Research Article

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Analysis of dangers in the operation of city buses at the intersections

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Summary: Operation of motor vehicles should take into account the elimination of the possibility of accidents. The article considers selected problems occurring in the operation of public transport buses at intersections. Compliance with the requirements of the safety system during signal change on the signaling device controlling traffic at the intersection was analyzed. The human factor in ergonomics is important. Ending the green signal display (in special situations) causes a dilemma of decisions. The driver brakes abruptly (resulting in potentially harming passengers on the bus) or passes through a signal light displaying a red signal. The need to introduce changes in the regulations that would allow the introduction of adequate solutions was pointed out. These are activities in the area of the active safety system in the operation of vehicles in road traffic. The need to provide advance information and change the provisions in applicable law has been demonstrated.

Keywords: bus operation, traffic lights, safety system

1 Introduction

Risks of accidents for passengers of public transport buses in cities in traffic affect everyone in the European Union: in a Member State (e.g. Poland) as well as in neighboring countries. Considering the safety system in the aspect of vehicle use – public transport buses, one must take into account the large role of ergonomics. There is always a risk of collision or accident in traffic. Human psychophysical limitations must be taken into account when using vehicles. The human factor – due to the mistakes made, has a decisive significance here – the authors discuss it in their works [1, 2]. In general, ergonomics deals with the adaptation of: working conditions and features of technical facilities to human psychophysical features – what is shown in the works [3, 4].

In the use of vehicles, it is necessary to adapt the movement conditions of road users (road infrastructure and its surroundings) to the psychological and physical capabilities of man. An example is taking into account the driver’s reaction time to an emerging stimulus, e.g. the need to stop the bus immediately (Figure 1). As a result, we strive for a low level of accident hazards with the best possible efficiency of the road system. Elements of this are, among others: throughput and communication speed. In the operation of public urban transport buses, among others, extreme situations occur at intersections with traffic lights. This applies especially to transient conditions. The end of the display of the green signal, further yellow and the start of the display of the red signal, as required by the Vienna Convention on Signs and Signals [5, 6]. As a result of sending the appropriate signal, the bus should stop in front of the traffic light.

The correct formulation of traffic regulations, which are a kind of operating procedure, has a great impact on the safety system in car operation. The vehicle can be stopped with different deceleration values. For large decelerations, there is a high risk of an accident for bus passengers. One of the elements that affects the collision-free and accident-free maintenance of vehicles is to regulate the rules of conduct – especially in transient states of extreme situations. And the basic condition of the safety system in the operation of

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Figure 1: Diagram of the stopping path of a bus $S_z$ in front of an obstacle – components where: $S_R$ – distance traveled during the driver’s response, $S_{nh}$ – distance traveled during braking force build-up, $S_h$ – distance traveled “during braking” with a constant deceleration, $S_z$ – bus stop distance, $V_p$ – initial value of the bus speed at the stop line, $V_k$ – final value speed of the bus.
vehicles is their observance. That is why there is a limitation on sudden braking in public buses. Drivers during braking should not exceed the deceleration value $a_{\text{max}} = 1.50 \text{ m/s}^2$.

Larger values of decelerations when braking a bus, streetcar, trolley bus are especially dangerous for passengers traveling in a standing position. This may cause the traveler to fall and cause injury. This situation occurs when the bus is far enough away from the traffic light that it will not be able to pass during the yellow signal. Then the driver (avoiding sudden braking) must enter behind the signaling device already displaying the red signal. Another solution is then braking in front of the siren at high deceleration values. Observation on the behavior of road users indicates that there are many reservations as to their correctness resulting from poorly planned regulations. Huge technical progress and rapid development of devices enable the use of supporting solutions for bus drivers in this area, previously unavailable.

The purpose of the research is to analyze the dangers and assess the impact of the signal change (on the intersection signaling device, from green to yellow) on the possibility of injury to city bus passengers passing the intersection as a result of sudden braking.

The scope of tests includes the analysis of possible events during the passage of the city bus through the intersection in an extreme situation – change on the green signal light to yellow. Two states will be considered: the possibility of passing through the intersection before the red signal lights up or the possibility of stopping the bus in front of the traffic light with low braking decelerations.

The subjects of the study are the drivers of city buses in public transport in cities. Their individual features and restrictions resulting from regulations affect the safety system in bus operation.

The subject of the study are provisions regulating road traffic and provisions regarding traffic lights at intersections. The disclosure of defects occurring in them will make it possible to introduce changes that improve the road safety system.

The research method was used to analyze the mathematical and kinematic relationships of the bus movement at the junction access with traffic lights during signal change. In European Union (EU) Member States, city bus passengers can travel in a standing position. Long deceleration during braking may cause the passengers to fall over and cause injury. Regulations regarding traffic light control at intersections are based on the Vienna Convention on Signs and Signals [5]. In European countries, traffic lights cause similar problems when changing the green signal to yellow. Crossing a road may require extreme braking in extreme situations. Changing the sudden transmission of the signal (without prior notice, surprising the bus driver), creates a risk of accident for passengers.

In the available literature, the authors discuss it in their works [7–10] dealt with the “dilemma zone” resulting from the existence of the yellow signal and the dangers caused by it. This is a slightly similar subject matter, affecting all traffic participants. No publications were found on the problem considered in the article regarding the rapid braking of public transport buses when changing the transmitted signal. In legal regulations for national regulations, this problem is not recognized.

Questions arise: should the law take into account and anticipate extreme situations? What level of danger is acceptable and which is not? Should we accept solutions that pose a threat to health? Are we obliged to eliminate them from existing legislation? The above questions were the inspiration for the article.

2 Analysis of records in applicable law

The basic legal act regulating and affecting the safety system in the operation of vehicles is the Highway Code based on the Vienna Road Convention [11]. Among other things, it defines the rules on road traffic applicable to its participants also in the scope of their use considered here. In addition, Poland has a regulation on road signs and signals based on the provisions of the adopted Vienna Convention on Signs and Signals [5]. In accordance with applicable regulations, the speed limit in cities is 50 km/h and 60 km/h. For a higher speed value we have even more difficult conditions for the bus driver.

In these considerations, the length of the yellow signal (after green) with the value of $t_{\text{yellow}} = 3.0 \text{ s}$ (applicable in accordance with applicable regulations in signaling at intersections) was adopted. Internal regulations of companies providing public urban transport provide that drivers during braking should not exceed the value of decelerations $a_{\text{max}} = 1.50 \text{ m/s}^2$. This is due to safety reasons, especially for passengers in a standing position. A bus traveling at a speed of $V = 50.0 \text{ km/h} \ (13.89 \text{ m/s} \sim 14.0 \text{ m/s})$ will travel while the yellow signal is being displayed ($t_{\text{yellow}} = 3.0 \text{ s}$) [6] road $S = 41.7 \text{ m}$. Below, an analysis of transient conditions at the intersection will be carried out when traffic light signals change. The aim is to demonstrate the dangers caused by the current regulations, based on the provisions of the Vienna Convention in the field of regulations on signs and signals [5]. The considerations carried out are intended to demonstrate the need to make the necessary changes to
these provisions. This is to guarantee the elimination of possible dangers – among other things by entering advance information about the change to take place.

3 Kinematic analysis of the possible scenario – test results

We also deal with extreme scenarios in bus operations. There are situations when the signal changes from green to yellow when the bus is in an area far enough away from the traffic light (further than 42 m) that it will not be able to pass during the yellow signal. Another possibility is sudden braking in front of the siren at large (exceeding acceptable) deceleration values. It is an area (traps) that means that to avoid sudden braking (and overturning passengers) you need to enter behind the signaling device displaying the already changed red signal (Figure 2). An incorrectly worded provision enables shaping the signaling which causes a dilemma for the bus driver – choosing a wrong solution. The lack of advanced information favors this negative phenomenon.

![Figure 2: Diagram of the occurrence of the “trap area” for a city bus, before the intersection with signaling at the yellow signal displayed.](image)

The space-time coincidence of the process should take into account the value of the much longer stopping distance $S_z$ of the braking bus with significantly limited deceleration values. The driver should receive much earlier information about the upcoming signal change. The following factors should be considered: driver’s reaction time, braking time, limited deceleration, braking distance, yellow signal display time (after green).

Additionally, when changing the transmitted signal, the position of the bus in front of the signaling device should be taken into account [3, 7]. In bus operation, the safety system under consideration does not sufficiently take into account the restrictions resulting from ergonomic principles. Psychophysical limitations strongly influence the safety system in the operation of vehicles. Calculations of the stopping distance and decelerations were made according to the relationship (1 and 2) for a simplified “trapezoidal” time course of braking deceleration, with the following assumptions:

- Signaling regulating traffic at intersections, located in places where the speed limit is in force: 50 km/h and 60 km/h – values for cities.
- The calculations also took into account the extreme values: maximum and minimum driver response time and maximum and minimum braking force rise time (assumed when analyzing the course of accidents).

$$S_z = S_{rk} + S_{nh} + S_h = V_p \cdot t_{rk} + V_p \cdot \frac{t_{nh}}{2} + \frac{V_p^2}{a \cdot 2}$$ (1)

$$a = \frac{V_p^2}{(S_z - S_{rk} - S_{nh}) \cdot 2} = \frac{V_p^2}{(S_z - V_p \cdot t_{rk} - V_p \cdot t_{nh}^2) \cdot 2}$$ (2)

where:

- $S_z$ – bus stop distance,
- $S_{rk}$ – distance traveled during the driver’s response,
- $S_{nh}$ – distance traveled during braking force build-up,
- $S_h$ – distance traveled “during braking” with a constant deceleration,
- $V_p$ – value of speed at the access to the intersection – permissible, determined by the regulation,
- $t_{rk}$ – driver response time,
- $t_{nh}$ – braking force rise time,
- $a$ – bus braking permanent deceleration.

In Tables 1 and 2, input data and calculation results are presented. Sample results of calculations of stopping

<table>
<thead>
<tr>
<th>L.p.</th>
<th>$t_{rk}$ [s]</th>
<th>$V_p$ [km/h]</th>
<th>$t_{nh}$ [s]</th>
<th>$a_{dop}$ [m/s$^2$]</th>
<th>$S_z$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1.20</td>
<td>50.0</td>
<td>0.40</td>
<td>1.50</td>
<td>83.8</td>
</tr>
<tr>
<td>2.</td>
<td>0.80</td>
<td>50.0</td>
<td>0.10</td>
<td>1.50</td>
<td>76.1</td>
</tr>
<tr>
<td>3.</td>
<td>1.20</td>
<td>60.0</td>
<td>0.40</td>
<td>1.50</td>
<td>119.9</td>
</tr>
<tr>
<td>4.</td>
<td>0.80</td>
<td>60.0</td>
<td>0.10</td>
<td>1.50</td>
<td>106.8</td>
</tr>
</tbody>
</table>

Table 2: Data for calculating the deceleration value with initial assumption bus location $S_z = 43.0$ m, in front of the traffic light

<table>
<thead>
<tr>
<th>L.p.</th>
<th>$t_{rk}$ [s]</th>
<th>$V_p$ [km/h]</th>
<th>$t_{nh}$ [s]</th>
<th>$S_z$ [m]</th>
<th>$a$ [m/s$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1.20</td>
<td>50.0</td>
<td>0.40</td>
<td>43.0</td>
<td>4.10</td>
</tr>
<tr>
<td>2.</td>
<td>0.80</td>
<td>50.0</td>
<td>0.10</td>
<td>43.0</td>
<td>3.10</td>
</tr>
<tr>
<td>3.</td>
<td>1.20</td>
<td>60.0</td>
<td>0.40</td>
<td>43.0</td>
<td>7.01</td>
</tr>
<tr>
<td>4.</td>
<td>0.80</td>
<td>60.0</td>
<td>0.10</td>
<td>43.0</td>
<td>4.82</td>
</tr>
</tbody>
</table>
distance and decelerations for selected bus location (43.0 m) in the “trap area” are shown.

Lack of advance information about the upcoming signal change favors the existence of a “trap area”. Calculations were carried out for selected changing speed values as well as times: steering response and braking force increase. The selected extreme input values are to show the results obtained by analyzing the phenomenon in extreme conditions. In-depth research should carry out a broad analysis of the impact of parameters on the course of the phenomenon.

Calculated values of stopping distance in Table 1, significantly exceed the values of the distance traveled during the yellow signal duration $t_{\text{yellow}} = 3.0 \, s$. Similarly in Table 2, the calculated values of decelerations during bus braking significantly exceed their allowable values. The above calculations can and should be the basis for requesting a change in the law in order to reduce the hazards in the operation of vehicles. The law should specify a framework that takes into account the comments from research conducted on buses in traffic.

3.1 Another possible scenario – analysis

A scenario is also possible when a long vehicle in front of it travels in front of the city bus (with a yellow signal) and stops in front of the traffic light (Figure 3 and 4). A tractor with a semitrailer (16.5 m) or a truck with a trailer (18.75 m) can experience big decelerations up to $a = 8.0 \, m/s^2$ during sudden braking. The road to stop the vehicle combination is radically shorter. It is also possible to realize during the yellow signal duration $[3, 4, 8]$. Unlike the bus, decelerations for such a team are limited only by the condition of the road surface and the value of the tire friction coefficient against the road. This situation further aggravates the already existing situation of the present case.

A long set of vehicles traveling in front of a bus can brake suddenly. It will then take part of the distance in front of the traffic light and thus limit the potential value of the bus stopping distance. In this situation, the bus driver cannot enter the traffic light, even after the red signal is on. To avoid colliding with the preceding vehicle combination, it will be necessary to make significantly longer decelerations on the bus than allowed.

Tractor unit with a semi-trailer, stopped in front of the traffic light, reduces the road usable by the braking bus (Figure 4). In an extreme situation, a bus being in the trap area must increase the braking deceleration. This can increase the severity of injury to passengers on the bus. Selected examples show the existence of a problem in bus operation. It is necessary to conduct in-depth analysis and propose appropriate changes.

4 Analysis of test results

The currently binding regulations applied at the intersection cause a situation in which a dilemma zone appears [4, 9]. Additionally, the introduction of an obligation to register event cameras at the intersection will result in registering the bus entry behind the signaling device after transmitting a red signal. Thus, public bus city bus drivers will have to comply with the rules. This can force the bus to brake with decelerations significantly exceeding the permissible values. If the bus does not brake and passes, it will be fined on the red signal. On the other hand, rapid braking will cause the possibility of injuries to passengers traveling in a standing position. The problem considered here is currently not recognized by those responsible for the safety system in the operation of buses. Because now no entries are commonly registered (after the red signal is on). Bus drivers, surprised by the change of signal, instead of suddenly braking, enter the intersection on the “red” signal. Tolerating such a state is due to the fact that such events have not been noticed and there is impunity for such behavior. In the analysis of the phenomenon under consideration, mathematical formulas based on the theoretical course of the phenomenon were used. In the case of the theoretical model, the error of the method of analysis of the process being investigated can be ignored. The inaccuracy of determining the distance may result from the inaccuracy of determining the speed of vehicles. The speed measure-
ment error is small and negligible in qualitative assessment. The calculations were made taking into account the three significant digits of the numbers on which the operations were performed. The results were also given as three significant figures. Such simplification is contained in so-called “engineering inaccuracy” and is acceptable. The adopted simplifications are sufficient to draw qualitative conclusions of the analyzed problem. The calculations made were used to qualitatively assess the analyzed phenomenon.

5 Summary and conclusions

Technical progress and development of devices create a chance for buses and road infrastructure solutions supporting bus operation in the discussed scope. The law should specify a framework that takes into account the comments from research conducted on buses in traffic.

In some cities, signal duration displays are installed on traffic lights. They are, but only at intersections with controllers have become temporary. They help drivers make the right decision – without a dilemma. It is a form of preemptive information transmission, very necessary and useful in such situations. This improves the safety system of road users.

However, currently widespread modernization of intersections and replacement of controllers for time-varying (accommodative) prevents the use of time displays in the current formula. Unfortunately, this happens in accordance with applicable regulations in this area. It seems obvious that current regulations favor collisions and accidents. They should be changed, re-developed and saved in applicable law. Drivers of buses in road traffic should be assisted by appropriately adapted regulations.

In addition, technical devices must be used to provide advance information. The simplest solution would be to introduce green flashing in the last four seconds of the green signal display. This is a reasonable solution, however, requires a change to the Vienna Convention on Signs and Signals. Visible huge technical progress and development of devices make it possible.

The conducted analysis showed that the binding regulations cause too large decelerations values. This is the case in special situations when the bus is braked at an intersection with traffic lights. The article presents the results of analyzes of the theoretical course of the process of occurrence of adverse events for passengers related to sudden braking. Research under real conditions is planned. The experiment is to verify theoretical considerations. This may require changes to the regulations. The results of the experiment will be published in the next article.

References


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