

# Robust, Optimal, Predictive, and Integrated Road Traffic Control

## *Research proposal*

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*Abstract*—The development of control strategies for traffic lights, ramp metering installations, and variable speed limits to improve the throughput of road traffic networks can contribute to a more efficient use of road networks. In this project, a hierarchical controller will be developed for the improvement of the throughput of a road traffic network. In this paper the research objective of this PhD project, and the direction of the solution to reach this objective will be detailed. Furthermore, it will be discussed how this algorithm can be robust, optimal, predictive, and integrated.

*Index Terms*—robust, optimal, predictive, integrated, intersection control, ramp metering, variable speed limits.

### I. Introduction

Currently, road networks are not efficiently exploited. One of the reasons for this is that the actuators that influence the traffic, such as, traffic lights, ramp metering installations, and variable message signs, are not efficiently controlled. This research focuses on the development of control strategies for traffic lights, ramp metering installations, and variable speed limits that improve the throughput of a road network.

As the title of this paper indicates, the control strategy that will be developed should be robust, optimal, predictive, and integrated. In the remainder of this introduction these four terms will be detailed.

In this research, the term robust is used to denote that the control strategy has to be able to deal with variations in traffic conditions. For instance, the traffic demand is a stochastic phenomenon which changes with respect to time. Besides that, incidents can have large impacts on the traffic flow in a network. Hence, the performance of a robust controller should not be significantly affected when an unexpected event place.

Optimal means that the best possible control strategy for a given traffic condition is imposed. Typically, this control strategy is found by means of optimization. However, when

the outcome of such an optimization for a given situation is known, it is also possible to impose that control strategy without a need for on-line optimization. An example of such an approach is the SPECIALIST algorithm [1] which has improved freeway throughput in practice by using variable speed limits to resolve moving jams. This algorithm was inspired by studying the behavior of a model predictive controller.

Control strategies that anticipate on future changes in the traffic situation are predictive. Besides that, an important property of a predictive controller is that it can anticipate on changes in the evolution of the traffic that are caused by the control strategy that is imposed.

Finally, the term integrated indicates a control strategy that controls various actuators, such as ramp metering installations, variable speed limits, and traffic lights.

The remainder of this paper is structured as follows. The next section introduces background information of road traffic control. Then, section III introduces the research objective of this PhD research project. Section IV details the direction of the solution that will be investigated. Then, section V discusses how this solution direction can satisfy the criteria mentioned above. Section VI concludes this paper.

### II. Background

The control of road networks is a widely studied topic [2] and there are many challenges of the control problem left for research. An important challenge is to bridge the gap between control strategies that are proposed in the literature and the practice ready control strategies. For instance, by means of model predictive control, optimal control settings for traffic lights [3], [4], [5] or ramp metering and variable speed limits [6] to maximize the throughput of a road network can be computed. However, despite this optimal behavior, model predictive control is not applied in practice. According to Landman et al. [7], two important reasons that model predictive controllers are not applied in practice are that: 1) their computational complexity is too high, and 2)

they lack transparency – e.g. it is unclear to road authorities what control action these controllers will be taking.

An important reason why the computational complexity of model predictive controllers is so high is that the evolution of the traffic over road networks is a very complex process. For instance, different types of traffic, such as vehicles and pedestrians, have to use the same intersections, and public transportation and emergency vehicles require priority which perturbs the normal operation of the intersection.

Apart from that, congestion can propagate through road networks and can reach both urban regions and freeways. This implies that both urban and freeway traffic has to be controlled in order to reduce congestion. However, the control strategies for urban regions have different structures compared to freeway control strategies. Due to this dissimilar structure, control strategies for controlling both urban and freeway traffic can become very complex.

One way of reducing the complexity of the control problem is to consider regions which have similar characteristics and can be controlled by means of one control strategy. This is done by Diakaki et al. [8] in Glasgow, the United Kingdom where ALINEA [9] was used for ramp metering, and TUC [10] for the control of intersections. However, there was no communication between the different control strategies.

Hierarchical control is one way of controlling and coordinating the different actuators in a network. In Amsterdam, the Netherlands, a hierarchical control system is tested where the urban intersection controllers are supporting the ramp metering installations [7]. In that approach, communication between the different controllers is considered. In doing so, the control strategies for the urban intersections are decoupled from the control strategies of the ramp metering installations while they manage to cooperate through the communication that is realized by the hierarchical controller. Hence, for a hierarchical controller, communication is a very important property.

Apart from communication, the quality of the data that is used for control has a major influence on the performance of a controller. Much better data is becoming available due to the proliferation of in-vehicle technologies, such as route guidance systems. For instance, route guidance systems can provide position and routing information to road authorities, this is called floating car data. The road authorities in their turn can better anticipate on the current traffic demand and adjust the control action [11]. An even more advanced development of in-vehicle systems is when the control actions are matched to the individual road users. For instance, Hegyi et al. [12] propose a system where speed limits are imposed to individual vehicles in order to resolve a moving jam. Even though it is unclear when these in-vehicle technologies can be exploited, a control system has to be ready to benefit from these technologies.

### III. Research objectives

In line with the insights that are detailed in the introduction, the research objective of this PhD research is: **the development and evaluation of a hierarchical control system that improves the throughput of a road traffic network by controlling traffic lights, ramp metering installations, and variable speed limits.** The control strategy will be developed with near-future field implementation in mind and has to be able to benefit from in-vehicle technologies.

The hierarchical controller will consist of two levels. The upper level will distribute traffic over the network. The bottom level consist of two controllers for the freeway and urban regions. In this way, the complexity of the control problem is simplified by considering separate controllers for urban regions and the freeway, and the communication between the controllers is realized by means of the upper level.

In order to reach this objective, the following sub-objectives will be treated:

- *Literature review: Evaluation of control strategies for both urban, and freeway traffic;*
- *Development and evaluation of a controller for traffic in urban regions;*
- *Development and evaluation of a controller for freeway traffic;*
- *Development and evaluation of a controller for the distribution of the traffic;*
- *Development and evaluation of the hierarchical control scheme for the integration of the different controllers.*

As stated in the introduction, the control of road traffic is a complex task. The hierarchical control approach will simplify the control problem. However, additional simplifications are necessary in order to keep this research project comprehensible. Therefore, the focus of this research will be on the control of vehicular traffic. Another important assumption is that the focus will be on the control of saturated traffic networks.

### IV. Solution direction

As pointed out in the research objective, a hierarchical controller will be developed. Figure 1 shows a schematic overview of this controller. It can be seen that the controller consists of two levels. The upper level will distribute traffic among different regions – both urban and freeway regions – such that the number of vehicles in every region remains below or near capacity. The bottom level will control the urban or freeway regions such that the network can manage the demand that is provided by the upper level, and take adequate action when, for instance, an incident takes place. In this section, some more insight into the different controllers will be provided.

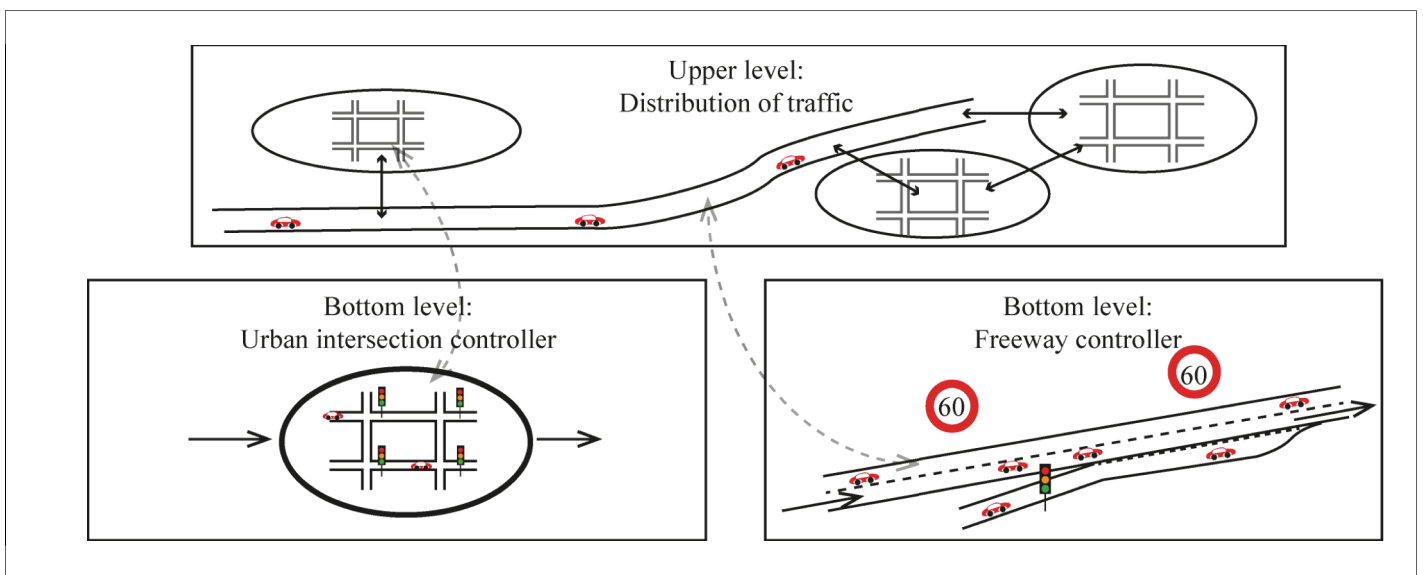


Figure 1: Schematic overview of the hierarchical control scheme that will be developed in this PhD research

### A. The upper level

The task of the upper level controller is to manage the distribution of the traffic over different regions. These regions can be parts of an urban network or parts of a freeway. The goal of this controller is two-fold: 1) the controller has to make sure that the number of vehicles in every region remains below or at the capacity, and 2) the upper level controller has to provide the bottom level controllers with a prediction of the in-flow and out-flow of a region. In their turn, the bottom level controllers can provide feedback to the upper level controller when the realized in-flows or out-flows differ from the predictions

At the moment, the distribution of traffic over different regions is an actively studied topic. A model predictive control approach for urban regions based on the network transmission model is proposed by Hajiahmadi et al. [13]. Model predictive control for the distribution of traffic over urban and freeway regions is reported by Haddad et al. [14], who use the asymmetric cell transmission model to predict the evolution of the traffic on the freeway, and macroscopic fundamental diagram to predict the evolution of the traffic in urban regions.

For this research, an approach will be selected from the literature and implemented and the focus will be on the interaction between the upper and bottom levels. Which approach will be used is not yet determined at the moment. In-vehicle technologies will be considered by assuming that floating car data, and the routes of the traffic are available.

### B. Bottom level: the urban controller

The task of the urban controller is to control the traffic in such a way that the output of the region matches the output that is determined by the upper level. In-vehicle technologies are considered by assuming that the routes, and positions of vehicles are known.

In this research, a controller that coordinates all the intersections in a region will be developed. The main focus will be on the development of a feedback controller for

saturated traffic conditions [10, 15]. The reason for this is that such a controller has low computational complexity, and control is most needed when the conditions are saturated. Besides that, there exist approaches to create green-waves with these types of controllers, [16]. Thus, it is expected that the focus on saturated conditions is not that limiting at all.

### C. Bottom level: the freeway controller

In some cases, due to, for instance, incidents or disturbances, congestion on the freeway can occur, even when the upper level controller has reduced the in-flow to the freeway such that the freeway flow is at the capacity. In those cases, the freeway controller has to coordinate variable speed limits and ramp metering in order to prevent or resolve congestion.

This integration can be realized in various ways. A popular method found in literature is model predictive control [6]. A feedback based approach for the integration of ramp metering and variable speed limits is reported by Van de Weg et al. [17]. However, this approach has been developed for a 100% in-vehicle system. It is expected that the new algorithm, COSCAL v2 [12] will be able to be integrated with ramp metering in a similar way as is done by Van de Weg et al. [17]. The focus of this research will be on the application of that algorithm for the integration of multiple ramp metering installations and variable speed limits in order to resolve moving jams.

## V. Discussion

This section discusses to what extent this kind of control system is robust, optimal, predictive, and integrated. It will be discussed how this solution direction can satisfy every criterion. Thus, a short discussion of every criterion is presented below.

### A. Robust

The control system is robust when its performance is not deteriorated when traffic conditions vary or unexpected

events occur. The different levels of the controller have to realize this in different ways.

The upper level uses routing information to anticipate on future traffic conditions. When the traffic conditions are different from the expectations, the controller has to adjust its action. Besides that, when an unexpected event happens, for instance, an incident which reduces the capacity of a region, the upper level controller has to redistribute traffic such that the demand of this region is below the reduced capacity. The controller has to be able to deal with these incidents or other unexpected changes in the traffic conditions.

The urban region controller has to distribute traffic in the region in such a way that it can deal with unexpected events. The upper level will assist this region when an unexpected event takes place. However, preferably, local problems should be dealt with locally.

The freeway controller is specifically developed to resolve moving jams. Thus, when a moving jam is caused due to a disturbance, despite the control action of the upper level, the freeway controller will start intervening in order to resolve the congestion. In that sense, it is a robust controller.

#### B. Optimal

As pointed out in section II, optimization will cost a lot of computation time. Therefore, on-line optimization is not feasible for a control system that has to be implemented in the near future. However, due to the prediction and redistribution of the traffic, optimization for the upper level might be inevitable. It is expected that the computational complexity of this upper level is low enough for on-line implementation.

For the bottom levels, the controllers for the urban regions and freeway will take action that is in line with the action that a model predictive controller would take. On the freeway this is the resolving of congestion, in the urban regions the task will be to distribute traffic in such a way that the output is in accordance with the output demanded by the upper level.

#### C. Predictive

Prediction will be taken into account by using the routing information from the vehicles. In doing so, the controllers can anticipate on future traffic demands.

#### D. Integrated

The hierarchical controller is integrated since it will combine urban intersection controllers with ramp metering installations and variable speed limits.

### VI. Conclusion

This paper introduced the research proposal of the PhD research project with the title 'Robust, Optimal, Predictive, and Integrated Road Traffic Control'. The main goal of this research is the development and evaluation of a hierarchical control system that improves the throughput of a regional road network by controlling traffic lights, ramp metering installations, and variable speed limits. The control system is

developed with near-future field implementation in mind and it has to benefit from in-vehicle technologies.

The concept that will be worked out in this PhD research project is introduced in this paper as well. The hierarchical control system consists of two levels. The upper level distributes traffic over different regions, and the bottom level consists of a controller for urban traffic, and a controller for the freeway traffic. It has been discussed how the controller can be robust, optimal, predictive, and integrated.

### VII. Acknowledgement

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