Optimization of traffic light phases at adjacent intersections

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Abstract. The article studies the relationships between the time intervals of traffic light phases and intersections. Traffic light objects can be mutually useful in relation to each other if they are correctly adjusted and the existing load is distributed. The necessary frequency of updating and control of traffic light phases to improve their influence is also revealed. Counting cars on free exits and updating traffic light cycles based on the data obtained provides a field for analyzing and adapting neighboring intersections. The proposed algorithm can help improve the road situation in problem areas of urban connections in the presence of free roads ready for the redistribution of flows.

1 Introduction

The rapid growth of urban populations and increasing vehicle ownership rates have led to significant challenges in traffic management across many cities worldwide. This issue is particularly pronounced in parts of the Siberian Federal District, where daily evening traffic congestion can reach extreme levels, often rated at 10 points on congestion scales. The lack of alternative transportation options exacerbates this problem, leaving personal vehicles as the primary means of mobility for many residents.

In contrast to the Siberian region, major urban centers in central Russia, such as Moscow and Nizhny Novgorod, have invested in sophisticated traffic management programs and dedicated control centers. These initiatives leverage advanced analytics and forecasting techniques to address transportation challenges proactively. However, the implementation of such comprehensive systems is often justified by large population sizes and substantial economic resources, which may not be available in less densely populated or economically diverse regions.

The financial constraints faced by many municipalities present a significant barrier to adopting high-tech traffic management solutions. For instance, the installation of a single traffic light system with accompanying surveillance cameras can cost upwards of a hundred thousand dollars. In areas with limited funding, such investments may not be economically viable, as the return on investment could take years to materialize [1].

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Given these challenges, there is a pressing need for cost-effective and efficient traffic management solutions that can be implemented in various urban contexts, regardless of population size or economic status. This research aims to address this need by focusing on the optimization of traffic light phases at adjacent intersections, a targeted approach that has the potential to yield significant improvements in traffic flow without requiring extensive infrastructure overhauls or prohibitively expensive technology deployments.

By examining the relationships between time intervals of traffic light phases and the interactions between neighboring intersections, this study seeks to develop strategies that can enhance overall traffic management efficiency. The goal is to create a system that can adapt to changing traffic patterns in real-time, redistributing vehicle flows to maximize the utilization of existing road infrastructure and minimize congestion.

This research not only contributes to the field of urban traffic management but also addresses broader societal issues related to environmental sustainability, economic efficiency, and quality of life in urban areas. By proposing innovative yet practical solutions to traffic congestion, this work aims to provide valuable insights for urban planners, traffic engineers, and policymakers seeking to improve mobility in their communities.

In the central part of Russia, Moscow and Nizhniy Novgorod, special programs and centers for traffic management have been developed. Analytics, forecasting are improving and trying to help the population with solving transport problems. All these actions are justified by a large population and the receipt of economic funds. Setting up one traffic light object and installing fixation cameras can cost hundred thousand dollars, which is not recouped for areas with low funding.

2 Problem statement and methods

Nearby intersections are important in traffic regulation. Poorly tuned traffic light phases can provoke congestion and deterioration of the overall transport situation. A common problem is when one intersection can miss a lot of cars, while the next one can no longer cope with its overloaded task, where it becomes a stumbling block in the jam. Also, if one intersection copes with its task and can receive additional traffic load, and cannot due to the fact that all flows are oriented to other directions of movement.

In this sense, it is necessary to collect statistics from intersections constantly and regulate the situation based on the problem in these minutes. Online Navigators cannot always give a specific setting on intersecting streets due to the variety of traffic at each intersection. Navigation can determine the situation as difficult, but the difficulty will be that a large number of motorists will seek to turn to another street, when the time for this action will be very limited and not have time to fulfill all the needs of turning cars.

The option with digitization of data from video surveillance cameras can be costly for the city, for correct and high-quality work for each road, it is necessary to install a camera [2] so that with high detail it is possible to distinguish vehicles and subsequently distinguish them. At the same time, in snowy regions and with heavy rainfall, cameras cannot clearly determine the presence or absence of a vehicle, which can affect statistics.

Among the alternative options for collecting statistics can be elements of the roadway, inside which there are sensors for reading passing cars [3]. Such systems can monitor both the roadway, also help in the collection of statistical data and not be affected by the environment. Maintenance and installation costs are significantly less than video cameras.

The state can try to develop the transport network by building roads, but they have no practical sense without bypass roads. If we build an additional road, the number of those who decide to use a car will increase, and, as a result, the entire city will again stand still. This phenomenon can be explained by the paradox of the German mathematician Dietrich Braes, which he formulated at the end of the last century. The Braes paradox states that adding

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additional capacity to a single network can reduce its productivity if the route is chosen by the road users themselves. For example, if additional roads or lanes are put into operation, drivers will choose those routes that at the moment look less congested. However, this can lead to the opposite result: traffic will become even denser.

Automobile transport is becoming more sophisticated every year due to new standards and technological developments. Radio communication, satellites and globalization of Internet connections will also contribute to the fight against traffic jams in the future. But not every car owner can afford all the innovations and the cost of systems installed in new cars is passed on to buyers, which affects their interest in favor of older cars [4].

Control over intersections also helps to avoid accidents, driving through red lights and hitting pedestrians. For countries where the speed limit in cities is over 50 km/h, it is highly relevant due to the high pedestrian mortality rate.

3 Results and discussion

In previous studies, systems for optimizing traffic flows at intersections and options for their regulation were considered [5]. This paper proposes to regulate adjacent traffic intersections in order to redistribute traffic flows by increasing the travel time of intersections and at the same time reducing them depending on the current traffic situation at neighboring intersections. The lack of space for travel in no way affects the transport situation, and only aggravates it due to the ability to occupy free roads by other road users.

In the Siberian Federal District there is the city of Krasnoyarsk with a population of over a million people. There are approximately 0.8 cars per capita, which is a lot. After the construction of the new bridge, the roads did not expand in any way, which aggravated the already bad situation with the transport road system. The following are adjacent intersections that have problems during peak hours.

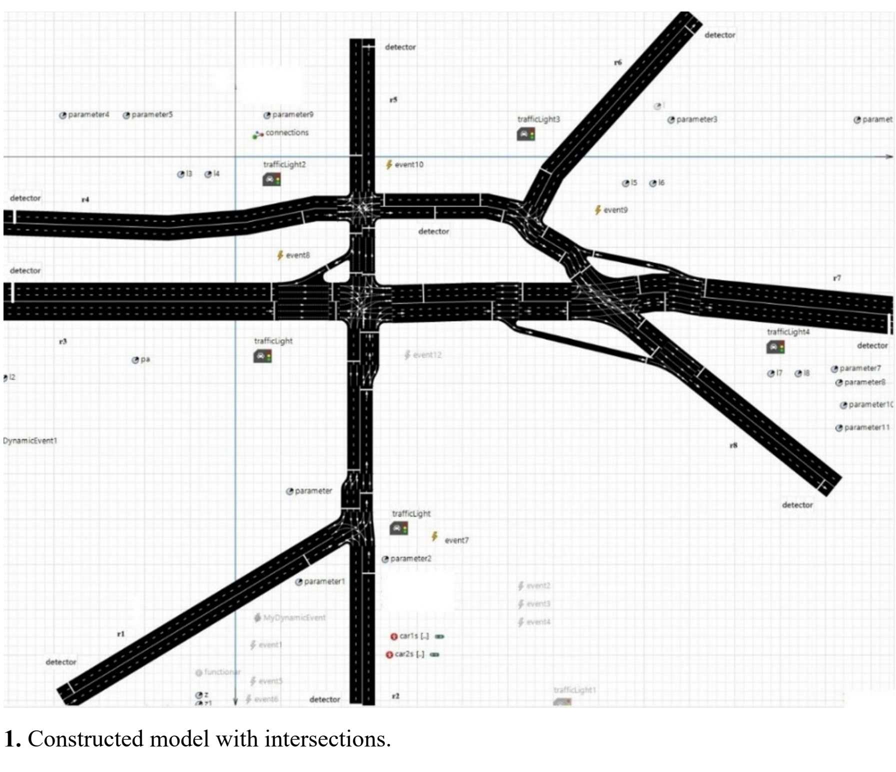

Fig. 1. Constructed model with intersections.

The following figure shows how 8 roads (r1...r8) are connected to each other. On the r7 side, a bridge is built and the road to the end of the r3 in both directions is usually overloaded. There is also a lot of road transport on the sides of r1,2,5 due to the presence of residential areas. Roads r4,6 usually experience problems due to overloading of the rest of the roads.

The following method of analyzing and correcting data at traffic lights is proposed:

In the form of reading elements in the modeling program, stop lines work, which are installed at the ends of roads. Each traffic light cycle of a nearby intersection updates the data on the stop lines (detector). If the stop lines are not full (the overflow should be configured depending on the statistical information), in turn, the traffic lights change their time frames to also set plus, minus X values. In the work, the values were taken plus, minus 10 seconds. Parameters 1... n are responsible for the duration of the traffic light phases and can change by X value. Variables i1... n are responsible for detectors on stop lines, which are updated at the end of each traffic light cycle and based on them new values of the green and red phases of the intersection are set.

An example of the software code of the intersection near the r6 road is shown in Figure 2. Each intersection has its own identical program code. Codes can be increased depending on which intersections should be interconnected.

```
if (l5 > 20  && l6 > 20)
{parameter3=50; parameter6=40;
event8.restart(parameter3+parameter6,SECOND);}
else if (l5<20 && l6>10)
{parameter3=40; parameter6=30;
event9.restart(parameter3+parameter6,SECOND);}
l1=0; l2=0;
```

Fig. 2. Constructed model with intersections.

The storage units (detectors) also collect the final statistics for each road and record them in the storage units; based on the data obtained, the model can be upgraded.

In the system, traffic participants also include pedestrians, who can be allowed to move as road users based on sensors detecting the presence or absence of a pedestrian.

4 Conclusion

Based on the obtained results, Table 1 was formed, where the number of machines that passed through the system in different directions per hour is indicated. Data shall be provided at a time in all directions starting from one. Low means creating 30 cars per hour towards each direction. High means creating 60 machines per hour towards each direction. It is also believed that very frequent control of traffic lights will not have a positive result due to the fact that the traffic situation has not yet changed [6]. Therefore, it is proposed to control traffic lights no more than 15 minutes. In the tests, measurements were made with different time values. The results of the study are presented in Table 1.

The analysis of the simulation results reveals several key findings regarding the optimization of traffic light phases at adjacent intersections. When the system reaches its capacity limits, vehicles are unable to exit the network, resulting in residual congestion. The optimal parameter values for both high and low traffic scenarios were identified and highlighted in the data. The implementation of coordinated traffic light control at adjacent intersections demonstrates a modest improvement in overall traffic flow. Simulation results indicate potential enhancements of up to 15% in throughput, although real-world applications may yield more conservative improvements, likely capped at approximately 10%. This discrepancy between simulated and practical outcomes underscores the complexity of translating theoretical models to actual urban traffic environments.

Table 1. Summary table with the results obtained.

Road/traffic	Low (no changes)	High (no changes)	Low (timing changes) (2.5min)	High (timing changes) (2.5min)	Low (timing changes) (15min)	High (timing changes) (15min)
r1	192	264	201	**281**	**225**	261
r2	63	125	**67**	**138**	61	133
r3	208	311	**213**	**334**	112	254
r4	**126**	198	122	204	109	**249**
r5	117	186	115	193	**134**	**198**
r6	132	**215**	140	211	**167**	206
r7	266	379	**285**	**392**	156	311
r8	83	132	**93**	131	83	**142**

It is noteworthy that infrequent adjustments to traffic light timing do not consistently yield positive outcomes in dynamic traffic conditions. This observation suggests that the frequency of control interventions plays a crucial role in the effectiveness of traffic management strategies, particularly in rapidly changing urban traffic scenarios. From a practical standpoint, the study proposes that data collection for traffic analysis can be effectively accomplished using built-in road detectors, potentially eliminating the need for more costly security camera installations. This approach offers a cost-effective alternative for municipalities seeking to implement advanced traffic management systems within budgetary constraints. These findings contribute to the ongoing discourse on urban traffic optimization and provide valuable insights for traffic engineers and urban planners in developing efficient, adaptive traffic management solutions.

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