DSR relevance cycle. An evaluation in cooperation with a company dealing with different problem attributes in transportation can lead to future amendments of the developed routing model and of the web-application. In this sense, using LocalSolver's LSP language for modeling the Multi-Attribute VRP has the benefit of being easily maintainable and extendible.

The rigor cycle as part of the DSR process concludes with a new classification scheme for VRPs amalgamating previous taxonomic works and insights from the literature review on VRP model attributes. Comparing the attributes in the classification scheme to the considered attributes in the Multi-Attribute VRP is a way of pointing to future model expansions by identifying voids. In concrete terms, this means that the Multi-Attribute VRP should be extended to incorporate multiple periods, multiple product types, compartmentalized vehicles, driver regulations, customer inventories, and environmental/social considerations.
Chapter 4.4 demonstrates an example procedure how the Multi-Attribute VRP can be used from a dynamic perspective by adjusting routes during their execution. While applying a fast local search heuristic takes all its sense for adjusting routes in an online fashion, the benefit of the rerouting approach in terms of potential savings comes at the expense of time-consuming adjustments of input data. In practice, the utility of a dynamic planning component largely depends on its ease of use and degree of automation. In this regard, challenges mainly concern the implementation of a dynamic planning component in a software system, which constitutes a field of further research and improvement of the DSS.