Emerging Cutting-Edge Developments in Intelligent Traffic and Transportation Systems
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Issues of Increasing the Efficiency of Traffic Management on the Main Streets of Astana

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Abstract. Given the scarcity of funds in the city budget, the current way to improve the efficiency of traffic management is to coordinate traffic lights at a number of regulated intersections or pedestrian crossings, that requires a minimum cost. In this article the authors discuss the possibility of introducing a coordinated traffic light regulation on the section of R. Koshkarbayev Avenue, Astana.An analysis of the current traffic situation on the avenue under consideration was carried out, using the methods of studying the traffic flow parameters with the help of surveillance cameras. To develop a coordinated motion control schedule, a graphical-analytical method was used in the Microsoft Excel program.The purpose of this article is to assess the possibility of introducing coordinated traffic light regulation at a number of regulated intersections and pedestrian crossings of R. Koshkarbayev Avenue. Solutions are proposed for the introduction of coordinated traffic control at a number of regulated intersections or pedestrian crossings, R. Koshkarbayev Avenue. Introduction of the traffic coordination plan on the section of R.Koshkarbayev Avenue will increase the speed of communication and the level of traffic safety by reducing the amount of delays and the number of vehicle stops.

Keywords. traffic flow, delay of vehicles, bandwidth, traffic control, traffic intensity, traffic light regulation, coordinated traffic control.

1. Introduction

Currently, due to the increase in the level of motorization, congestion on the road network have acquired the status of one of the most acute problems in Astana

The increase in traffic congestion on the road network, high density, and traffic intensity of vehicles (V) reduce the efficiency of the road network, as a result, contributes to an increase in the number of traffic accidents [1]. New technologies in intelligent transportation systems (ITS), such as vehicle-to-vehicle and vehicle-to-infrastructure communication, have the potential to have a huge impact on safety, travel comfort, travel time, and energy consumption, reducing the likelihood of traffic accidents [2]. A

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particularly useful application of these technologies is the coordinated traffic control (green wave) at highway intersections [3].

Obtaining the most efficient control of traffic flow through a highway requires coordination between the streets included in this main street. Although signal synchronization is the main means of traffic control on surface streets, there are several other methods of traffic control and traffic flow coordination [3]. Unlike traditional intersection management, vehicle networking technologies allow coordinating traffic not only within an intersection, but also by controlling vehicles long before they arrive at the intersection.

Such a paradigm makes it possible to significantly reduce the time at the approaching controlled intersections, improve fuel efficiency and is the subject of this article.

2. Main part (Problem statement)

It is particularly relevant in Astana and technically possible to introduce coordinated traffic control in some sections of the road network. First, there is a need for introduction at the sites of entry and exit to the city.

In this paper, the possibility of introducing coordinated traffic light regulation on the section of R. Koshkarbayev Avenue is considered. The avenue under consideration is in the central part of the city, connects the Almaty district with the Yesil district of Astana. The total length of the avenue is about 7.3 km. At present, the Almaty district of Astana city is being intensively built up with residential complexes. Therefore, there is a significant amount of freight traffic along R. Koshkarbayev Avenue.

Accident statistics confirms the relevance of developing evidence-based measures to improve the efficiency of traffic management on R. Koshkarbayev Avenue. The accident map shows that in 2022, there were 20 accidents on the current avenue, 16 of them on TL, and collisions of vehicles (9 accidents) and pedestrians (7 accidents) at intersections predominate (Figures 1,2).

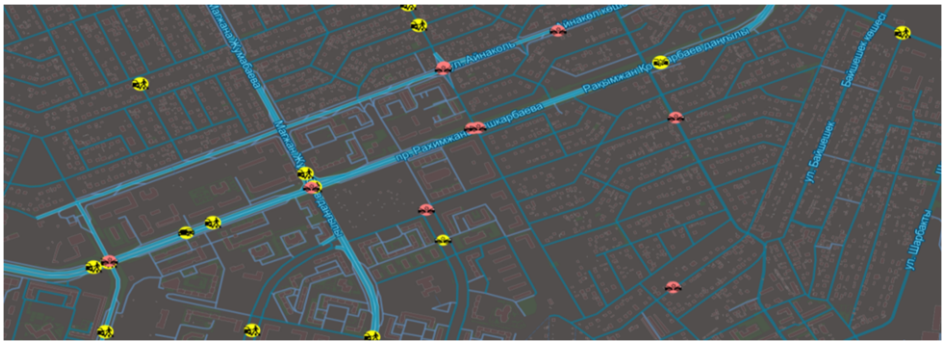

Figure 1. Topographical analysis of accidents

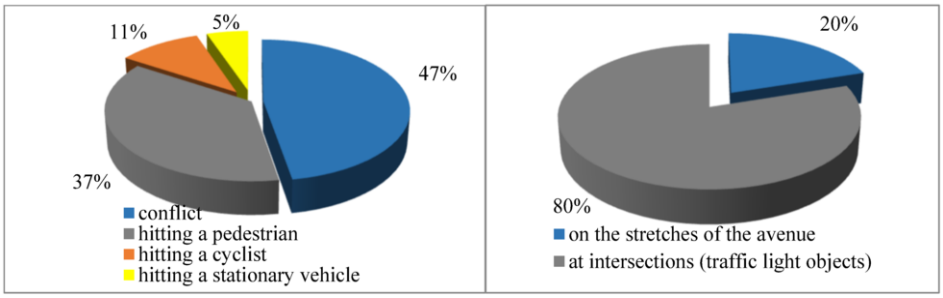

Figure 2. Accident rate analysis of R. Koshkarbayev Avenue (situation for 2022)

There are 18 traffic light objects (TL) on R. Koshkarbayev Avenue, 14 of them are at intersections and 4 at pedestrian crossings. TL5 (R. Koshkarbayev Avenue – K. Amanzholov Street) is included in the ITS system. At TLO9 (R.Koshkarbayev – M. Zhumabayev avenue), TL15 (R. Koshkarbayev – M. Tolebayev Avenue), two-program TL operation modes are functioning, at the other TL - single-program modes (Table 1). In this regard, on R. Koshkarbayev Avenue, there is a need to introduce multi-programmed modes of operation of traffic lights, which will consider fluctuations in traffic intensity at different periods of the day.

An analysis of the current situation on R. Koshkarbayev Avenue shows the following shortcomings:

- accident centers are mainly intersection zones (TL);
- single-program TL modes do not allow taking into account fluctuations in traffic intensity associated with such factors as time, traffic, road architecture and capacity utilization;
- frequent stops of the vehicle at the TL, associated with the lack of coordinated control at sufficiently high speeds of the traffic flow.

3. Research methods

Various approaches that are used to control traffic on the main streets were analyzed [1-4]. Most of the literature in the field of coordination-based management of intersections focuses on reducing traffic congestion, preventing collisions of vehicles at the intersection [5].

In this paper, we used methods for studying traffic flow indicators, methods for calculating the duration of a cycle and its elements using the Webster formula [6], methods for constructing a graph of coordinated traffic control (Figure 3).

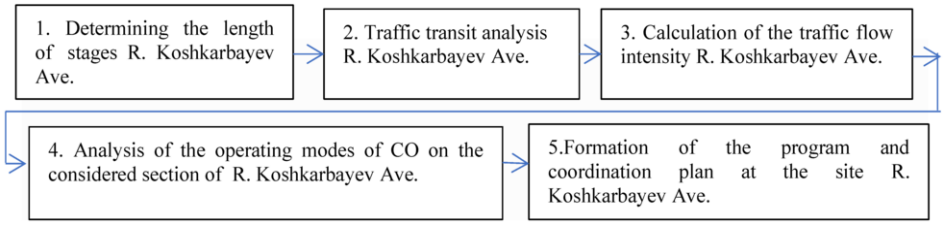

Figure 3. Stages of the study (procedures)

4. Research results

For the development of coordinated traffic control on R. Koshkarbayev Avenue, a section covering eleven TL was selected (Table 1). The length of the hauls between TL was determined using Google Maps. Direct direction in this case involves movement in the direction from the M. Tolebayev Street towards the U. Zhanibek Street.

Table 1. Length of hauls of R. Koshkarbayev Ave.

№ s/n	Name of TL (crossings, pedestrian crossings)	Length of hauls, m		The difference in the length of the hauls
		Direct	Reverse	
1TL	M. Tolebayev Street	-	-	-
2TL	пк 25-40	420	374	46
3TL	U. Zhanibek Street (142 st.)	236	266	-30
4TL	47 Street	368	376	-8
5TL	Korday Street	293	299	-6
6TL	ПК 28 (37+80)	336	292	44
7TL	M. Zhumabayev Street	308	348	-40
8TL	пк.45+70	479	440	39
9TL	S.Nurmagambetov Street (Sarykol)	320	370	-50
10TL	ул. ПК8-20	380	342	38
11TL	K. Amanzholov Street. (Obagan)	367	396	-29
	Total:	3507	3503	4

The length of hauls of the considered section of R. Koshkarbayev Avenue is within 200...500 m (Table 2). Therefore, the length of a group of vehicles (pack of cars) at the hauls increases by 1.5-2 times compared to the original, i.e. a moderately high efficiency of coordination is achieved, therefore, the introduction of "Coordinated traffic control" on the considered section of R. Koshkarbayev Avenue will be appropriate.

During this study, an analysis was made of the traffic transit on the considered section of R. Koshkarbayev Avenue. It has been established that the traffic transit along R. Koshkarbayev Avenue is more than 70%.

Table 2. Analysis of traffic transit on the section of R. Koshkarbaev Avenue (on a weekday)

№ of approach	Traffic intensity, units/hour			Amount, unit/hour	Transit,%
	forward	to the left	to the right		
7.30-8.30 morning rush hour					
1	963	338	203	1504	64
2	256	305	153	714	36
3	997	128	179	1304	76
4	639	303	167	1109	58
18.00-19.00 evening rush hour					
1	956	278	265	1499	64
2	579	217	267	1063	54
3	904	143	206	1253	72
4	482	217	113	812	59
15.00-16.00 off-peak period					
1	774	230	152	1156	67
2	271	174	207	652	42
3	853	91	159	1103	77
4	329	143	94	566	58

A significant proportion of the traffic flow intensity on R. Koshkarbayev Avenue is made up of trucks, which is due to the intensive development of the Almaty district of Astana (Figure 4).

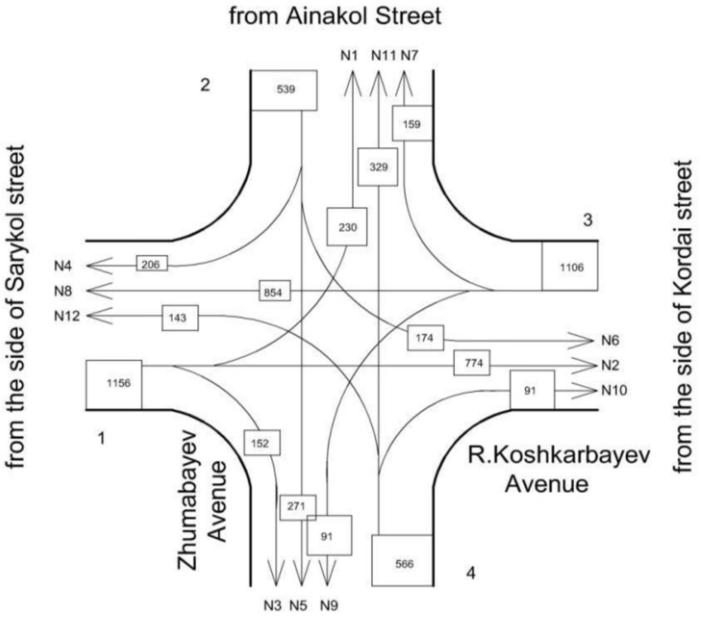

Figure 4. Digital diagram of the traffic flow intensity at the intersection of R. Koshkarbayev Avenue and M. Zhumabayev Street (off-peak period 15.00-16.00)

Intense turning flows from and to the main street impair the efficiency of coordinated traffic control [6]. Transit directions are considered as the directions of movement in the flows of vehicles passing the previous TL on the street section in the main direction [6]. Thus, the transit nature of the flow is directly related to the turning movement at the intersections of the section under consideration. The requirement for transit means the predominance of forward flows on the current highway.

The share of traffic transit at the regulated intersections of the section of R. Koshkarbayev Avenue is determined based on the data obtained on the traffic flow intensity during peak periods. Based on the analysis, it was found that the considered section of the R. Koshkarbayev Avenue corresponds to the conditions for conducting coordinated management (Table 3).

Table 3. Analysis of compliance with the conditions for the introduction of coordinated management on the site of R. Koshkarbayev Avenue

Conditions for the introduction of coordinated traffic control	Compliance with the conditions for the introduction of coordinated traffic control
The number of lanes in each direction is at least 2	3 lanes in each direction
Cycle time same/multiple	After adjustment, the duration of the control cycle is the same
Transit flow not less than 70%	Transit flow over 70%
The distance between adjacent TLO does not exceed 800 m	Does not exceed 800 m

Estimated speed throughout the considered section of the R. Koshkarbayev Avenue and on its individual hauls is assumed to be equal to the average speed of vehicles moving in groups on its individual hauls of this avenue.

An analysis of the existing modes of operation of eleven TL shows that the longest durations of the control cycle are 107 and 99 s. (Table 4).

Table 4. Analysis of the existing modes of operation of TL on the considered section of R.Koshkarbayev ave.

№s/n	Single phase control	Duration, s						
		T_{om1}	T_{np1}	T_{om2}	T_{np2}	T_{om3}	T_{np3}	$T_{ц}$
1TL	2	29	6	29	6			70
2TL	2	40	4	23	4			71
3TL	3	40	6	25	6	16	6	99
4TL	2	40	6	25	6			77
5TL	2	40	5	25	5			75
6TL	2	39	4	23	3			69
7TL	3	35	4	30	4	15	3	91
8TL	2	45	4	24	4			77
9TL	3	34	3	25	3	39	3	107
10TL	2	40	3	24	3			70
11TL	3	34	5	25	5	12	5	86

To develop the first plan (for the off-peak period) of traffic coordination, TL3 was chosen as the key one, with a three-phase scheme of phase-by-phase passing (Figure 5). It should be noted that based on the analysis of foreign practice, to ensure traffic safety, since 2019 in Astana, a decision has been made to set the duration of the green flashing traffic light to 4 seconds.

During the study, the calculation of the control cycle duration and its elements was carried out according to the Webster method [7].

When adjusting the parameters of the control cycle (under the mode of the key TLO), the values of the intensity of the vehicle departure are considered. When developing the coordination schedule, the first phases of the TLO phase-by-phase passing schemes were synchronized.

When developing coordinated traffic control on the section of R. Koshkarbayev Avenue, the existing schemes of phase-by-phase passing (schemes of phase-by-phase passing without change) and the operating modes of eleven TL were used. To develop the first coordination plan, the cycle (99 s) of key TL3 (the intersection of R. Koshkarbayev Avenue with U. Zhanibek Street) was adopted as a settlement cycle.

Based on the calculation results, a coordination graph (GC) of the section under consideration was constructed, which is a graphical interpretation of the path-time dependence, depicted in a rectangular coordinate system (Figure 6). The horizontal axis shows the time of movement, along the vertical axis - the path traveled by the vehicle at the calculated coordination speed [8].

cycle	Cycle duration -99 seconds													
Phases	1 synchronized phase					2					3			
tact	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time, sec	36	4	2	1	1	28	4	2	1	1	12	4	1	2
1T														
2T														
3T														
4T														
5P														
6P														
7P														
8P														
9C														

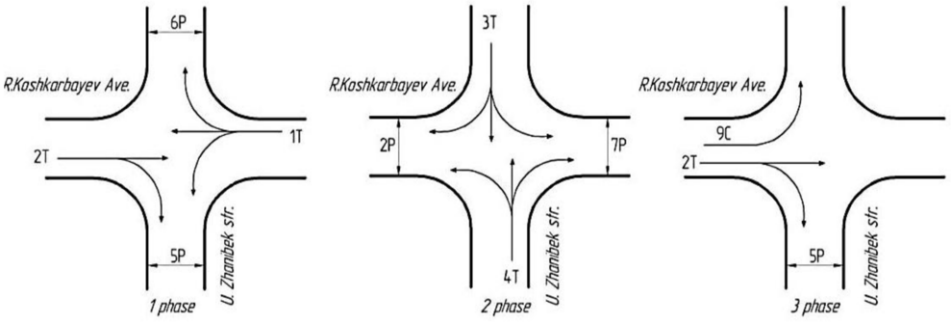

Figure 5. Scheme of phase-by-phase siding and TL operation mode at the intersection of R. Koshkarbayev Avenue and U. Zhanibek Street

The minimum width of the time tape is chosen (1) not less than 0.3Tz.

$$T_z = 0.3 \times T_c = 0.3 \times 99 \approx 30s. \quad (1)$$

While study, it was impossible to provide coordinated traffic control (green wave) throughout the considered section. Therefore, it becomes necessary to divide the incoming flow into zones. In the forward direction, the coordination schedule is divided into 3 zones, in the reverse direction, into 2 zones (Table 5). As a result, when drivers drive three or more TLO (almost 1 km) non-stop, they do not notice internal contradictions and this already positively affects their psycho-emotional state, which will accordingly determine road safety.

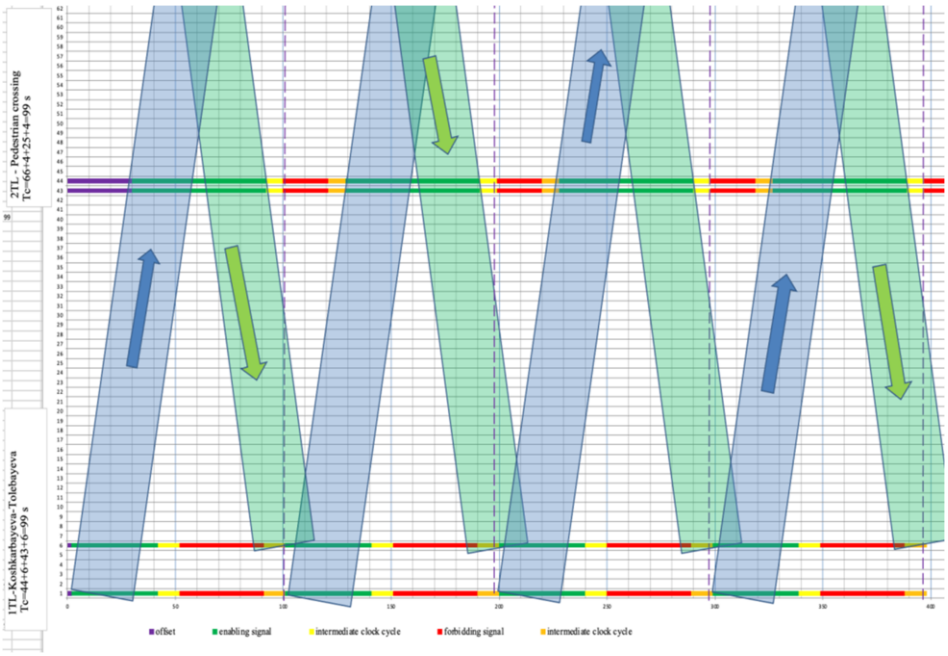

Figure 6. A fragment coordination graph on the section of R. Koshkarbayev Avenue (section TL1-TL3)

Table 5. Conditional division of the coordination graph into zones

Traffic direction	Direct	Reverse
TL included in the first zone of the GC	TL:1,2,3	TL: 11, 10,
Length of 1 zone, m	+-1040	+-830 м
TL included in the second zone of the GC	TL: 4,5,6,7	TL: 9, 8,7,6,5,4,3,2
The length of the second zone, m	+-1206	+-2230 м
TL included in the third zone of the GC	TL: 8,9,10,11	
The length of the third zone, m	+-1100	

Note: in the reverse direction, TL1 is partially included in the coordination graph (15 s).

The operating modes of the TL included in the system of coordinated traffic control on the site of R.Koshkarbayev ave. have been developed. Practice shows that after the implementation of the proposed mode of coordinated traffic control, it may be necessary to adjust the offset to the changed actual speed.

The proposed solution for the introduction of coordinated traffic control on the section of R.Koshkarbayev ave. will increase the speed of communication and the level of traffic safety by reducing the amount of delays and the number of vehicle stops.

5. Discussion

Coordinated traffic control is successfully used both in our country and abroad [1-9]. There are both preferred calculation methods and software products that simplify the application of coordinated traffic control. However, besides the advantages, such measures also have some disadvantages, which also take place at the ordinary regulated intersections that are not included in the network of coordinated traffic control.

In this study, an analysis of the current state of the organization of traffic on R. Koshkarbayev Avenue in Astana was provided and the possibility of introducing coordinated control was studied. The results of this study are distinguished by the fact that actual initial data are used, in particular, the existing schemes of phase-by-phase passing and operating modes of TLO, data on traffic intensity. The coordinated traffic control graph was built in Microsoft Excel, considering the practical experience of the organization's engineers in the field of traffic control in Astana.

The advantage of this approach is based on the construction of a coordination graph in Microsoft excel and is to reduce the planning complexity that is computationally intensive and to simplify the solution for a highway that is not included in the ITS.

The practical significance of the study lies in its applied nature, the results of which are proposed for implementation to improve traffic conditions on R. Koshkarbayev Avenue. Particular attention should be paid to further develop a library of coordination plans for different periods of rush hour, considering changes in traffic.

6. Conclusion

In accordance with the aim of the study, the following tasks were performed:

- an analysis of the existing modes of operation of eleven traffic lights on R. Koshkarbayev Avenue was carried out. It is recommended to introduce multi-program modes of TL, considering the fluctuations in traffic intensity;
- solutions for the introduction of coordinated traffic control at several regulated intersections or pedestrian crossings of R. Koshkarbayev Avenue are proposed. In the forward direction, the coordination graph is divided into 3 zones, in the reverse direction, into 2 zones.
- develop a further library on coordination plans for implementation in the traffic management system on R. Koshkarbayev Avenue which will consider the fluctuations in traffic intensity associated with factors such as time, traffic, road architecture and capacity loading are important traffic elements.
- after the introduction of the proposed regime, it is recommended to analyze the effectiveness of coordinated traffic control on the considered section of R. Koshkarbayev Avenue

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