Operations Research Proceedings

Janis S. Neufeld · Udo Buscher
Rainer Lasch · Dominik Möst
Jörn Schönberger *Editors*

Operations Research Proceedings 2019

Selected Papers of the Annual International Conference of the German Operations Research Society (GOR), Dresden, Germany, September 4-6, 2019

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Editors

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ISSN 0721-5924 ISSN 2197-9294 (electronic)
Operations Research Proceedings
ISBN 978-3-030-48438-5 ISBN 978-3-030-48439-2 (eBook)
https://doi.org/10.1007/978-3-030-48439-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

OR2019, the joint annual scientific conference of the national Operations Research Societies of Germany (GOR), Austria (ÖGOR), and Switzerland (SVOR), was held at the Technische Universität Dresden on September 3–6, 2019. The School of Civil and Environmental Engineering of Technische Universität Dresden supported it, and both the Faculty of Transport and Traffic Science and the Faculty of Business and Economics acted as the hosts of OR2019.

After more than 1 year of preparation, OR2019 provided a platform for more than 600 experts in operations research. OR2019 was the host for guests from more than 30 countries. The scientific program comprised 3 invited plenary talks (including the presentation of the winner of the GOR science award), 7 invited semi-plenary talks, and more than 400 contributed presentations.

The Operations Research 2019 proceedings present a carefully reviewed and selected collection of full papers submitted by OR2019 participants. This selection of 99 manuscripts reflects the large variety of themes and the interdisciplinary position of operations research. It demonstrates that operations research is able to contribute to the solution of the large problems of our time. In addition, it shows that senior researchers, postdocs, and PhD students as well as graduate students cooperate to find answers needed to cope with recent as well as future challenges. Both theory building and its application fruitfully interact.

We say thank you to all the people who contributed to the successful OR2019 event: the international program committee, the invited speakers, the contributors of the scientific presentations, our sponsors, the GOR, the ÖGOR, the SVOR, more of 50 stream chairs, and all our session chairs. In addition, we express our sincere gratitude to the staff members from TU Dresden who joined the organizing committee and spent their time in the preparation and the execution of OR2019.

Dresden, Germany — Janis S. Neufeld
Dresden, Germany — Udo Buscher
Dresden, Germany — Rainer Lasch
Dresden, Germany — Dominik Möst
Dresden, Germany — Jörn Schönberger
January 2020

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Part I
GOR Awards

Analysis and Optimization of Urban Energy Systems

Kai Mainzer

Abstract Cities and municipalities are critical for the success of the energy transition and hence often pursue their own sustainability goals. However, there is a lack of the required know-how to identify suitable combinations of measures to achieve these goals.

The RE^{3}ASON model allows automated analyses, e.g. to determine the energy demands as well as the renewable energy potentials in an arbitrary region. In the subsequent optimization of the respective energy system, various objectives can be pursued—e.g. minimization of discounted system expenditures and emission reduction targets. The implementation of the model employs various methods from the fields of geoinformatics, economics, machine learning and mixed-integer linear optimization.

The model is applied to derive energy concepts within a small municipality. By using stakeholder preferences and multi-criteria decision analysis, it is shown that the transformation of the urban energy system to use local and sustainable energy can be the preferred alternative from the point of view of community representatives.

Keywords Urban energy systems · Renewable energy potentials · Mixed-integer linear optimization

1 Introduction

Many cities and municipalities are aware of their importance for the success of the energy system transformation and pursue their own sustainability goals. However, smaller municipalities in particular often lack the necessary expertise to quantify local emission reduction potentials and identify suitable combinations of technological measures to achieve these goals.

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J. S. Neufeld et al. (eds.), *Operations Research Proceedings 2019*, Operations Research Proceedings, https://doi.org/10.1007/978-3-030-48439-2_1

There exist a number of other models that are intended for supporting communities with finding optimal energy system designs. However, many of these models fail to consider local renewable energies and demand side measures such as building insulation. Additionally, almost all of these models require exogenous input data such as energy demand and local potentials for renewable energy, which have to be calculated beforehand. This leads to these models being applied usually only within a single case study and not being easily transferable to other regions.

For an energy system model to be useful to such communities, it should:

- Determine the transformation path for the optimal design of the urban energy system, taking into account the specific objectives of the municipality
- Consider sector coupling, in particular synergy effects between the electricity and heat sectors
- Consider interactions between technologies and optimal technology combinations
- provide intuitive operation via a graphical user interface, ensuring ease-of-use
- Implement automated methods for model endogenous determination of the required input data, especially energy demand and local energy resources
- Use freely available, "open" data
- Provide strategies for coping with computational complexity at a high level of detail

2 The RE^{3}ASON Model

In order to adequately meet these requirements, the RE^{3}ASON (Renewable Energy and Energy Efficiency Analysis and System OptimizationN) model was developed. The model consists of two parts: the first part provides transferable methods for the analysis of urban energy systems, which are described in Sect. 2.1. The second part of the model uses these methods and the data obtained for the techno-economic optimization of the urban energy system and is described in Sect. 2.2. For a more detailed model description, the reader is referred to [1].

2.1 Modelling the Energy Demand and Renewable Energy Potentials

The RE^{3}ASON model provides transferable methods that can be used to determine the energy infrastructure and the local building stock, the structure of electricity and heat demand and the potentials and costs of climate-neutral energy generation from photovoltaics, wind power and biomass within a community (c.f. Fig. 1).

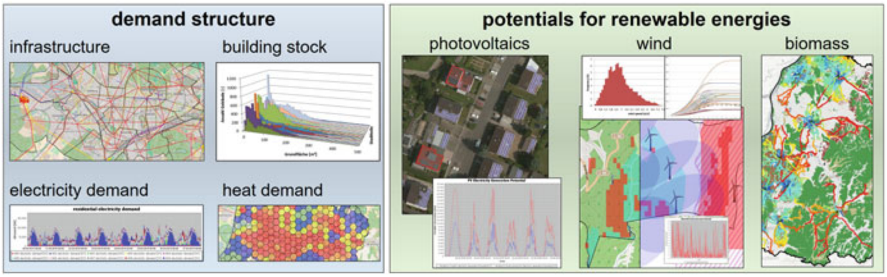

Fig. 1 Exemplary illustration of the methods for modelling the energy demand structure (left) and the potentials for renewable energies (right)

Fig. 2 Possible module placement for new PV systems with lowest possible electricity production costs (blue/white) and roofs that are already covered with PV modules (red border). Own depiction with map data from Bing Maps [2]

The unique feature of these methods lies in the use and combination of public data, which are available nationwide and freely. For this reason, the developed model is transferable in contrast to previous models, so that arbitrary German, with some of the methods also international municipalities, can be analyzed with comparatively small effort. For the implementation of these features, different methods were used, e.g. from the fields of geoinformatics, radiation simulation, business administration and machine learning.

This approach enables, for example, a very detailed mapping of the local potentials for renewable energies, which in several respects goes beyond the capabilities of previous modelling approaches. For example, the model allows, for the first time, the consideration of potentially new as well as existing PV plants solely on the basis of aerial photographs (c.f. Fig. 2). Other notable new methods are the consideration of the effects of surface roughness and terrain topography on the power generation from wind turbines as well as the automated determination of the capacity, location and transport routes for bioenergy plants. In contrast to comparable modelling approaches, all model results are made available in a high temporal and spatial resolution, which opens up the possibility of diverse further analyses based on these data.

2.2 Techno-economical Energy System Optimization

Furthermore, a mixed integer linear optimization model was developed, which uses the data determined with the previous methods as input and determines the optimal design of the urban energy system from an overall system perspective. Various objectives and targets can be selected (c.f. Chap. 3), whereupon the model determines the required unit dispatch as well as investment decisions in energy conversion technologies over a long-term time horizon. The structure of the model is shown in Fig. 3.

The optimization model is implemented using GAMS and generates about 6 million equations and 1.5 million variables (13,729 of which are binaries). On a 3.2 GHz, 12 core machine with 160 GB RAM, depending on the chosen objective, it can take between 7 and up to 26 h to solve within an optimality gap of 2.5%, using CPLEX. The processing time can be reduced significantly (by up to 95%) however, by providing valid starting solutions from previous runs for subsequent alternatives.

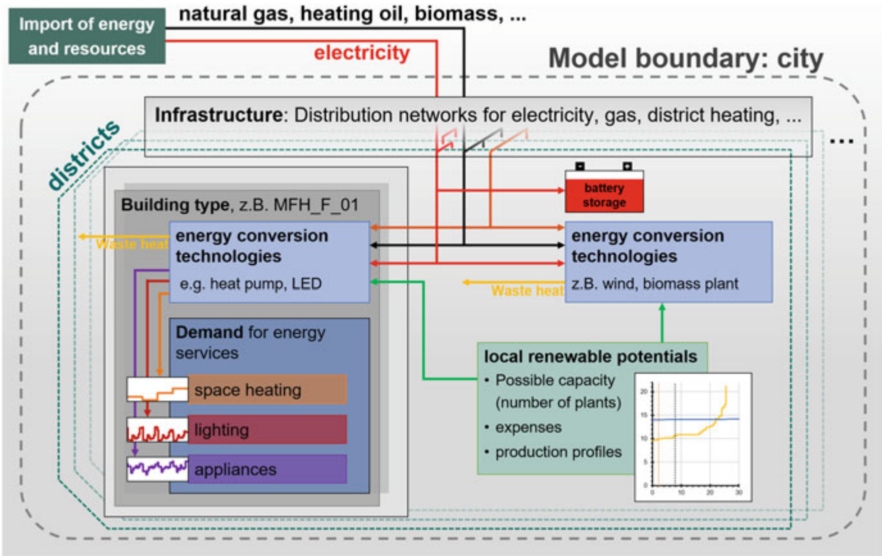

Fig. 3 Structure of the developed optimization model

3 Model Application and Results

In order to demonstrate the transferability of the model, it has been applied to a heterogeneous selection of municipalities in Germany. For details about this application, the reader is referred to [1], Sect. 6.1. The model has further been applied in a more detailed case study to the municipality of Ebhausen, Germany. This chapter represents an excerpt from this analysis, more details can be found in [3].

Ebhausen had a population of about 4700 in 2013, consists of four distinct districts and has a rather low population density of 188 people per km^2 (compared to the German average of 227). It is dominated by domestic buildings and a few small commercial premises, but no industry.

In this case study, the community stakeholders have been involved by means of three workshops that have been held within the community during the project. The workshop discussions revealed three values: economic sustainability, environmental sustainability, and local energy autonomy. A total of eight alternatives for the 2030 energy system have been identified to achieve these values: three scenarios which minimize only one single criteria, namely costs (A-1), emissions (A-2) and energy imports (A-3). Based on A-2, three additional emission-minimizing scenarios have been created, which additionally restrict costs to a maximum surplus of 10% (A-2a), 20% (A-2b) and 50% (A-2c) as compared to the minimum costs in A-1. In A-2c, (net) energy imports have additionally been forbidden. Based on A-3, two additional energy import minimizing scenarios have been created which also restrict costs to a 10% (A-3a) and 20% (A-3b) surplus. Table 1 shows results for the portfolio of technological measures as derived from the optimization model, Fig. 4 shows a comparison of the target criteria for the eight examined alternatives.

It is clear that these results differ substantially from one another. Alternative A-1 implies moderate PV and wind (three turbines) capacity additions, insulation

Table 1 Portfolios of technological measures associated with the eight alternatives

#	PV capacity (MW)	Wind capacity (MW)	Dominant heating system	Insulation[a]	Appliances[b]
A-1	2.0	6.0	Gas boiler	2	50
A-2	1.7	2.0	Pellet heating	3	100
A-2a	1.5	8.0	Heat pump	2/3	90
A-2b	0.6	8.0	Heat pump	2/3	90
A-2c	24.9	0	Heat pump	3	90
A-3	23.9	0	Heat pump	3	100
A-3a	18.3	6.0	Heat pump	2	30
A-3b	24.8	0	Heat pump	2	40

[a]Dominant level of building insulation employed, i.e. from 1 (low) to 3 (high), whereby 2/3 implies a roughly 50/50 split
[b]Fraction (%) of highest standard, i.e. A+++

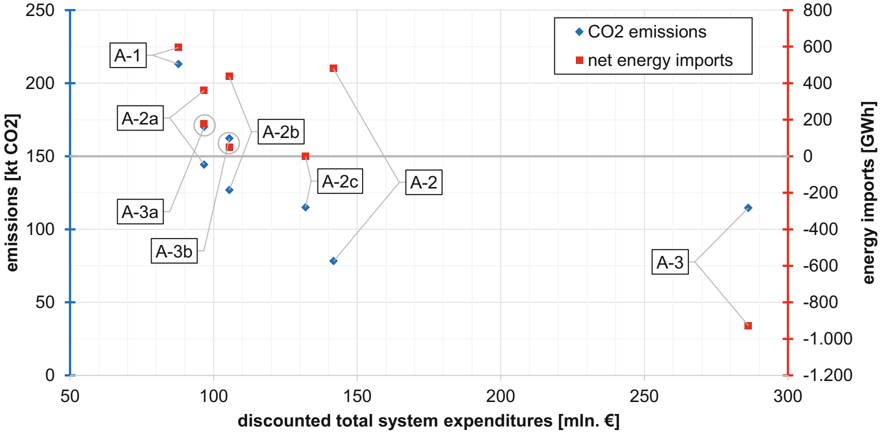

Fig. 4 Comparison of the target criteria in the eight alternatives examined

and electrical appliance improvements, with a mixture of heating systems including gas boilers and heat pumps, as well as some electric storage heaters. In contrast, the alternatives A-2 and A-3 have rather extreme results. The former translates into a moderate PV and wind capacity, maximum efficiency levels of insulation and appliances, and heating dominated by pellets boilers. The latter alternative involves a very high level of PV capacity, no wind capacity, maximum efficiency levels of insulation and electrical appliances, as well as heating systems dominated by heat pumps. The other five alternatives represent a compromise between these extremes, some of which have additional constraints. It is thus possible to quantify the additional level of energy autonomy and/or CO_2 emissions that can be achieved by increasing the total costs from the absolute minimum to 110%, 120% or even 150% of this value. It becomes apparent that significant emission reductions can be achieved with only minor additional costs (cf. Fig. 4). For example, allowing for a 10% increase in total costs leads to a 51% (of total achievable) emission reduction or a 27% net import reduction, and allowing for a 20% increase in costs leads to a 64% (of totally achievable) emission reduction or a 36% of net import reduction. In addition, these relatively small relaxations in the permissible costs result in substantially different energy systems.

In the second workshop with the community representatives, inter-criteria preferences (i.e. weights) for the three values economic sustainability, environmental sustainability and local energy autonomy were elicited. The results show that the alternatives A-1 (Costs first) and A-3 (Imports first) are outperformed by the other alternatives and that the remaining six alternatives achieve very similar performance scores, of which alternative A-2c (Emissions focus with cost and import constraints) achieves the highest overall performance score for the elicited preference parameters.

4 Conclusion

The results highlight the importance of automated methods for the analysis of the urban energy system as well as of the participatory approach of involving the key stakeholders in order to derive feasible energy concepts for small communities. While the first enables also smaller communities with no expertise in energy system modelling to gain transparency about their current and possible future energy systems, the latter makes it possible to take their specific values and objectives into account, ultimately enabling them to achieve their sustainability goals.

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Optimization in Outbound Logistics—An Overview

Stefan Schwerdfeger

Abstract In the era of e-commerce and just-in-time production, an efficient supply of goods is more than ever a fundamental requirement for any supply chain. In this context, this paper summarizes the author's dissertation about optimization in outbound logistics, which received the dissertation award of the German Operations Research Society (GOR) in the course of the OR conference 2019 in Dresden. The structure of the thesis is introduced, the investigated optimization problems are described, and the main findings are highlighted.

Keywords Logistics · Order picking · Transportation · Machine scheduling

1 Introduction

A few clicks, this is all it takes to get almost everything for our daily requirements. A banana from Ecuador or Australian wine, Amazon Fresh has everything available and, as members of Amazon Prime, we receive our orders within the next few hours. Naturally, the internet is not limited to exotic foodstuff, and customers are free to order everywhere, but it is a basic requirement of today's commercial life that everything is available, at any time and everywhere. To achieve this, distribution centers mushroom all over the world, and trucks sneak along the street networks everywhere. In Germany, for instance, there are about 3 million registered trucks, which transported almost 79% of all goods and contributed 479 million tkm (tonne-kilometers) in 2017 [15]. Thus, efficient logistics processes have become the backbone of the modern society.

In this context, the paper on hand takes a look at a subdiscipline of logistics, which focuses on all logistics activities after the finished product leaves production until it is finally handed over to the customer. This subdiscipline is called outbound

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J. S. Neufeld et al. (eds.), *Operations Research Proceedings 2019*, Operations Research Proceedings, https://doi.org/10.1007/978-3-030-48439-2_2

logistics, which is an umbrella term for a variety of processes, among which we focus on order picking (Sect. 2), transportation (Sect. 3), and the question of how to balance logistics workload in a fair manner (Sect. 4). The following sections summarize papers, which are part of the cumulative dissertation [10]. Given the limited space of this paper, however, we only roughly characterize the problems treated as well as the results gained and refer the interested reader to the respective papers for details.

2 Order Picking

The first part of the dissertation investigates order picking problems and is based on the papers [3, 11]. Order picking is the process of collecting products from an available assortment in a specified quantity defined by customer orders. In the era of e-commerce, warehouses face significant challenges, such as a huge amount of orders demanding small quantities, free shipping, and next-day (or even same-day) deliveries [2].

Thus, it is not surprising that there is a bulk of optimization problems in the area of order picking, such as layout design and warehouse location at the strategic level, as well as zoning, picker routing, order batching, and order sequencing at the operational level [5–7]. In this context, the first part of the thesis is devoted to two sequencing problems, which are highly operational planning tasks and thus demand fast solution procedures. While the papers both seek for a suited order sequence, they differ in their underlying storage system (A-Frame dispenser [3] vs. high-bay rack [11]) and thus their specific problem setting, resulting in different constraints and objectives. In general, however, they can (unanimously) be defined as follows. Given a set of orders $\mathcal{J} = \{1, \ldots, n\}$, we seek for an order sequence π, which is a permutation of set $\mathcal{J}$ and a picking plan $x(\pi) \in \Omega$ minimizing the total picking costs $F(x(\pi))$ (caused by, e.g., picking time, wages, and picking errors):

$$\text{Minimize } F(x(\pi)) \tag{1}$$

$$\text{s.t. } x(\pi) \in \Omega. \tag{2}$$

where Ω denotes the set of feasible solutions.

Within our investigations, it turned out that (1)–(2) is NP-hard for both problems [3, 11], so that determining an optimal solution for an increasing problem size may become difficult. However, the good news is that our complexity analysis further revealed that the remaining sub-problems are solvable in polynomial time when the order sequence π is given, i.e., the corresponding picking plan $x(\pi)$ can efficiently be determined. Thus, we utilized this property to develop effective solution approaches. To obtain an initial solution, a straightforward greedy heuristic turned out as a promising approach determining good solutions within negligible computational time. More precisely, the procedure starts with an empty sequence and in each iteration, it appends the order increasing the objective value least. In this way, a first solution is generated as a starting point for further improvements due to tailor-made metaheuristics or exact algorithms. In [3], we propose a multi-start local search procedure using various neighborhoods to alter the sequence and improve the solution. The algorithm shows very effective within our computational study and robust against an increasing problem size, so that even instances of real-world size can be solved. In [11], a branch-and-bound procedure is introduced where each branch of the tree corresponds to a (partial) order sequence. With the developed solution techniques on hand, we further examine the gains of optimization. We compare the picking performance due to the optimized sequences and benchmark them with traditional first-come-first-serve sequences. Our results reveal a huge potential for improvement over the status quo.

More precisely, in [3], workers continuously refill the A-Frame dispenser. However, whenever the workforce is not able to timely replenish the SKUs, additional utility workers take over to guarantee an error-free order picking process. For the solutions obtained by our optimization approaches in only about 7% of all replenishment events a utility worker have to step in. Therefore, a reduction of 75% of the required utility workers can be achieved. On contrary, in [11], we showed that our tailor-made solution procedures decreased the overall order picking time up to 20% for a high-bay rack with crane-supplied pick face where pickers move along the pick face to collect all SKUs demanded.

3 Transportation

The second part of the dissertation examines transportation problems and is based on the papers [1, 12]. Broadly speaking, the general task of transportation is to transfer goods or people from A to B. What sounds so simple, is often actually a complex planning problem, especially when facing real-world requirements, such as free shipping and tight time windows. From a company's point of view, transportation (and other logistics activities such as order picking) is a vital part of their supply chain, but not a value-adding one. Therefore, it is crucial to keep the costs low and plan wisely.

In the world of operations research, transportation of goods is most often associated with the well-known vehicle routing problem, and a vast amount of literature is available that considers a plethora of different problem settings. Given the current requirements of e-commerce, however, just-in-time (JIT) deliveries, i.e., the supply with goods at the point of time they are needed, are of particular interest. Thus, we focus on the JIT-concept in both papers [1, 12] and investigate a basic network structure of a single line where goods have to be transported from A to B.

In [12], the task is to find a feasible assignment of goods to tours and tours to trucks, such that each delivery is in time and the fleet size is minimized, i.e., we allow multiple subsequent tours of the trucks. Thus, we face with the problem to assemble truck deliveries and to schedule the trucks' departure times at the same time. To solve this NP-hard problem, we develop an effective binary search method. The binary search approach is based on tight bounds on the optimal fleet size. Therefore, we identify relaxations that can be solved in polynomial time to obtain lower bounds. The upper bound is determined by dividing the problem into two subproblems, where the first one is solved by a polynomial time approximation scheme to determine the truckloads/tours at the first step. Afterward, at the second step, the procedure applies an optimal polynomial time approach to assign the loads/tours to trucks and to schedule the respective departure times (see [12]). Finally, we used our algorithms for a sensitivity analysis. It shows that the driving distance, the level of container standardization, and the time windows of the JIT-concept have a significant impact on the potential savings promised by optimized solutions [12].

In [1], we determine the trucks' departure times for the example of truck platooning. A platoon describes a convoy of trucks that drive in close proximity after each other. The front truck controls the followers and due to the reduced gap in between them, the aerodynamic drag reduces and less fuel is consumed. Platooning is not only beneficial for economic reasons (e.g., lower fuel costs), but also for environmental ones (e.g., less pollution). In [1], the complexity status for different problem settings (cost functions, time windows, platoon lengths) is investigated. The presented polynomial time procedures provide a suited basis to tackle large-sized problems efficiently. Furthermore, the sensitivity analysis reveals that each of the investigated influencing factors (diffusion of platooning technology, willingness-to-wait, platoon length) strongly impacts the possible fuel savings and a careful planning is required to exploit the full potential of the platooning technology. In particular, our investigations showed that the possible amount of saved fuel might be considerably lower than the technical possible ones. This is indeed a critical result, as our single road problem setting supports the platooning concept, as finding (spatially and temporally) suited partners becomes increasingly unlikely for entire road networks. However, in light of technological developments such as autonomous driving, substantial savings (driver wages) can be achieved justifying the investment costs of truck platooning technology [1].

4 Workload Balancing

The last part of the dissertation examines balancing problems and is based on the papers [9, 13, 14]. Generally speaking, the purpose is to assign a set of tasks $\mathcal{J} = \{1, \ldots, n\}$, each defined by its workload p_j ($j \in \mathcal{J}$), to a set of resources $\mathcal{I} = \{1, \ldots, m\}$ in order to obtain an even spread of workload. Let $x_{ij} = 1$, if task $j \in \mathcal{J}$ is assigned to resource $i \in \mathcal{I}$ and $x_{ij} = 0$ otherwise, then the problem can be defined as

$$\text{Minimize } F(C_1, \ldots, C_m) \tag{3}$$

$$\text{s.t. } \sum_{j=1}^{n} p_j x_{ij} = C_i \qquad i = 1, \ldots, m \tag{4}$$

$$\sum_{i=1}^{m} x_{ij} = 1 \qquad j = 1, \ldots, n \tag{5}$$

$$x_{ij} \in \{0, 1\} \qquad i = 1, \ldots, m;\ j = 1, \ldots, n \tag{6}$$

where F represents different alternative (workload balancing) objectives, such as the makespan $C_{\max} = \max_{i \in \mathcal{I}} C_i$, its counterpart $C_{\min} = \min_{i \in \mathcal{I}} C_i$ (see [9]), the difference $C_{\Delta} = C_{\max} - C_{\min}$, or the sum of squared workloads $C^2 = \sum_{i \in \mathcal{I}} C_i^2$ (see [13, 14]). These problems are also known as machine scheduling problems and despite of their simple structure, they are mostly NP-hard.

Problems like (3)–(6) often occur as subproblems or relaxed problem versions. For instance, assume that there is a set of orders, which must be assembled in a warehouse. As a result of the picking problem, we obtain a set of picking tours $\mathcal{J}$ with length p_j ($j \in \mathcal{J}$), which must be assigned to the set of pickers $\mathcal{I}$. One goal might be efficiency, so that we aim to minimize the total makespan for picking the given order set, i.e. $C_{\max}$, or we seek for a fair share of work, i.e. C^2. Moreover, assume that there is a picking tour having to retrieve three washing machines, whereas during a second tour only a pair of socks has to be picked. Then, p_j might represent the ergonomic stress of a picking tour $j \in \mathcal{J}$ instead of its length and applying the objective C^2 yields an ergonomic distribution of work.

A major drawback of traditional objectives such as $C_{\max}$, $C_{\min}$, or C_{Δ} is that they only take the boundaries into account. Thus, the workload of the remaining machines is only implicitly addressed and may even contravene the balancing issue. Thus, all machines must be considered explicitly, e.g., by C^2. Previous approaches tackled this problem with local search algorithms where the neighborhood is defined by interchanging jobs between pairs of machines. In the case of two machines, however, all the above objectives are equal and the procedure, thus, does not adequately target the general balancing objective. Therefore, we develop an effective solution method to optimally solve the three-machine case [13] and the m-machine case in general [14]. Moreover, we propose a suited local search algorithm to solve C^2 [13].

In [14], we further demonstrate that the developed exact and heuristic solution procedures can handle a vast amount of objectives ($C_{\max}$, $C_{\min}$, C_{Δ}, and other related objectives). Furthermore, tests [13, 14] show a significant improvement compared to benchmark instances of [4, 8, 13] and the off-the-shelf solver Gurobi. The proposed algorithms do not only improve on the solution quality, but they were also capable to reduce the computation time by several orders of magnitude.

5 Conclusion

The thesis [10] is equally devoted to solving important practical problem settings and deriving theoretical findings for selected problems from the field of outbound logistics. We translate problems motivated from business practice into mathematical optimization problems and, based on their complexity status, develop suited solution procedures capable of handling large-sized instances within short response times. Thus, these algorithms can be applied for operational and tactical planning tasks, such as order sequencing in warehousing, the scheduling of truck deliveries, or workload balancing.

It can be concluded, that sophisticated optimization is a suitable tool to considerably improve over the simple rules-of-thumb that are usually applied in business practice. Technological developments are often merely a first step to gain competitive advantages but optimization deciding on an intelligent application of the technologies is almost always equally important. For instance, in our platooning example, test applications show that fuel savings up to 10% or even 15% are technologically possible. However, this requires that, at any time, a suited platooning partner is available. Therefore, sophisticated matching algorithms to form platoons are needed which constitutes a delightful task for optimization.

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