Urban Logistics Routing Problems: Analysis of Heuristic Methods

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Abstract

Acknowledgments

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1 Introduction and Motivation

With the rise of online trading and the resulting merchandise respectively personal movements, urban logistics problems become ubiquitous optimization problems nearly all modern enterprises have to deal with. The approach to logistics determines crucially the effectiveness of economic action. No matter whether a food delivery provider wants to maximize the occupancy rate of his drivers, courier express parcel service providers aim to minimize costs or the growing urban population necessitates more efficient waste collection, logistic challenges require optimization. Urban logistics, thereby, deal especially with the transport of goods in the business-to-consumer relationship. The urban last mile delivery counts towards the most expensive piece in the supply chain because of high personnel costs (Gevaers et al., 2009).

Especially in times of big data and of a social shift to a more data-driven culture, such optimizations cannot be solved exactly in a reasonable amount of time. The need for fast approximate procedures arises. This becomes even more imminent as a result to the increasingly complex environment these companies operate in, the mounting economic pressure and the growing customer demands. Consequently, couriers, food deliverers and waste disposal companies as well as all other businesses operating in urban areas introduce automate logistical concepts for distance minimization (Van Audenhove et al., 2015).

This development makes the following research question necessary:

How do approximate methods compare for solving urban logistics problems?

This question can be further subdivided into the following issues.

- What are approximate methods companies could use to solve their logistic related questions?
- How does the performance of the methods compare?
- Is there a best logistic optimization concept?
- What are future challenges logistic concepts will face?

1.1 A Machine Learning View on Logistic Solutions

One possible way to solve such problems is by the use of machine learning, to be more specific the sub-area of reinforcement learning. Reinforcement learning methods solve optimization problems by letting an agent learn the effects his actions have on the objective function (Birattari, 2004).

Heuristics were already proposed in the bygone century to tackle these kinds of problems. However, they provide us with merely good initial guesses for not more than specific tasks. The surge of literature on metaheuristics, which can be tailored to solve any optimization problem, can be explained by the demand for more general approximate procedures (Osman and Kelly, 1996).

Metaheuristics explore the large solution search space of optimization problems by restricting the effective size of the search space and sifting through it efficiently, often mimicking natural phenomena. In the case of logistics problems, this means that some possible routes are just neglected and other (more likely optimal) routes are improved iteratively. As a result, these methods are not only flexible and robust, but also scalable and fast (Blum and Roli, 2003).

Nevertheless, most of the introduced optimization algorithms have been proposed decades ago. Since then new developments such as a fourth industrial revolution have changed the environment in which urban routing problems are supposed to be solved sustainably. Industry 4.0 and the Internet of Things impose new challenges, but also opportunities in the field of logistics. For example, the latter provides us with real time information on consumer demand and workflows (Van Audenhove et al., 2015).

In order to train such more complicated models, learnheuristics have been introduced. While traditional metaheuristics only build upon reinforcement learning, learnheuristics also incorporate elements of supervised machine learning. The idea is to learn heuristics to make them even more general and less susceptible to local optima.

1.2 Aim of this Paper

Addressing the lack of literature summarizing the recent developments in the field of logistics problems and comparing the performance of diverse optimization algorithms, this paper aims to provide a thorough review of the available methodology to tackle modern logistics. In particular, we will highlight the surge of metaheuristics for solving routing problems and elaborate on a contrasting juxtaposition of these algorithms, namely exact methods and heuristics. It is important to note that a vast amount of relevant methods is proposed every year. While we exemplary present some recently proposed state-of-the-art machine learning models, we cannot cover all algorithms, but carefully choose the most important, diverse and representative ones to be presented in the remaining part of this paper.

We aim to provide a unified view on the algorithms by presenting their implementation using either pseudo code or visualizations based on the presentation of business processes in order to increase the transparency and the comparability across methods. Further, we

introduce a new framework for classification of optimization methods for solving especially urban logistics problems.

In both a large-scale simulation study and an empirical evaluation, we contrast the particularities of the most renown optimization techniques. Our code is made available in an online GitHub repository.

Last but not least, we address future challenges and opportunities a change in consumer behavior, environmental awareness, Internet of Things and Industry 4.0 provide us with. All in all, we aim to address all the research questions listed above.

Among the main contributions of this thesis are especially

- the introduction of a new framework of classification of heuristics,
- the review of the most important such algorithms and
- the implementation of a large scale simulation study for a thorough performance analysis and comparison across methods in Python.

We base our results mainly on papers published in well-known journals and topic-specific books, but also on internet articles. We included websites as *jstor*, *elsevier* or *Springer Link* for the research of relevant literature. Journals such as *Operations Research*, *Journal of Optimization Theory and Applications* and *Advanced Science and Technology Letters* among others were then taken into consideration. We especially focused to present recently proposed methods, such as *Gnowee* which was only published in 2019, in order to capture the most state-of-the-arts algorithms from artificial intelligence.

1.3 Thesis Structure

The remainder of the paper is structured as follows. We start by summarizing related work in Section 2. We then introduce the common approach to solving logistics problem by referring to the design science research concepts used in this paper in Section 2. In Section 3, we provide the reader with the preliminaries needed for the understanding of Section 4, the urban logistics optimization problems. In the following sections, we introduce several solution concepts and classify them. We also present recently proposed learnheuristics which build upon neural networks, a popular method in artificial intelligence. After elaborating on our experimental setup in Section 12, the subsequent part discusses our results. The last section concludes and proposes future directions for research.

16 Conclusion

This thesis introduced the reader to the area of urban logistics. In the scope of this work, we dealt with optimization solution approaches to solve corresponding logistical concepts. We presented a general framework to classify a wide range of optimization algorithms for urban logistics problems. We differentiated between exact methods, heuristics, metaheuristics and thus hybridizations of all the aforementioned instances, while focusing on the (meta-) heuristic for their variability.

We especially stressed the importance of state-of-the-art machine learning methods. Learnheuristics where supervised machine learning methods are employed to (meta-)heuristics for a specified problem, have shown to generalize well. To incorporate crucial methods of Artificial Intelligence remains to be a fast developing, promising and steep progress in the future.

In both a large-scale simulation study and an application to real-world-conditions, we compared the performance of a chosen subset of relevant methods. From this we could quantify both, advantages and disadvantages of the employed methods. All in all, we provide decision support for parcel service providers, city authorities, and other relevant businesses.

16.1 Results

As a result of our analysis we found out that when it comes to the quality of solutions, nothing was able to compete with the exact methods, as theoretically explained. Among the simple (meta-)heuristics, we could not identify a single best solution. Yet, being only introduced recently to the field of combinatorial optimization, the Gnowee algorithm performed best and came to close to the results obtained by exact methods. We recommend to further investigate the field of hybrids then.

Further, it could be shown that learnheuristics do not improve the quality of solutions provided by both, traditional (meta-)heuristics and hybrids. However, they can be applied in a more general manner, being even less problem-specific than metaheuristics, but leave a lot of scope for further research.

Since the exact optimization algorithms are not feasible (for the most simple instance we had a total calculation time of over 30 minutes), we aim to find a balance between the accuracy, the scalability and the computational time solver requires. In most cases, there exists a trade off between the optimality of the solution and the time it takes to find it. As Einstein once said,

> "Everything should be made as simple as possible, but not simpler."

Following this quotation, we recommend the use of metaheuristics instead of heuristics, due to their wider range of application.

Further, the implementation of nature-inspired techniques in the field of computational optimization shall be given less attention. Even though most of the explained and used metaheuristics belong to this particular group, the amount of innovation in this setting is minimal and so is the gained performance.

16.2 Outlook

There are several directions for future work that arise from the results of this paper.

(Meta-)Heuristic methods have been proposed in a time where computational power was rare. In modern times where we have vast access to fast computing machines with sufficient working memory, we can also make use of either more accurate methods. In particular, we highlight the importance of cloud computing as evolving paradigm that describes the 'ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources' (Mell et al., 2011). Even though its use still incurs costs, computational more exhausting methods can be used. If the goal is to reduce these costs, one might opt to use hybrid methods as the Gweeno. For its configuration is tedious, once established it delivers results comparable or even equal to the results delivered by exact methods in a fraction of time.

But not only the medium to solve routing problems has changed, but also the complexity of the problems themselves. In recent time, there has been a surge of papers that analyze dynamic logistics problems (Arnau et al., 2018). It is reasonable to assume that the cost a path incurs depend on a state and cannot be prognosticated as a fixed number beforehand. For example, we can think of the traveling time in a metropolis during rush hour. The same street could take less than a tenth of the time in the night compared to the time it would take to traverse it at 5 pm.

In an ever-changing economic environment, the requirements towards optimization methods of logistics problems are fast evolving. Accordingly, new application areas of routing problems arise. For example, demand-side management in station-based car sharing concepts make adjustments of generally applicable metaheuristics necessary (Broihan et al., 2018). Especially, in urban areas green zones in city centers allow environmentally friendly cars only to traverse them. Consequently, optimization algorithms should differentiate between different types of salesmen. Another simulation study based on our results could address especially the needs of newly evolved routing problems and propose task-specific fitting.

All in all, urban logistics are expected to become even more important with the rise of

Industry 4.0. Optimization algorithms dealing with them should thus be advanced.