

# Preface

In many business relationships, unexpectedly occurring events lead to unfavorable situations which cause a high inconvenience or high costs for affected customers. Two examples of such situations are the unsuccessful delivery of newspapers to subscribers and the breakdown of important machines during production processes. In such situations, affected customers demand urgent assistance from a service company which resolves the situation by delivering required goods which can be material or immaterial, e.g., newspapers or repair services. In order to maintain customer loyalty, the minimization of customer inconvenience which increases with the required time for delivering the demanded goods (denoted as response time) is increasingly becoming the most crucial objective in such processes. Due to this urgent demand, these goods are considered as *perishable goods* in this book. In real-world applications such as the mentioned subsequent delivery of newspapers or in repairman companies operating under Service Level Agreements (SLAs), a quick service of customer requests which dynamically arrive during the execution of the transportation process is the highest priority. The considered applications are denoted as the Real-time Distribution Of Perishable Goods (RDOPG).

In this book, three contributions are made to the field of dynamic vehicle routing. First, based on results that have been achieved by recent marketing research, an appropriate dynamic routing model for RDOPG applications is formulated. In this model, customer inconvenience arising along with the response time achieved for occurring customer requests is considered and its minimization is pursued as the main objective. Specifically, in this book, we evaluate the impact of a linear and a quadratic evolution of customer inconvenience depending on response time combined with a maximum allowed response time on the attained solution quality. Moreover, a comprehensive introduction to tour planning is given and existing classifications for routing problems in the literature are presented. Based on these classifications, a new approach for classifying routing problems according to RDOPG-specific attributes is proposed. The second contribution represents the main part of this book. It evaluates the benefits that can be attained in the solution quality through the integration of stochastic knowledge about expected future customer requests in RDOPG applications. In order to evaluate these benefits, a new deterministic real-

time control approach which centrally coordinates the transportation process during its execution is proposed. This real-time control approach considers the concurrency of tour plan execution and tour plan adaptation. The transportation process is adapted during its execution by solving individual problem instances utilizing a proposed stage-based Tabu Search metaheuristic. Moreover, the mathematical model used for representing the individual problem instances is introduced. The proposed deterministic real-time control approach is then extended to a pro-active real-time control approach which additionally makes use of stochastic knowledge about the spatial and temporal occurrence of expected future customer requests. The utilized stochastic knowledge is solely generated from past request information by a proposed forecasting approach and no prescribed probability distributions are utilized. Different quality criteria are considered in the proposed forecasting approach in order to ensure a minimum defined quality of the generated stochastic knowledge. In order to implement the pro-active real-time control approach, ways of handling and integrating the stochastic knowledge into the solution process by using dummy customers are proposed. According to the considered objective of minimizing customer inconvenience, the stochastic knowledge is used to guide vehicles to request-likely areas before real requests arrive there in order to service them quicker and thereby attain a higher solution quality.

Comprehensive computational experiments are carried out on real-world request data from a subsequent delivery of newspapers process ( $S^{\text{REAL}}$ ) as well as on generated test scenarios ( $S^{\text{GEN}}$ ). In all experiments, the effects of a variety of parameter settings are evaluated in order to analyze the effects on the solution quality. In order to identify scenarios in which the application of the proposed pro-active real-time control approach achieves superior results compared to the proposed deterministic real-time control approach, we introduce *structural quality* for classifying the value of stochastic knowledge in a given routing problem scenario according to the available request data. Specifically, we derive the structural quality of a request data set from two newly proposed criteria denoted as *structural distortion* and *structural diversity*. In addition to defining both criteria in detail, we also propose methods for determining the structural distortion and the structural diversity of a given request data set. Besides evaluating a proposed approach for determining structural distortion on request data sets with different levels of structural distortion, we introduce a two-dimensional structural diversity classification which is used to generate request data sets of  $S^{\text{GEN}}$  with significant differences in structural quality. Computational results show that in scenarios with high levels of structural diversity, the proposed pro-active real-time control approach is able to achieve significantly improved results compared to its proposed deterministic counterpart. Specifically, depending on the evolution of customer inconvenience, improvements in the solution quality of up to 26 % (linear2X customer inconvenience) and 47 % (quadratic customer inconvenience) above the ones attained by the deterministic real-time control approach can be achieved. Thanks to the proposed classification of structural diversity, differences in results obtained among the tested scenarios become explainable. On the  $S^{\text{REAL}}$  request data, additional improvements of up to 7 % could be achieved by using the pro-active real-time control approach. In order to explain the differences

in the additionally attainable improvements on  $S^{\text{GEN}}$  and  $S^{\text{REAL}}$ , we performed a visual analysis on both types of request data. In this analysis, further characteristics of scenarios which support an efficient application of the pro-active real-time control approach could be identified. Moreover, we propose a measure denoted as the degree of structural diversity (*dosd*) for determining the structural quality of given, arbitrary request data sets. We show the effectiveness of the *dosd* by analyzing correlations existing between the *dosd* and the improvements attained by the pro-active real-time control approach on  $S^{\text{GEN}}$  and  $S^{\text{REAL}}$ . The results show that there exists a strong linear correlation between the proposed *dosd* and the attainable improvements. Therefore, the proposed structural diversity and the *dosd* provide good starting points for assessing the structural quality of given request data sets which supports an efficient application of stochastic knowledge in real-time control approaches under different scenarios. Moreover, the *dosd* also provides management with decision support in efficiently customizing the proposed stochastic knowledge generation approach in given scenarios using results achieved in the computational experiments.

The third contribution of this book is a method for considering driver inconvenience aspects which arise from vehicle en-route diversion activities. Specifically, a method is proposed which makes it possible to restrict the number of vehicle en-route diversion activities performed by the real-time control approach by restricting the allowed vehicle en-route diversion activities to those which improve the solution quality by at least a defined threshold value. Computational experiments show the efficiency of the proposed method. Specifically, by utilizing appropriate threshold parameter values, driver inconvenience can be reduced by significantly lowering vehicle en-route diversion activities and yet still achieving significant improvements compared to completely forbidding vehicle en-route diversion activities. As also shown in the second contribution, the pro-active real-time control approach provides a significantly higher solution quality in request data scenarios comprising a high structural quality compared to the deterministic real-time control approach. Even when all vehicle en-route diversion activities are completely forbidden, the pro-active real-time control approach still achieves a significantly better solution quality compared to the deterministic real-time control approach with all vehicle en-route diversion activities allowed.

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