

# Improving the Level of Information Support for Drivers at Controlled Intersections in the Context of Urban Freight Transport and Sustainable Development

Serhii Turpak<sup>a</sup>, Viacheslav Trushevskiy<sup>a</sup>, Tomasz Dudek<sup>b</sup>, Olexiy Kuzkin<sup>a</sup>,  
Olena Ostrohiad<sup>a</sup>

<sup>a</sup> National University Zaporizhzhia Polytechnic, Universytetska St., 64, Zaporizhzhia, 69063, Ukraine

<sup>b</sup> Maritime University of Szczecin, ul. H. Pobożnego 11, 70-507 Szczecin, Poland

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## Abstract

The article examines existing European and Ukrainian practices to provide additional information to drivers of rail and non-rail road vehicles about the priority given when passing through an intersection signalized by traffic lights.

It is proposed to revise the existing priority when driving on the arrow signal in an additional section of a traffic light. It is also proposed to introduce new traffic light signals: a white arrow surrounded by a white ring, which means permission to move without priority, and a red contour arrow, which means prohibition of driving in the direction signalized by an additional section of a traffic light.

It is also proposed to change the colour and designation of traffic light signals used to regulate traffic on public routes to increase the efficiency of their perception by all road users. The positive features and disadvantages of using an additional traffic light signal in the form of a Greek cross are considered, and a method for introducing this signal into the general structure of the traffic light signalization cycle and determining its required duration is given, taking into account the minimum time intervals between conflicting permitting signals of the traffic and pedestrian directions of traffic light signalization.

To avoid the inconsistency of the signal used in practice in the form of a flashing pedestrian figure to indicate pedestrian crossings from the side of the carriageway in the zone of a signalized intersection, at which drivers making a turn must give way to pedestrians moving on the green signal of a pedestrian traffic light, a proposal to change the colour and type of this signal is substantiated in order to prevent its incorrect perception by drivers. Using updated signals will allow increasing the level of road safety and throughput at intersections signalized by traffic lights.

In addition to safety considerations, the study addresses the implications of signal priority design for urban freight transport efficiency and environmental sustainability. Frequent stopping and acceleration of delivery trucks and heavy vehicles at signalized intersections significantly increase fuel consumption, greenhouse gas emissions and noise levels in densely built-up areas. Therefore, improving the clarity and structure of permissive and priority signals may contribute not only to higher safety levels but also to the reduction of the environmental footprint of urban logistics systems.

Keywords: Traffic Lights; Priority Signals; Urban Freight Transport; Signal Redesign; Environmental Impact.

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## 1 Overview of the problem

Nowadays, improvement of the capacity of approaches to signalized intersections in heavily trafficked areas of large cities is a topical issue. The problem is of special significance at transport hubs used by street public transport. Route-based public transport is characterized by high passenger capacity and its comparatively higher utilization rate than that of private cars. In modern urban areas, signalized intersections also play a crucial role in the functioning of urban freight transport systems. The rapid growth of e-commerce and last-mile delivery services has led to a substantial increase in the number of light commercial vehicles and medium-duty trucks operating within urban areas. These vehicles are particularly sensitive to stop-and-go conditions due to their higher mass, lower acceleration dynamics and higher fuel consumption during repeated start-up cycles. Consequently, inefficient signal control directly affects both the operational efficiency of freight distribution and the environmental performance of urban transport systems.

As a result, the cost of traffic delays for buses, trolleybuses, and trams is much higher than the average cost of a one-hour delay for a passenger car. From an economic perspective, delays affecting freight vehicles generate additional logistics costs related to fuel consumption, driver time, delivery reliability and supply chain

performance. In time-sensitive distribution systems, especially those serving retail, hospitality and health-related facilities, even small increases in intersection delay may accumulate into significant systemic inefficiencies. Therefore, optimizing signal priority rules may produce measurable economic and environmental benefits in urban freight distribution networks. The use of intelligent transportation systems for traffic signal control is a promising direction to find additional capacity reserves at signalized intersections. The effectiveness of traffic flow management in terms of such systems can be improved greatly by increasing the level of information provided to drivers, i.e. the data regarding movement priority when a vehicle is proceeding on a permissive traffic signal.

Even within the available signal system, it is possible to observe different levels of priority when vehicles proceed on a permissive signal from various types of traffic lights. In particular, a green signal in an auxiliary section, activated simultaneously with the green signal of the main section, provides absolute priority. When traffic lights with arrows on all signals are used, traffic must be conflict-free. When proceeding on a circular green signal, drivers are required to yield to other vehicles only when making a left turn. Movement in the direction indicated by a white sign with an arrow is permitted only when all road users approaching from other directions are given way.

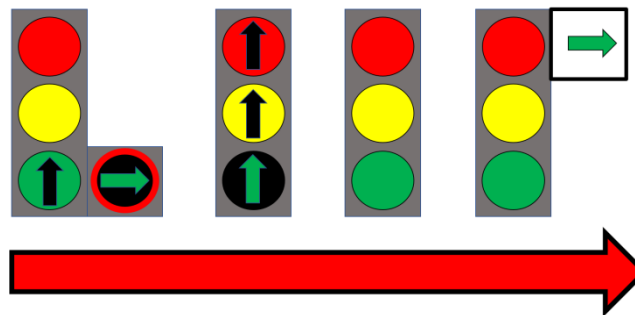


Figure 1. Types of traffic signals in accordance with the descending order of movement priority on a permissive signal

While developing modern algorithms to control traffic signals [1], traffic delays influencing right-turning vehicles caused by conflicts with non-motorized vehicles (bicycles, electric scooters, and mopeds) travelling straight ahead are taken into account. When flexible control algorithms are applied to adapt the structure of a signal cycle and its parameters to fluctuating traffic intensity, it is necessary to allow for the temporal combination and separation of partially conflicting trajectories for which the way-giving order is defined by the Road Traffic Regulations. Under such conditions, the saturation flow rate for individual lanes depends largely on the fact if a given trajectory has priority in a partial conflict situation [2].

While considering the main causes and contributing factors related to cyclist safety assurance at signalized intersections, study [3] notes that 53% of all traffic accidents analysed in major German cities over a five-year period occurred at conflict points with turning trajectories. The implementation of separate signals to regulate turning movements reduces significantly the accident rates; however, it leads to an increase in signal cycle length. As a result, the average traffic delay increases along with the number of signal violations among cyclists.

Paper [4] studies the effect of combining the left-turn maneuver with the opposing traffic by using a flashing yellow left-pointing arrow from the American signal system. It was found that combination of this signal with the offsetting the left-turn lanes made it possible to reduce the total number of traffic accidents at the intersection by 27%, including a 43% reduction in left-turn crashes and a 36% decrease in the overall number of injury-related accidents.

Study [5] compares the overall effectiveness of different approaches to regulating left-turn movements at intersections. The approaches are as follows: protected (conflict-free) left turns; combination of a conflict-free left turn with a left turn under partial conflict (yielding to opposing traffic) in a single signal cycle; and use of a flashing yellow left-pointing arrow only (left turn under partial conflict). The study found that compared to the combination of conflict-free and partially conflicting left turns in a single signal cycle, the implementation of conflict-free left turns reduces accident rates at signalized intersections by more than 50%. However, during peak hours, the conflict-free left-turn control results in an increase of average vehicle delay by 10%.

The sequence of traffic signal changes when using a flashing yellow left-turn arrow is analysed in studies [6, 7]. These papers examine transitional signals between the conflict-free left-turn interval and a flashing yellow arrow, indicated by yellow or red left-pointing arrow signals. A comparative analysis of accident rates at signalized intersections with these signal system variants suggests the necessity of applying a time interval, indicated by a red arrow, and a delay for the flashing yellow left-turn signal, while the duration of signal change intervals has only a minor effect on the number of violations committed by drivers.

Study [8] considers the impact on road safety in terms of switching from a signal control mode with a conflict-free left turn to a mode that, depending on traffic intensity, combines conflict-free left-turn control with a partially conflicting left-turn yielding to opposing traffic. The research was conducted for intersections with one and two left-turn lanes. It was found that in case of intersections with two left-turn lanes, accident rates increase by 31% when the combined mode is introduced. At the same time, at intersections with a single left-turn lane, the number of traffic accidents decreases by 60%. The issue of turning conflicts is particularly relevant for heavy goods vehicles operating in urban areas. Due to larger blind spots, longer wheelbases and increased turning radii, trucks are more vulnerable to conflicts with pedestrians and cyclists at signalized intersections. Clear differentiation between priority and non-priority permissive signals may significantly reduce the cognitive load imposed on drivers of freight vehicles, thus lowering the probability of decision errors in partially conflicting situations. In the context of sustainable urban mobility policies, improving intersection safety for freight vehicles is consistent with the principles of the Vision Zero strategy aimed at eliminating fatal and severe road injuries.

Traffic lights with one or more flashing or non-flashing auxiliary signals, which not only permit movement in a certain direction but also indicate, if there is a priority over other road users approaching the conflict zone from different approaches, are already in use in various countries (Figure 2).

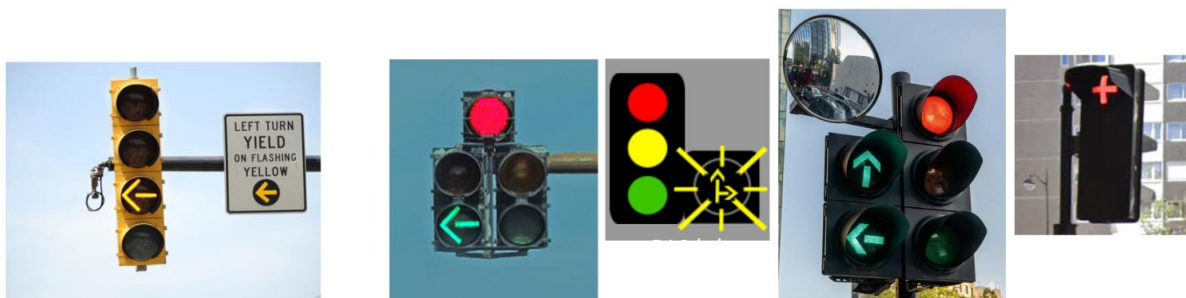


Figure 2. Traffic lights with permissive signals of different priority degree

## 2 Studies and recommendations

To improve the level of information provided to drivers of vehicles controlled by a signal located in an auxiliary traffic light section, the current national standard of Ukraine requires using a red circle to outline an auxiliary section of the traffic light. The red circle is illuminated during the period when the auxiliary section signal is off. The use of this circle has been mandatory since the introduction of the updated version of the national standard. According to the requirements of the Traffic Rules of Ukraine [9], vehicles are prohibited from moving in the direction indicated by the arrow of the auxiliary traffic light section if the arrow is not illuminated green. However, when the arrow is not lit, it is impossible to determine which direction is being regulated by the auxiliary section. A red circle does not solve this problem either, since it does not indicate the direction in which the auxiliary section regulates traffic.

Since, according to the updated national standard [10], the use of outlined arrows on traffic signals is no longer foreseen and will be replaced by inverse arrows, this form of signal can be repurposed, i.e. it can be used to indicate a prohibitory signal for the auxiliary section. When an outline is used instead of a circle, it defines clearly the direction in which movement is prohibited by the deactivated signal of the auxiliary section (Figure 3).

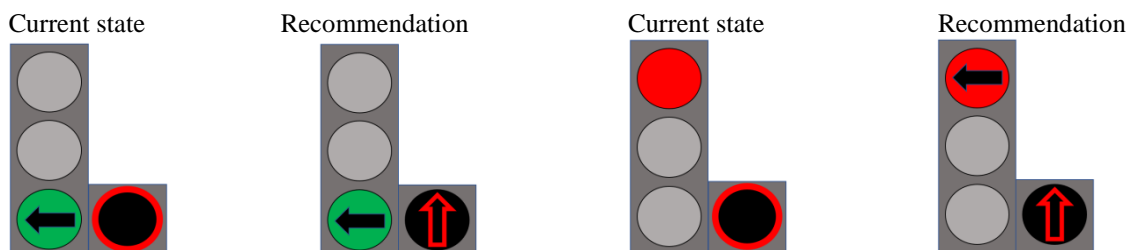


Figure 3. Use of a red outlined arrow in the auxiliary section

Since, in the current system, a contrast arrow is applied only to the green signal, it is completely unclear during the red signal in which direction movement is prohibited by the deactivated auxiliary section and which directions are controlled by the main section.

Using an auxiliary section instead of a sign improves the signal's contrast against other signals of the traffic light and makes it possible to turn on a red signal only during the off-peak hours. When determining the possibility of permitting a turning vehicle trajectory during the red signal, the degree of conflict between this trajectory and pedestrian flows at the intersection entry and exit is assessed; the available conflict points and traffic intensity indices at these points are assessed as well. During peak and off-peak hours, the structure of a signal cycle can change; consequently, the vehicle and pedestrian movements, creating partial conflicts with a non-priority turning trajectory, may appear or disappear in the cycle structure due to the reasons unrelated to the turning movement. Moreover, traffic intensity along the turning trajectory and along conflicting trajectories changes, leading to variations in the intensity indices within the conflict points.

The colour of the signal as well as its shape (its outlining circle) allows distinguishing it from the auxiliary section signal being currently in use (even by the individuals having difficulties with signal colour distinguishing). In addition, its permissive nature excludes hazardous situations when drivers may be unfamiliar with the meaning of a new signal.

When defining feasibility of permitting a turning vehicle trajectory during the red signal, a degree of conflict between the trajectory and pedestrian flows at the intersection entry and exit, as well as the availability of conflict points and traffic intensity indices at these points, is assessed. During the peak and off-peak hours, a signal cycle structure can vary; therefore, the vehicle and pedestrian movements creating partial conflicts with a non-priority turning trajectory may appear or disappear within the cycle due to certain reasons unrelated to the turning movement. In addition, traffic intensity along both the turning trajectory and conflicting trajectories changes, resulting in varying intensity indices at the conflict points.

Unlike a green arrow signal on a white sign, an auxiliary section in the form of a white arrow with a circle operates during other signals of the main section, not only during the red signal (Figure 4).

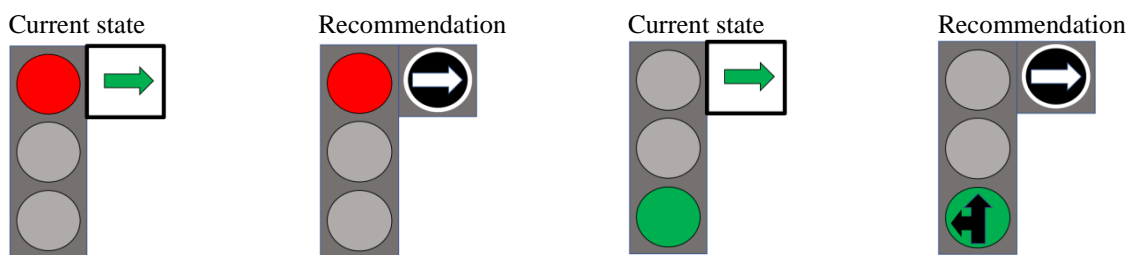


Figure 4. Use of an auxiliary section instead of a sign displaying an arrow

In this case, white colour of the signal indicates that the signal itself does not provide complete information about movement priority, unlike a green arrow. The movement priority in the direction of the white signal is determined by the main section of the traffic light according to the current regulations: combination with the green signal of the main section grants priority, while combination with other signals requires yielding during movement. Thus, the movement priority for the white signal of the auxiliary section has two levels: when combined with the green signal, it corresponds to the current principle for turning on the green circular signal when there is no auxiliary section; and when combined with the red signal, its meaning corresponds to a sign showing an arrow in the current signal system. Unlike the current auxiliary section arrow, however, when moving in the direction of the white arrow during a red circular signal, drivers must yield not only to all vehicles but also to all pedestrians, including those entering the intersection.

The use of an auxiliary section with a white arrow at the red signal level helps control the right turns (for example, enabling the green signal start for cyclists before giving permission to turn). During certain periods of the day, using a sign with a green arrow may be unjustified, for instance, when pedestrian traffic increases at the intersection approaches (Figure 5).

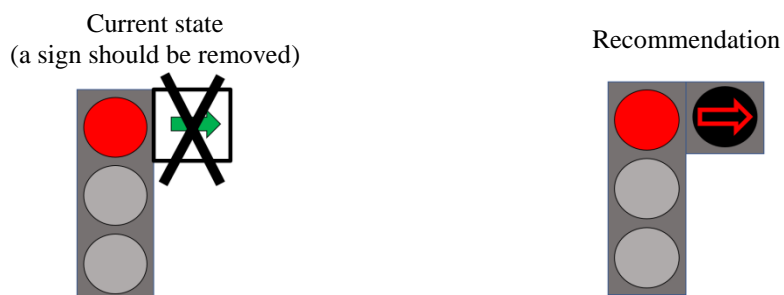


Figure 5. Possible regulation of right turns during a red signal

To prohibit right turns together with the main section in the current system, a green-arrow sign must be removed, and an auxiliary section must be installed (Figure 6).

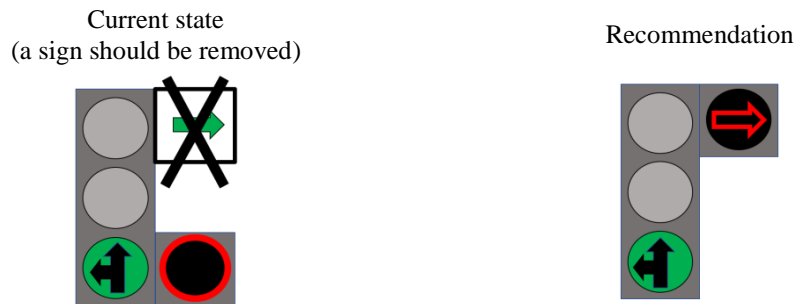


Figure 6. Possible regulation of right turns independently from the main traffic flow

When only an auxiliary section with a white arrow is used, an inverse arrow is applied to the green circular signal to specify that the green circular signal itself does not grant the right to move in the direction of the auxiliary white-arrow section. No inverse arrow is applied to the red signal, emphasizing its connection to the white-arrow signal in terms of priority cancellation.

On the one hand, a red-outlined arrow in the auxiliary section when the white arrow is off prohibits movement along the turning trajectory, and the role of the green circular signal as a reference for the white arrow is the same as the one of the red signal, but with the opposite meaning. Therefore, the inverse arrow could theoretically be omitted from both the green circular and the red signals. On the other hand, the meaning of traffic signals is a highly sensitive area for drivers' understanding; it has a major impact on road safety, making substantial changes inadvisable. Their so-called "softness", i.e. their preventing hazardous situations if drivers interpret signals according to their previous meanings, is also an important benefit of the recommended changes. Consequently, inverse arrows are applied to the green circular signal to prohibit turning when the white arrow is off.

In the proposed signal system, the green arrow signal always ensures movement priority, regardless of the main section signals. Inverse arrows are shown in the main section to prevent the auxiliary section signal from being associated with the main section signal (Figure 7).



Figure 7. Application of inverse arrows applied to the main section signals

In many cases, during the red circular signal, the trajectories corresponding to the direction of the auxiliary section (which may include multiple lanes, such as bike lanes or tram tracks) may have no conflict points during that signal phase. In such cases, the drivers on the approaches that create these conflict points may not have priority as well (for example, when making a left turn on a green circular signal). Therefore, a necessity arises to convey information about movement priority to drivers travelling in the direction of the auxiliary section during the red circular signal. Such additional information can increase significantly a vehicle speed at the stop line and, consequently, raise the saturation flow in the direction of the auxiliary section. This is particularly important for public transport and road trains, which are characterized by large dimensions and limited visibility from the driver's seat (Figure 8).

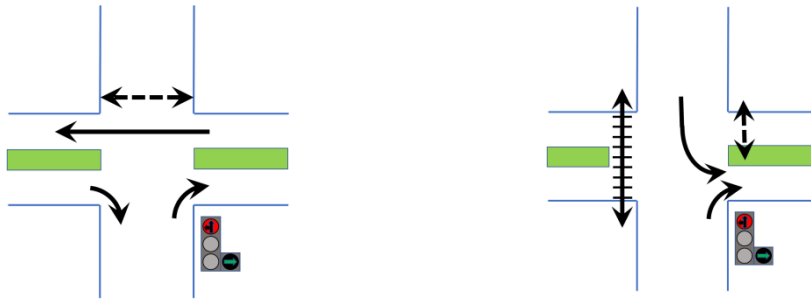


Figure 8. Example of using an auxiliary section in a new signal system

When a turn in the direction of the arrow is made without priority, an auxiliary section with a white arrow signal and a white border, positioned at the level of the red signal, is used.

In the proposed signal system, when a traffic light has both green and white auxiliary sections for the same direction, the green arrow grants the priority movement regardless of the main section signal (Figure 9).

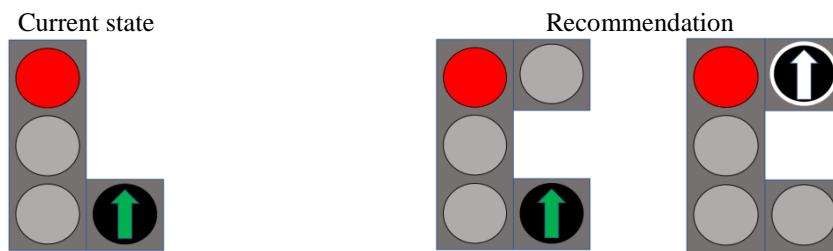


Figure 9. Equivalence of signals depending on priority

White colour of the auxiliary section arrow and no contrasting arrows on the main signal encourage drivers psychologically to transfer the meaning of the main signal to the movement priority indicated by the arrow. In this case, the arrow indicates the movement direction and permission to proceed, while the main signal shows the priority.

Simultaneous illumination of green signals in the main and auxiliary sections does not indicate priority inheritance, unlike in the current system. This helps prevent drivers from subconsciously mistaken granting priority incorrectly to a left turn in the direction of the main section when the auxiliary section is active (Figure 10).

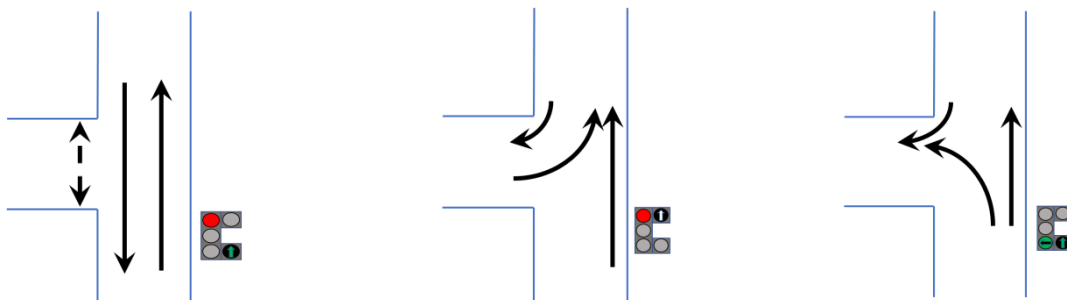


Figure 10. Example of using traffic lights with two auxiliary sections

In the current signal system, the priority of permitted movement in the direction of the auxiliary section arrow depends on the main section signals. To eliminate this priority inheritance, it is required to use traffic lights of another type, all signals of which control movement only in a specified direction(s). In the proposed signal system, priority inheritance from the main section signal is provided only for the white arrow, while the green arrow in the new system always grants priority regardless of the main section signals (Figure 11).

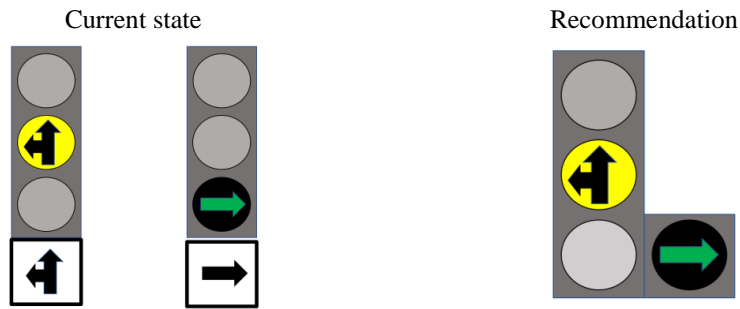


Figure 11. Use of traffic lights with an auxiliary section similar to the traffic lights of another type

In the current system, illumination of the red “plus” indicates only the stopping of the opposing traffic flow. In the proposed signal system, activation of the auxiliary green section in the equivalent signal grants the right to move with priority, including prohibition of pedestrian movement along the vehicle trajectory (Figure 12).

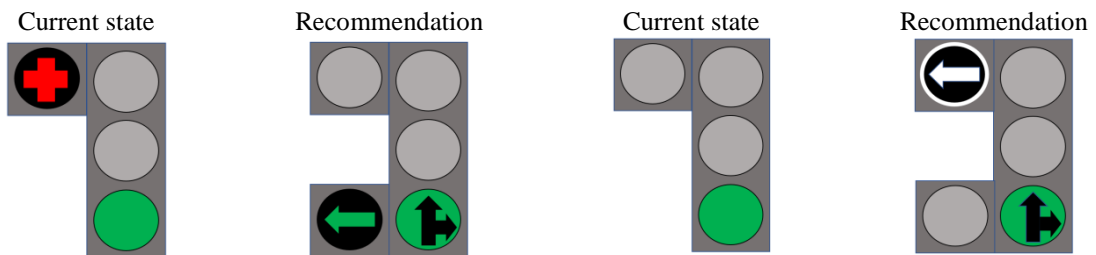


Figure 12. Equivalence of signals based on priority

If pedestrians at the intersection exit and/or opposing traffic must be yielded to when making a left turn, a white arrow in the auxiliary section is used; according to the previously described principle, the arrow inherits the priority of the activated main section signal (green circular).

If the left-turn trajectory has no conflicts with vehicles or pedestrians or has priority in the conflict zones, the green auxiliary section is activated. In the proposed signal system, the green arrow in the auxiliary section not only permits movement in the direction of the arrow but also grants movement priority in that direction, according to the principle described above (Figure 13).

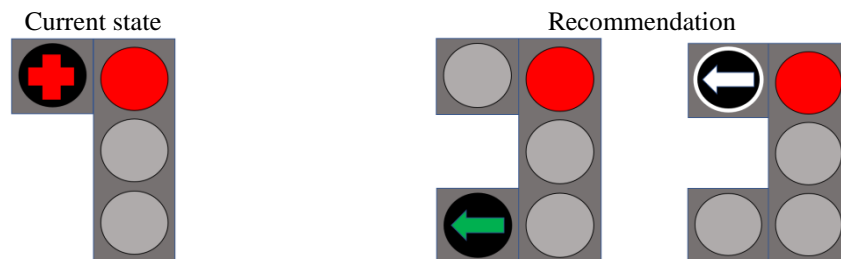


Figure 13. Equivalence of signals based on priority

When opposing left turns are allowed simultaneously, a white signal in the auxiliary section is used together with a red main signal, since the mutual positions of opposing left-turn trajectories are not defined by the traffic rules.

In the current signal system, when a red “plus” signal is used, it is activated simultaneously with the red signal of the traffic light for the opposing direction. Taking into account the sequence specified by the national standard [10] for switching traffic light signals from green to red by means of a flashing green signal and the standard durations of the flashing green and yellow signals of 3 seconds each, the following can be determined. The total duration of the conditional minimum clearance interval period between the left-turn direction controlled by the “plus” signal and the opposing traffic flow is 6 seconds. Examine for which geometric parameters of a signalized intersection this duration is sufficient to ensure an adequate level of road safety.

When considering the structure of a traffic light cycle while using a red “plus” signal, two types of structures can be distinguished: “early start” and “green auxiliary signal”. The classification is based on the relative positions in the signal-timing diagram of the green signal of the traffic light with which the red “plus” is used,

and the green signal of the traffic light for the opposing direction. If the “plus” is activated after the end of the green signal for the opposing direction, it is referred to as a “green auxiliary signal”. If it is activated before the start of the opposing green signal, it is referred to as an “early start”. The classification is important for defining the initial position of the vehicle executing its turn under the “plus” signal. In terms of the “early start” scenario, a vehicle starts moving from the stop line and requires a certain amount of time to travel along a curved trajectory to the conflict point with the opposing traffic. In terms of the “green auxiliary signal”, left-turning vehicles enter the intersection centre in advance and, when the “plus” signal appears, begin moving directly into the conflict zone with the opposing traffic flow.

Following formula is applied to determine the minimum clearance interval between permissive signals of the conflicting traffic movements [11]:

$$t[i, j] = t_p + \frac{V_i}{2a} + \frac{B[i, j] + l_a}{V_i} - \frac{B'[j, i]}{V'_j} + 3, \tag{1}$$

where  $t_p$  is reaction time of a driver, s (0.8., .1.2 s),

$V$  is design travel velocity, m/s

$V'$  is maximum permitted velocity, m/s

$a$  is acceleration/deceleration,  $a^k = 4.0 \text{ m/s}^2$ ;

$B[i, j]$  is element of the matrix of distances to the far conflict point, m;

$B'[i, j]$  is element of the matrix of distances to the near conflict point, m;

$l_a$  is length of a design vehicle, m ( $l_a = 5 \text{ m}$ ).

It should be noted that the adopted design vehicle length of 5 m corresponds primarily to passenger cars. However, in the case of urban freight transport, delivery vans, rigid trucks and articulated vehicles are characterized by substantially greater lengths and different acceleration profiles. When modelling clearance intervals and minimum clearance interval times for intersections located on freight corridors or near logistics hubs, it is advisable to introduce vehicle-type differentiation into the calculation procedure. Accounting for heavy vehicle parameters may influence both safety margins and capacity assessment results.

Assuming that  $B'[i, j] = 20 \text{ m}$  and  $V' = 50 \text{ km/h}$ , a two-dimensional table is obtained. It helps conclude that activating the “plus” signal together with the opposing red signal is safe only within a certain range of design speeds and distances to the far conflict point (Figure 14).

		D, m																		
		10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
V <sub>i</sub> , km/h	30	5.04	5.64	6.24	6.84	7.44	8.04	8.64	9.24	9.84	10.44	11.04	11.64	12.24	12.84	13.44	14.04	14.64	15.24	15.84
	35	4.96	5.47	5.99	6.50	7.02	7.53	8.04	8.56	9.07	9.59	10.10	10.62	11.13	11.64	12.16	12.67	13.19	13.70	14.22
	40	4.94	5.39	5.84	6.29	6.74	7.19	7.64	8.09	8.54	8.99	9.44	9.89	10.34	10.79	11.24	11.69	12.14	12.59	13.04
	45	4.96	5.36	5.76	6.16	6.56	6.96	7.36	7.76	8.16	8.56	8.96	9.36	9.76	10.16	10.56	10.96	11.36	11.76	12.16
	50	5.02	5.38	5.74	6.10	6.46	6.82	7.18	7.54	7.90	8.26	8.62	8.98	9.34	9.70	10.06	10.42	10.78	11.14	11.50
	55	5.09	5.42	5.75	6.07	6.40	6.73	7.06	7.38	7.71	8.04	8.36	8.69	9.02	9.35	9.67	10.00	10.33	10.66	10.98
	60	5.18	5.48	5.78	6.08	6.38	6.68	6.98	7.28	7.58	7.88	8.18	8.48	8.78	9.08	9.38	9.68	9.98	10.28	10.58
	65	5.29	5.56	5.84	6.12	6.40	6.67	6.95	7.23	7.50	7.78	8.06	8.33	8.61	8.89	9.16	9.44	9.72	10.00	10.27
70	5.40	5.66	5.92	6.17	6.43	6.69	6.94	7.20	7.46	7.72	7.97	8.23	8.49	8.74	9.00	9.26	9.52	9.77	10.03	
75	5.52	5.76	6.00	6.24	6.48	6.72	6.96	7.20	7.44	7.68	7.92	8.16	8.40	8.64	8.88	9.12	9.36	9.60	9.84	

Figure 14. Results of the numerical experiment for a case involving the approach of another conflicting direction to the conflict zone

If the approach distance is assumed to be  $B'[i, j] = 0$ , then all values in the studied range exceed 6 seconds. It can be concluded that, when using a traffic light cycle structure with a “green auxiliary signal”, simultaneous activation of the “plus” signal and the red signal for the opposing movement is unsafe (Figure 15). From an environmental standpoint, insufficient clearance intervals that force sudden braking or acceleration may lead not only to safety risks but also to increased emissions of CO<sub>2</sub>, NO<sub>x</sub> and particulate matter [12]. This issue becomes particularly significant in tourist cities and health resorts, where environmental quality constitutes a key socio-economic asset. In such areas, adaptive signal control systems capable of dynamically adjusting priority rules depending on traffic composition and seasonal demand may contribute to maintaining both mobility efficiency and environmental standards.

		<i>D, m</i>																		
		10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
<i>V<sub>l</sub>, km/h</i>	30	6.84	7.44	8.04	8.64	9.24	9.84	10.44	11.04	11.64	12.24	12.84	13.44	14.04	14.64	15.24	15.84	16.44	17.04	17.64
	35	6.76	7.27	7.79	8.30	8.82	9.33	9.84	10.36	10.87	11.39	11.90	12.42	12.93	13.44	13.96	14.47	14.99	15.50	16.02
	40	6.74	7.19	7.64	8.09	8.54	8.99	9.44	9.89	10.34	10.79	11.24	11.69	12.14	12.59	13.04	13.49	13.94	14.39	14.84
	45	6.76	7.16	7.56	7.96	8.36	8.76	9.16	9.56	9.96	10.36	10.76	11.16	11.56	11.96	12.36	12.76	13.16	13.56	13.96
	50	6.82	7.18	7.54	7.90	8.26	8.62	8.98	9.34	9.70	10.06	10.42	10.78	11.14	11.50	11.86	12.22	12.58	12.94	13.30
	55	6.89	7.22	7.55	7.87	8.20	8.53	8.86	9.18	9.51	9.84	10.16	10.49	10.82	11.15	11.47	11.80	12.13	12.46	12.78
	60	6.98	7.28	7.58	7.88	8.18	8.48	8.78	9.08	9.38	9.68	9.98	10.28	10.58	10.88	11.18	11.48	11.78	12.08	12.38
65	7.09	7.36	7.64	7.92	8.20	8.47	8.75	9.03	9.30	9.58	9.86	10.13	10.41	10.69	10.96	11.24	11.52	11.80	12.07	
70	7.20	7.46	7.72	7.97	8.23	8.49	8.74	9.00	9.26	9.52	9.77	10.03	10.29	10.54	10.80	11.06	11.32	11.57	11.83	
75	7.32	7.56	7.80	8.04	8.28	8.52	8.76	9.00	9.24	9.48	9.72	9.96	10.20	10.44	10.68	10.92	11.16	11.40	11.64	

Figure 15. Results of the numerical experiment for a case without the approach of another conflicting direction to the conflict zone

When movement in the direction of the auxiliary sections on the near section to the active main signal is prohibited, a red outlined arrow is illuminated to inform drivers that movement in this direction is controlled by the auxiliary section signal and is currently prohibited (Figure 16).



Figure 16. Signal display during a complete prohibition of movement on the approach

If the intensity of left-turn or opposing traffic increases, to prohibit the permissive left turn in terms of the current system, the “plus”-signal section should be removed and an auxiliary section should be installed instead (Figures 17, 18).



Figure 17. Traffic lights with a “plus” auxiliary sign and two auxiliary sections

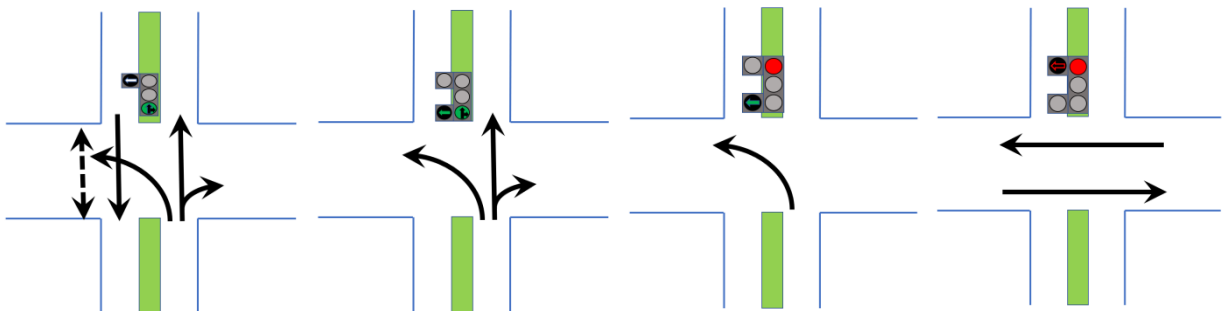


Figure 18. Examples of the use of traffic lights with the auxiliary sections

It is proposed to indicate the end of the permissive signal of the tram traffic light by flashing of the lower section and the upper sections that correspond to the controlled directions whose permissive signal is terminating (Figure 19).



Figure 19. Flashing signal in a public transport traffic light

Recently, the practice of using European-style traffic lights to regulate the movement of public transport vehicles has become increasingly widespread. These signals are applied on approaches where only one controlled direction is provided for public transport movement. An advantage of such traffic lights compared with the model specified in the national standard is the available indications similar to the yellow signal and the red-and-yellow signal. However, if auxiliary sections with white arrows are introduced, the use of these traffic lights in Ukraine would have to be discontinued, since the permissive indication (a vertical white bar) and the prohibitive indication (a horizontal white bar) could be perceived mistakenly as arrows of similar configuration in the auxiliary section. However, the previously mentioned benefit of these traffic lights is diminished due to the lack of a flashing green signal and a red-and-yellow signal in the sequence typical of European traffic light systems. Thus, the total number of indications (3) is the same in both implementations of traffic lights intended for route public transport vehicles operating with priority in dedicated lanes (Figure 20).

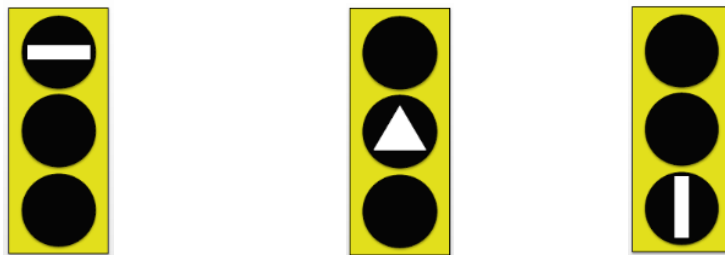


Figure 20. Signals of traffic lights regulating public transport movement in Europe

Special traffic lights with chevron indications are used to display the position of tram switches. The traffic signal is linked to the automatic switch and indicates its position accordingly.

In order to eliminate redundancy in the number of signals simultaneously perceived by public transport drivers, for traffic lights regulating public transport vehicles it is proposed to apply a principle similar to that used in railway systems, i.e. interlocking of switches and signals (Figure 21).



Figure 21. Traffic light signals indicating positions of tram switches

In case of tram switches, this principle means that the road controller activates the permissive signal on the traffic light intended for public transport vehicles not only according to the signal-timing plan or the

corresponding adaptive algorithm but also upon receiving a signal from the trackside remote-control devices of the automatic switches. The devices are located along the trajectory corresponding to the controlled direction, confirming that the switch positions along the trajectory are correct for the movement to be allowed.

The proposed modifications to traffic light signalization may have broader implications for urban freight transport systems beyond their direct safety benefits. Signalized intersections constitute critical nodes in urban logistics networks, where delays, conflicts and uncertainty accumulate and propagate along distribution routes. By clearly distinguishing between priority and non-priority permissive signals, the proposed system reduces ambiguity in driver decision-making processes. This is particularly important for freight vehicles, whose operational characteristics differ substantially from passenger cars. Reduced hesitation time at the stop line and improved predictability of movement priority may increase flow rates for selected turning movements, thus enhancing the overall efficiency of freight corridors.

From the environmental perspective, minimizing unnecessary stop-and-go cycles contributes to lower fuel consumption and reduced greenhouse gas emissions. Heavy vehicles are responsible for a disproportionate share of urban transport-related emissions [13-16]; therefore, even marginal improvements in intersection performance may translate into measurable environmental gains. The integration of enhanced signal priority logic with intelligent transportation systems may further support sustainable freight distribution strategies, including time-window management, low-emission zones and consolidation-based delivery models.

In tourist destinations and health resorts, where transport-related noise and emissions directly affect quality of life and economic attractiveness, the application of flexible and clearly interpretable signal systems may serve as an important supporting instrument of sustainable urban policy. Thus, the proposed signal redesign aligns with the broader objectives of sustainable development and environmentally responsible urban logistics planning.

## Conclusions

The use of additional traffic light signals that indicate not only permission or prohibition of movement but also the controlled direction priority makes it possible to improve road safety and use more effectively the capacity reserves on the approaches to signalized intersections.

It is proposed to assign priority to the permissive signal in the form of a green arrow, independently of the main section signals. To ensure better visual perception and appropriate flexibility in control, it is suggested to replace the white-arrow sign with an auxiliary section at the level of the red signal, introducing a new traffic light signal – a white arrow in a circle. This signal, in combination with the green signal of the auxiliary section, also replaces functionally the “plus” red signal.

To regulate the movement of route public transport, it is recommended to use a T-shaped traffic light, supplementing its set of signals with flashing not only of the lower section but also of the corresponding upper section. To reduce the information load on tram drivers, it is proposed to interlock the T-shaped traffic lights with the corresponding tram switches, similar to the interlocking of switches and signals in railway systems.

The proposed innovations will help use more effectively the capacity of approaches to signalized intersections, improve the performance of intelligent transportation systems, and ensure an adequate level of road safety within the areas where traffic flows intersect or merge under partial conflict conditions. These achievements are fully aligned with Sustainable Development Goal 11, as declared by the United Nations [17]: to ensure the openness, safety, livability, and environmental sustainability of cities and human settlements (11.2: by 2030, provide access for all to safe, affordable, accessible, and sustainable transport systems).

In addition to improving road safety and operational performance, the proposed signal solutions support the development of sustainable urban freight systems by reducing unnecessary vehicle idling, fuel consumption and emission levels at signalized intersections. By integrating priority differentiation with adaptive control strategies, cities may enhance both logistics efficiency and environmental quality, contributing to the long-term objectives of sustainable urban mobility and climate-oriented transport policy.

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