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Traffic Control under Dynamic Loading Conditions with Risk Analysis Methods

PhD Thesis

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Abstract

This thesis examines the complex problem of dynamic traffic management with mesoscopic approach methods. The users of a transport system experience different congestion levels during their everyday activities. The losses in travel time due to congestion is a consequence of the dynamic interdependence of travel demand served by the system and are influenced by the parameters that define its operating characteristics.

The main objective is to investigate and formulate appropriate reasoning, methods and tools for efficient traffic management and tackling the congestion problem in urban networks, offering a different approach to the problem through the analysis and management of travel time risk.

The approach is based on the concepts of risk and the loss of productive travel time. The travel time risk is defined as the combination of loss of productive time due to congestion and the likelihood of this loss to occur over the analysis horizon taking into account the dynamic traffic phenomena. The Conditional Value-at-Risk was used to quantify and predict the risk of high levels of congestion for both the transport system performance and the optimization of traffic control.

The need for formulating a system that can handle the information, the complexity of the parameters of multiple problems and the breadth of the alternative solutions involved in traffic management led to the development of a Decision Support System. The proposed architecture of the System incorporates risk analysis and dynamic mesoscopic approaches for the representation of traffic conditions in its subsystems.

Here, the Decision Support System is focused on the activities involved with the traffic control strategy formulation, incorporating the risk minimization methodology for finding the best traffic control plans as its main component.

At first, the problem for the isolated intersection is defined and analyzed, formulating and describing the methodology for finding the best combination of signaling phases and their optimal timings for offline fixed-time control aiming at minimizing the risk of experiencing higher levels of delay. The risk model for minimizing delays and the optimization algorithms are described for the isolated intersection are described. The model for estimating the delay for an extended peak period is based on multiple-period

analysis proposed in the Highway Capacity Manual 2010. The optimization problem is solved in MATLAB using two optimization algorithms, the genetic algorithm and the scatter search algorithm.

Next, the extended problem of finding the best traffic control for a network by minimizing the risk of delays is formulated as a predictive off-line and on-line subsystem as part of the proposed Decision Support System for traffic control. The proposed approach is defined and described in detail with regard to the risk model for the analysis of the network performance through the dynamic mesoscopic simulation, the risk minimization model for finding the best signaling settings, the search algorithm and the objective functions of the optimization problem. The optimization problem is solved using the multi-objective genetic algorithm in MATLAB by minimizing the risk of delays in the signalized intersections and the risk of non-coordinated pre-defined routes of the network, analyzing the traffic dynamics in the context of risk.

The proposed approaches of traffic signal optimization by minimizing the risk of delay were applied to reference intersection and network from the literature. Specifically for the isolated intersection the two optimization algorithms were compared in terms of their runtime and the accuracy of their estimated solutions. Furthermore, the proposed risk minimization methodology was compared with two alternative approaches for finding the optimal solution. In the current context, the validation of the estimated delay of the multiple-period model proposed in the Highway Capacity Manual 2010 was performed through microscopic simulation in Aimsun software. The

In the case of the coordinated network, the proposed risk minimization approaches using a mesoscopic approach were applied and compared with the results obtained by using the TRANSYT-7F software at three levels of demand. The proposed approaches were also compared to approaches from the literature focusing only on the peak hour rather than examining the demand distribution and the resulting delay in an extended peak period. The mesoscopic dynamic assignment performed in the Aimsun software.

The basic hypothesis of our proposed methodology is that traffic plans designed and optimized by minimizing the Conditional Value-at-Risk will offer users a lower risk of experiencing higher values of delays. This hypothesis was investigated through a sensitivity analysis of different demand levels and incidents occurring at the network.

In addition, the proposed risk minimization approach for network traffic control was also applied in the case of online adaptive control for selected scenarios and was compared to the corresponding fixed-time control and the application of TRANSYT-7F as a fixed-time and adaptive control method.

From the implementation of the proposed approach for both the isolated intersection and the coordinated network, it has been found that the approach of analyzing the evolution of congestion phenomena over an extended time period and the introduction of risk analysis in traffic management has many advantages. In particular, it was found that the risk of travel time and the risk of high congestion variations are reduced. In addition, it has been found that the proposed approach provides a better overall operation of the system (intersection and network), i.e. the total delay of all vehicles over the analysis period is better. The analysis of the methodologies and the results of their applications cover the main objective of the thesis, namely developing algorithmic processes, methods and tools for efficient traffic management and tackling the congestion problem in urban networks. Overall, the thesis contributes to the analysis of the problem through a different approach that has not been used in the past by enhancing traffic analysis methods and traffic management optimization methods through risk analysis and management.

The thesis examined an issue of both research and practical interest and its contribution can be maximized if the methods and procedures developed were implemented in real-world conditions of network analysis and management, improving the quality of life of users of the transport system and contributing positively to economy and the environment.