Hiking in the scheduling landscape

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This thesis investigates different optimization problems in the field of scheduling. Scheduling problems model situations in which limited resources have to be assigned to tasks over time as to minimize costs, maximize profits, balance workloads among resources or improve the efficiency of the usage of resources. The theory of scheduling is concerned with modelling simplified problems to gain a better understanding of the intrinsic structures and challenges faced when solving these problems. The goal is to develop algorithms which solve problems to optimality in an efficient amount of time. However, many scheduling problems turn out to be computationally hard such that we cannot hope to accomplish this goal. To overcome this, we consider approximation algorithms which offer a trade-off by computing solutions provably close to an optimal solution in an efficient amount of time. Approximation algorithms for simplified theoretical problems offer building blocks towards heuristics for applied problems with additional practical constraints. Furthermore, approximation algorithms guarantee that the possible loss compared to an optimal solution is guaranteed to be bounded from above. This is highly relevant as non-optimal solutions negatively affect costs, profits, fairness, customer satisfaction and other standard goals.

In *Chapter 2* we investigate load balancing problems on identical parallel machines. These problems model situations in which resources are used most efficiently whenever the workload is distributed fairly. While most of the approximation algorithms known for these problems follow the multiplicative approximation paradigm, we formalize the concept of additive approximation schemes. This concept may help future research to overcome challenges faced by multiplicative approximation algorithms. From a theoretical perspective, additive approximation schemes even lead to tighter guarantees when the chosen approximation parameter is much smaller than the value of the optimal solution. For practitioners, additive approximation guarantees allow for a quantification of the possible loss compared to an optimal solution and an economic or social cost analysis of the trade-off between closeness to the optimal solution and running time.

Chapter 3 extends the concept of machine conflict graphs to model situations in which machines require access to a server before and after processing jobs. This server, however, can only be accessed simultaneously by machines which are not in conflict with each other. The results presented in this chapter provide first building blocks towards a better understanding of such machine environments and may spark interdisciplinary research between the fields of scheduling and graph theory. The algorithms can be applied by any decision maker facing a machine environment with conflicts. The algorithm for bipartite conflict graphs and unit jobs can be used as a foundation for heuristics on other conflict graphs.

In *Chapter 4*, a just-in-time scheduling problem is investigated. Just-in-time scheduling is highly relevant in many applications where early as well as late completion of jobs is undesirable due to high storage costs, perishable products or customer satisfaction. Quadratic penalties model situations in which small deviations from due dates may not be desirable but should not be penalized as much as large deviations, e.g., when handling perishable products or aiming for customer satisfaction. The methods devised in this chapter can be applied in situations when the duration of all tasks are the same, e.g., in service industries when all jobs are essentially the same but the importance and due date is customer specific.

Chapter 5 investigates techniques to cope with uncertainty in scheduling problems. Uncertainty plays a significant role in practice as decision makers in manufacturing or service industries often face uncertainty or randomness such as the availability or duration of jobs. Stochastic online scheduling addresses these sources of uncertainty in order to provide solution techniques to practitioners which accurately cope with the uncertainty underlying the problem. In this chapter, we contribute to this line of research by devising and analysing stochastic online scheduling policies for a problem in the uniform parallel machine environment which is relevant in applications such as manufacturing, computing and compiler optimization. From a practical perspective, these policies allow decision makers to accurately address and solve problems with underlying uncertainties. Furthermore, the policies can be used as essential building blocks for heuristic techniques taking into account additional practical restrictions as well. As our computational study shows, the policies can be expected to perform better in practice than we proved theoretically. Moreover, from a theoretical perspective the analysis of the algorithms improves previous known performance guarantees for some special cases.

In *Chapter 6*, we introduce a model and solution techniques to address one of the key aspects and drivers towards green and sustainable transportation in Europe. Inland waterways offer a great opportunity as one of the most sustainable and CO_2-efficient means of transportation of goods. To utilize the full potential of inland waterways, mathematical optimization models and techniques such as the one introduced in our work are necessary to reach the goal of sustainable logistics. An important factor that we consider is uncertainty due to different types of vessels, weather and other factors. We introduce multiple techniques for skippers to reduce fuel consumption, emissions and cost in an uncertain environment leading to a sustainable and efficient transportation system in an uncertain environment. Most significantly, we show that even simple techniques which take into account uncertainty strongly outperform techniques which do not take into account this uncertainty at all. This is relevant for both practitioners and theoreticians. For skippers, this provides attractive and applicable methods to reach significant fuel savings and also underlines the necessity of such methods in order to reach a sustainable transportation system. Moreover, from a theoretical perspective this opens up the opportunity towards further considering these simple types of velocity policies to investigate the theoretical performance and use them as a foundation for solution methods to extensions of the considered model.