Large-Scale Signal Optimization: Traffic Platform Framework and Applications

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Abstract:

Junctions and in particular signalized junctions have a major impact on the traffic flow in urban areas. On the one side, the quality of the signal programs influences the quality of the traffic flow at single junctions and along the route of road users. On the other side, however, it is also possible to use signal programs as an instrument for strategic traffic management in networks and achieve a preferred distribution of the traffic flows. Consequently, very sophisticated methods for traffic-actuated rule- or model-based online signal control and optimization tools have been developed and implemented in many western cities in recent decades. In cities in emerging countries, however, the situation is different. Here typically fixed-time programs try to cope with the increasing traffic demand. Regular updates of all signal programs reflecting the changing demand and changing routes should be self-evident, but are seldom done due to limited workforce. Hence, we propose a Traffic Platform framework, which allows for automatic and fast signal program optimization of a high number of signalized junctions and take in account route changes due to changed signal plans. This Traffic Platform framework has been applied successfully in different projects and field implementations.

Keywords:

Signal optimization, emerging countries, traffic flow optimization, scenario management

INTRODUCTION

Frequent phenomena of emerging countries such as Brazil, India and China are rapidly growing cities and subsequently also rapidly changing, usually increasing traffic demand. E.g. in Brazil the State Traffic Department DENATRAN reports an increase of more than 100% on licensed vehicles in Brazil [1]. This often results in heavy traffic jams in particular in urban areas.

A common component of the transport infrastructure in these countries is a large number of signal controlled junctions in urban areas (up to 500 per 1 million inhabitants), which play a critical role in the network infrastructure. Thus, the need for regular optimizations of the signal programs is very high.

While in highly developed countries the research in signal optimization focuses on online and traffic-actuated optimization strategies (e.g. [2]-[5]), the technical standards in emerging countries are often lower and thus require other solutions. Here, the focus should be on providing a tool, which produces consistent and flow-orientated signal programs and which can be adapted easily to the changing and increasing traffic demand. Thus, the goal is not necessarily to find the best solution, but to find a very good solution under the following limitations.

(1) not enough workforces,

(2) data about traffic flows being unavailable and

(3) a lack of appropriate methods and tools for dealing with a high number of signal controllers.

Traffic counts are a usual basis for the optimization of signal programs; however, they have several disadvantages, which will be described in the first part of this paper. Then we will give an overview on the proposed framework using a macroscopic traffic flow model which overcomes these disadvantages and close the paper with an evaluative summary including a discussion of the limitations and applications.

The focus of this paper is not on describing each single step in great technical detail, as e.g. demand modeling and signal optimization have widely been discussed in several papers from researchers and practitioners. Instead we will show why and how we can put these steps together to create a framework which allows the transportation planner to incorporate signal optimization into the daily and long-term planning tasks.

SHORT-COMINGS OF COUNT DATA

Traffic counts are probably the most obvious and most used input data for signal optimization. However, using traffic counts for cities in emerging countries has some limitations, which are listed in the following

(1) Traffic counts at a high number of junctions (50+) are costly and cannot be performed area-wide due to a small workforce.

(2) Traffic counts are subject to high natural variations and are error-prone.

(3) Traffic counts can only describe past situations and do not allow for an anticipatory planning and traffic impacts of new developments.

(4) Traffic counts only give information on junction flows, but we do not know the full route of the vehicles. Some survey methods such as automatic license plate recognition (ALPR [6], Bluetooth etc.) can overcome this problem to a certain extent.

(5) Traffic counts have limited value in oversaturated networks, as they do not reflect the actual demand. Only over longer time intervals with total traffic flow below capacity do the observed volumes reflect the demand.

(6) Traffic counts do not provide an elastic demand and route choice model mechanism which is necessary to adapt signals to corridor or net-wide demand.

PROPOSED FRAMEWORK USING A MACROSCOPIC TRAFFIC FLOW MODEL

The above section has shown that traffic counts have some significant disadvantages when used as a basis for signal optimization in larger cities in emerging countries. We propose a methodology which goes beyond the level of microscopic counts and local optimizations. Our methodology (see FIGURE 1) uses a macroscopic traffic flow model as the basis for further signal optimization. Thus, instead of an individual junction-based optimization the origin-destination flows are considered as the "customers".

Once, the base demand and supply model has been developed, it can be used for several applications. This methodology overcomes the problems of local counts described above. TABLE 1 summarizes the advantages.

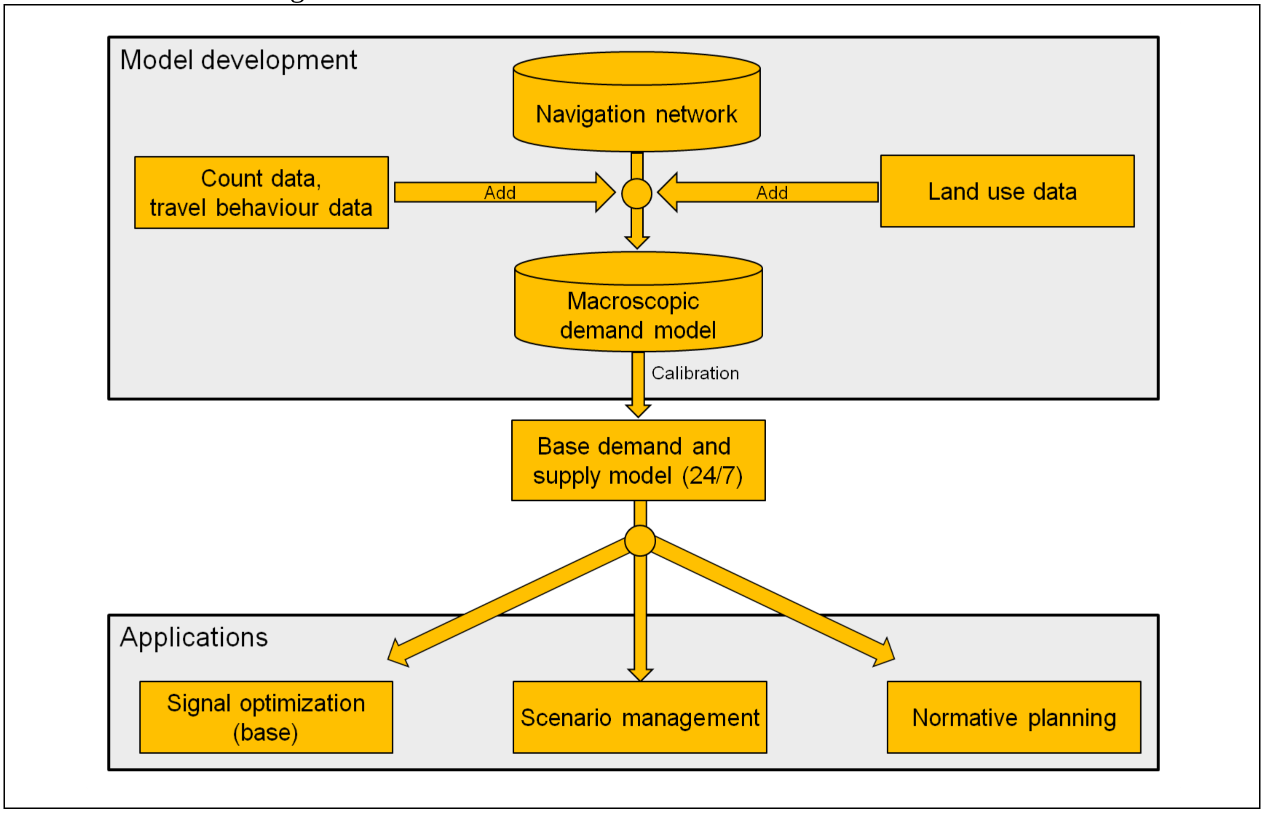

FIGURE 1: Proposed framework.

TABLE 1: Problems of local counts and solutions with the proposed methodology.

Problem with local counts	Solution with the proposed methodology
(1) High number of junctions	For the calibration of the base model initially only roughly 15-25% of the junction must be counted. For later updates fewer counts are sufficient.
(2) High variations and inconsistencies	A flow-based approach will smooth high variations and can help identifying errors in the traffic counts.
(3) Counts describe only past situations	Land use data changes may be available before the changes occur and thus can be incorporated into the model before the change takes place
(4) Counts describe only junction flows	Flows from the assignment in the base model describe the full path of each traveler. Thus, we can identify major flows and can optimize the offsets accordingly.
(5) Counts have limited value in oversaturated networks	In a macroscopic approach the modeler can calibrate larger time intervals with totally less than 100% saturation for the calibration and then apply time series to distribute the demand in these intervals.
(6) Counts do not provide elastic demand and route choice model	Using a macroscopic demand and flow model, modelers can model the impact of measures on demand (e.g. destination and mode choice) and route choice.

BASE DEMAND AND SUPPLY MODEL

The development of base demand and supply model is not the focus of this paper, as this has been widely discussed in many papers and is applied in many projects worldwide. Nevertheless, we want to discuss three issues which are special due to the planned application of the base model:

- For the later optimization of signal programs it is essential that all required input for analyses of junction must be modeled (e.g. number of lanes, signal program, factors for bus blockages, etc.).
- Going by our experience, the junction modeling is not only required for the later optimization, but already crucial for the calibration of the model, thus they should be considered during the assignment to approach user equilibrium [7] - [9]. However, this can lead to convergence problems, as the cost functions are no longer separable, e.g. turn delays of permitted or minor movements depend also on the volumes of conflicting movements. Here, a method of using iteratively re-calibrated volume-delay-functions instead of actual turn delays improves the convergence [10] - [12]. Furthermore, such an assignment can avoid V/C-ratios greater than one for turning movements.
- The assignment periods and method (static vs. dynamic) must carefully be selected according to the specifics of the project.

SIGNAL OPTIMIZATION

Optimization of fixed-time signal programs consists of three steps

- Split time (i.e. green time) optimization.
- Cycle time optimization.
- Offset optimization.

As FIGURE 2 shows, the first two steps refer to a single node and the last step considers the traffic flow in the network, for example from an assignment procedure. While online tools such as SCOOT [11] perform all of these steps online without interaction of the user, this is for offline analyses not necessary. Here, it is acceptable, but also desirable for higher acceptations of the results, that the engineer can influence and evaluate all steps of the optimization. The following describes these steps separately for the purpose of simplification.

FIGURE 2 also shows an outer iteration with additional assignment considering the junction model as described in the previous section. This is required whenever the signal optimization influences route choice, which in turn changes the flows and turning movements and thus the basis for the signal optimization.

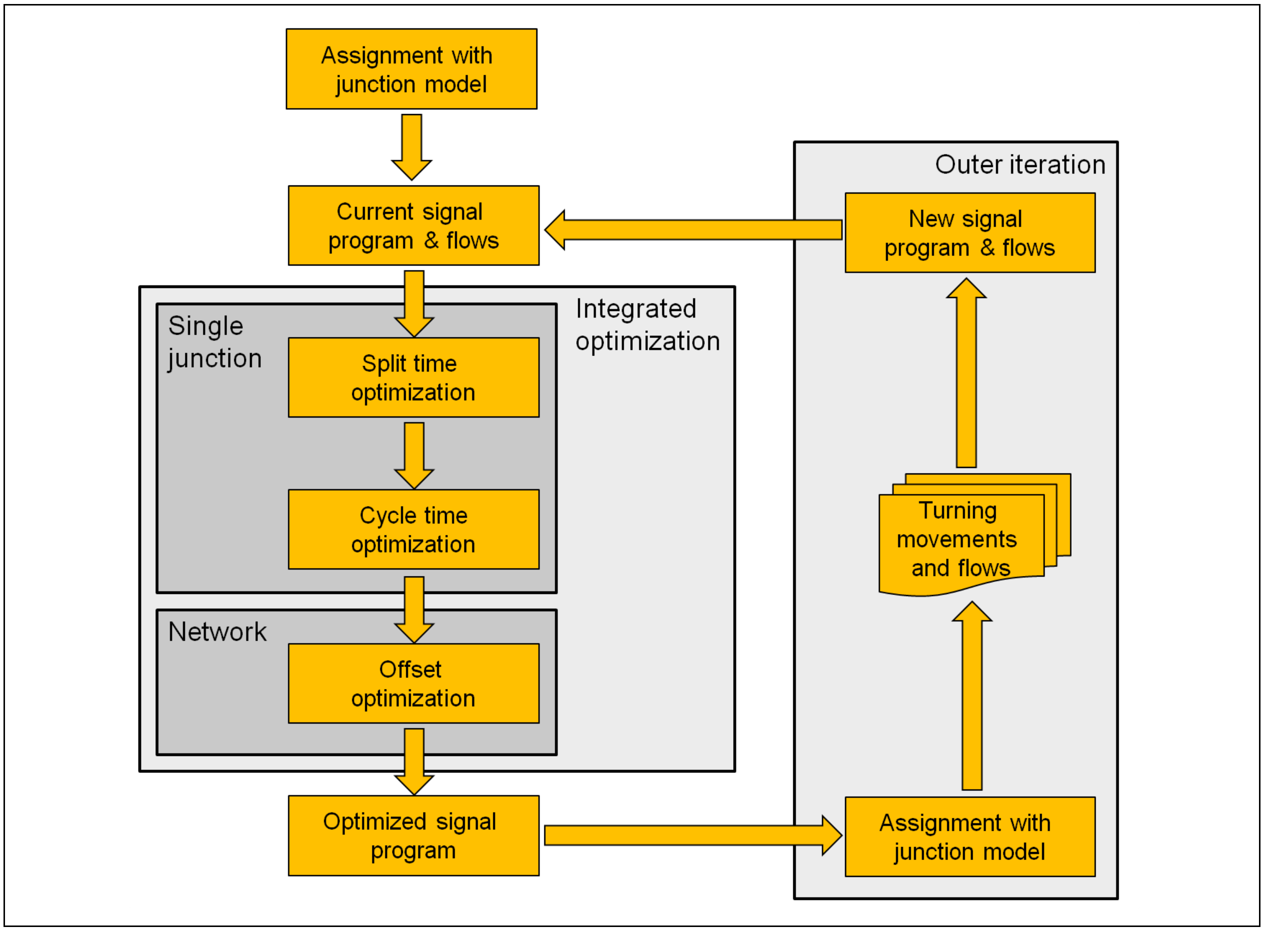

FIGURE 2: Signal optimization of fixed-time signal programs with outer iteration loop to a balanced network loading.

1. Optimizing green time split
Using the existing phasing system and given traffic flows from an assignment, it is possible to optimize the green time split. For this, there are generally two approaches:

1. Minimizing the mean delay time, e.g. according to the HCM [14].
2. Minimizing the maximum volume/capacity ratio

The difference is that the first approach tries to optimize the mean delay time of all streams at the junctions, and thus can neglect streams with very little traffic volumes.

The second approach balances in the first phase of the optimization the "critical" streams of the junction and should then, in further steps, balance the subordinate streams. "Critical" streams are in this context those streams with the highest volume/capacity ratio. This can lead to situations in which streams with little capacity (e.g. only one lane for a left-turner) can have a major impact on the results of the optimization.

Phase sequence may also be variable during this optimization step.

2. Optimizing cycle time

Changes in the cycle time can influence the traffic flows significantly. In the evening or during the night, lower cycle times reduce waiting times at red signals (uniform delay) and during the day longer cycle times increase the capacity of the junction, as the share of intergreen times is lower.

The simplest algorithm to optimize the cycle time of a signal controller is to optimize the signal program for all possible cycle times and then to choose this cycle time with the lowest mean delay time.

However, for the offset coordination of signal programs it needs to be considered that all programs have the same cycle time or the cycle times are in a adequate ratio (for example 2:1).

3. Optimizing offset

Signal offset optimization is used to optimize the offset between the signal times of neighboring nodes in such a way that vehicles can pass several consecutive signal controls on green. The general aim is to minimize the total waiting time and number of stops for all vehicles at the signal control.

There is significant research on calculating offsets in networks (e.g. [15] - [17]). Here the optimization algorithm should be capable of identifying the main streams automatically from the assignment and then optimizing the offsets accordingly. Particularly in grid networks, the major direction is not always clearly identifiable and can change during the day.

Current guidelines and offset optimization algorithms may be weak for oversaturated situations in which platooning is low [18]. Nevertheless, particularly in urban areas with low distances between signalized junctions, offset optimization must ensure a coordination which avoids unused green times. Unused green times can occur, when a downstream signal is green, but the flow to this signal is blocked by an upstream signal.

Other optimization steps

The methodology described above assumes a given junction layout and a given stage of definitions. Of course these too can be optimized, but in particular changes in the junction layout cannot be optimized automatically. Here, computer-aided identification of possible optimizations and automatic evaluations of the solutions can help the engineer.

Additionally, when looking at the whole day, the identification of the time-of-day breakpoints can be optimized. For example Park et. al [19] describe a genetic algorithm which optimizes the time-of-day breakpoints as an outer loop of the optimizations.

APPLICATIONS AND LIMITATIONS

A long paper could describe several applications of this proposed methodology in detail. Here we include this into the summary. Generally, the methodology has its main advantage, when large number of signal programs shall be updated regularly or even more if several signal programs for different traffic situations (e.g. football game, construction sites) shall be optimized.

Thus, applications include, but are not limited to:

- Regular implementation of optimized signal programs.
- Signal optimization for different scenario (e.g. incident management).
- Normative planning, i.e. using signal programs as planning instrument.

Limitations include the focus on fixed-time, time-dependant signal programs. However, most modern traffic-actuated controls need a base fixed-time program, too. Furthermore, the methodology requires a detailed supply and demand modeling, which has some initial costs, if a city has to start from the scratch. Finally, there may be limitations in modeling very complex junctions.

Altogether, advantages outweigh the above stated limitation. Once, the system has been setup, the costs updating and optimizing signal programs are very low. Even for this setup, only roughly 20% of the junctions need to be counted, as the methodology with the macroscopic flow model still ensures very good and consistent results. Finally, most of the time-consuming task such as the detailed supply and demand modeling will improve the quality of other tasks of transportations planners such as master planning and Integrated Corridor Management (ICM) Planning.

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