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POSSIBLE IMPACT OF LOCAL AUTOMATION OF TRAM PRIORITY ON THE DRIVER'S WORKLOAD AND PERFORMANCE

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Abstract: *The passengers in public transport in the EU are safer than other participants in urban traffic because in collisions involving public transport vehicles the number of injured and seriously injured other participants has increased. To reduce the number of accidents, it is necessary to reduce the impact of disturbance factors and factors of unfavorable circumstances from the traffic and/or work environment on the driver in public transport vehicles. The analysis of the statistical objective risk as well as the analysis of disturbance factor of drivers in public transport vehicles indicate the need for interventions in the traffic and work environment. By realizing the right of tram passing by means of automatic local placement of switches and signals at intersections, the following is expected to be achieved: reduction of workload of tram drivers, increase of performance level, increasing traffic safety and consequently fewer traffic accidents. Furthermore, the commercial tram speed is expected to increase, consequently the gross traffic work of each city transport line will increase, and transport will be more comfortable and attractive to tram passengers.*

Key words: *tram drivers; local automation of tram priority; tram cab design; reduction of workload; increase of cycle speed; safety increase; passenger comfort.*

1. INTRODUCTION

Research on driver behavior and/or design of traffic processes only according to a classical behaviorist approach based on objective statistical risk after expert accident is incorrect. In Europe, at the end of the last century [1] it was noted that statistical objective risk is not a determinant of driver behavior, although it is important for assessing traffic safety. The availability of research of public transport safety does not sufficiently include the segment of the impact of long and heavy public passenger vehicles (buses, metro, light rail, suburban railways and trams) on the safety of other participants in urban traffic. However, the authors would like to note that recent research approach to tram drivers' needs has not been fully respected during the tram cab design for new trams in Zagreb and Sarajevo. The research has shown that the tram drivers' workload during driving as well as traffic safety can be dominantly programmed with multiple factors [2] from the next three main groups: tram cab ergonomics, traffic environment as well as factors of weather conditions and time of day.

The main groups of driver's workload factors are time pressure, i.e., a short period of time to perform an individual task, multiple simultaneous tasks (number of hand-served commands), and the complexity of each task.

Factors of "traffic environment" and "traffic means" according to the TCI Fuller dynamically open model [3] shown in Figure 1 directly and/or indirectly affect the task difficulty, i.e., the workload. Thereby, extremely important is the grouping arrangement of related commands for the speed change [3] because the task demand in the TCI model does not depend on its complexity, and it is dominantly related to the speed change. It is important to note that the drivers most often do not perform the task with the maximum capability which they theoretically have, because of the many factors of the temporary psycho-physical readiness that are exposed before the beginning of the performance, which have not been included in TCI model shown in Figure 1.

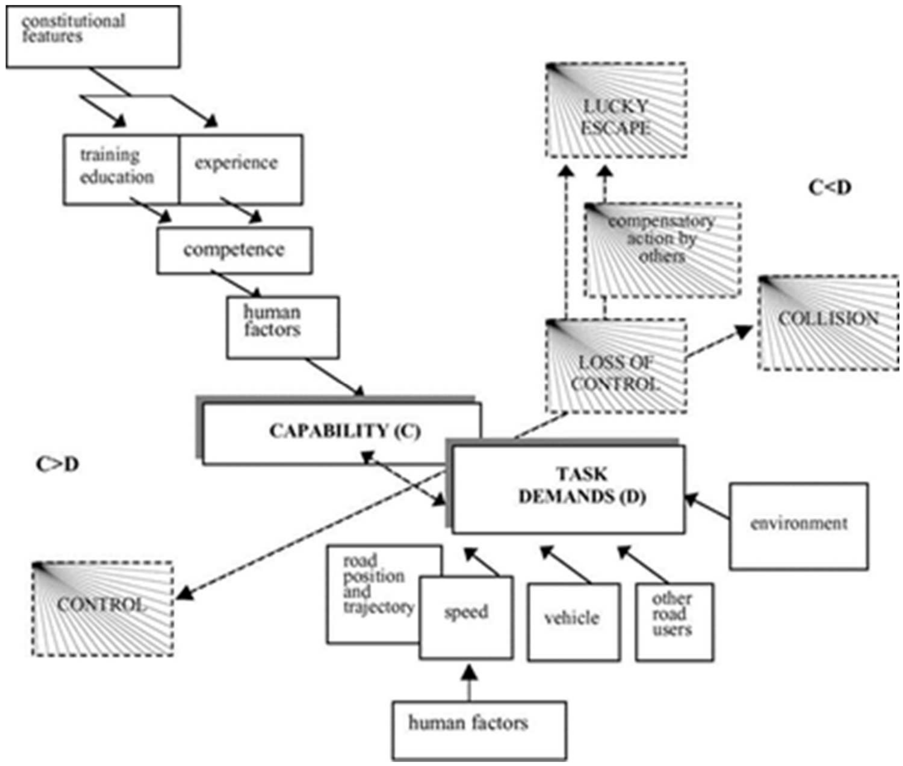

Figure 1. Open dynamic TCI model of “task demand–driver’s capability” interface.

The model shown in Figure 1 for the road traffic can also be applied to the tram traffic with certain modifications. It should be noted that the road vehicle driver changes the speed simultaneously with changing of the trajectory (direction), while the tram driving path can be set by:

- Manual setting the points outside of vehicle;
- Manually setting the points for electrically operated switches from the tram cab;
- Local automation;
- Remote control from one point (center).

Trams control in Sarajevo (B&H) and Zagreb (Croatia) is very similar [2]: frequent starts and stops, non-separation of tram and road traffic, small distance between stations and not leveled road/tram intersections. Commands are manually served for setting electrified switches from tram cab, even manual settings outside of vehicle with special tools for less frequent junctions (only in Zagreb). In Sarajevo, all electric power switch units are powered by the possibility of manual operation of the tram cab board command. In Zagreb, on a much larger network, switches are mostly electrically driven for manual operation by a switch from the tram cab board, and a smaller part of the switches cannot be handled by the tram driver from the vehicle. The manually served commands for setting the point using the switch on the control panel is among the most used and most important commands behind the multi-purpose controller for the grouped commands related to tram speed change and/or keeping the speed.

Own research in Sarajevo and Zagreb [2, 4] showed that in the tram cab, except of the grouped commands related to tram speed change such as multi-purpose left-hand controller (with integrated accelerator, braking module and “dead-man” function), the reduction of other manually served controls was not performed, the driver systems have not been implemented to a sufficient extent, specifically for the automatic junction control based on the priority of passing.

In the latest tram models in Zagreb (NT 2200 produced by Crotram) and Sarajevo (Satra II produced by GRAS Sarajevo), the most commonly used hand controls on the control panel in the tram cab are: “dead-man” function, accelerator, braking module, setting the points (switching or blocking), setting the direction indicators, track brake, send machine, horn or bell button, flashing light button, and commands for manipulation of the doors in the passenger area [4].

In case of grouped commands related to speed change such as multi-purpose left-handed controller (with integrated accelerator, braking module and “dead-man” function) further increase in performance as well as reducing the driver's workload is possible only by reducing the number of other frequently used and manually served commands.

The survey results by Vaitkus, A. have indicated a rather positive attitude of respondents to the speed management measures [5]. Limiting the trams speed to 50 km/h as well as possible measures to slow down the road traffic should reduce the statistical risk of traffic accidents in urban areas and reduce the consequences of traffic accidents if they occur.

2 FACTORS OF STATISTICAL RISK OF VEHICLES FOR PUBLIC TRANSPORT

According to publicly available research from the Netherlands of 2010 [6], the number of casualties among users of public transport (bus, tram/light rail, metro, and train) is limited: an annual average during the past ten years (2000 - 2009) is 1 fatality and 19 serious road injuries. The hazards of public transport vehicles are much higher for other road users: an annual average of 41 fatalities and 138 serious road injuries during the same period. Among them, 116 are casualties (16 of them fatalities) of crashes with buses and 63 (25 of them fatalities) of crashes with a tram or train.

The crash rate and the casualty rate are measured by relating the number of vehicle kilometers driven by passenger cars, buses and trams to the number of crashes or casualties. Comparison of the casualty rates shows that there are 7 times more crashes with a severe outcome (fatalities and/or serious road injuries) in crashes with buses than in crashes with a passenger car, and 12 times more in crashes with a tram. These ratios are even more unfavorable for fatalities: 15 times more in crashes with buses and 57 times more in crashes with a tram than in crashes with a passenger car.

With respect to fatalities, the trend in the number of casualties as result of crashes with public transport vehicles has been consistent with the trend in all fatal road accidents in the Netherlands during the last five years, which is shown in Figure 2. However, the level of the trend for public transport vehicles is slightly lower than for all road fatalities combined.

According to the Netherlands model [6], the statistical objective risk in Zagreb for collisions involving ZET trams will be analyzed with the aim of demonstrating the need for interventions to increase the safety of other urban traffic participants and to reduce the workload of tram drivers. In accordance with a recent cognitive approach to the research, beside other objective factors, next factors for trams’ accident risk in urban areas should be researched, such as factors of the shift schedules, possible influence of the rest break after continuous driving, as well as age and gender of tram drivers. Future research should prove or disprove whether local automation of tram priority at signal control junction can affect the reduction of statistical risk for collisions in Zagreb.

The trend for fatalities in crashes with trams seems more erratic because of the fewer numbers (an annual average of seven fatalities). The number of serious road injuries by trams alone has not been shown, because these data are not reliable in the current crash registration.

Figure 2 shows the trend for serious road injuries in crashes with trains/trams combined and we then see an increase since 2006 [6].

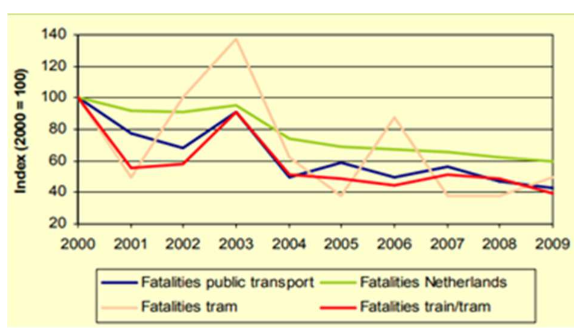

Figure 2. Trend in the annual number of fatalities in all crashes in the Netherlands, in crashes with public transport vehicles (bus, tram/light rail and train), in crashes with train/tram and in crashes with trams (2000=100).

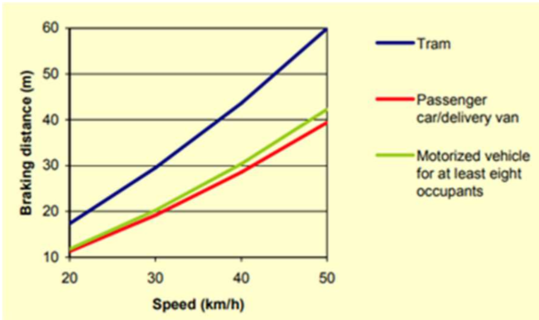

Figure 3. Braking distance of trams, passenger cars/vans, and motor vehicles for eight or more occupants, related to the driving speed.

3. BACKGROUNDS OF TRAM AND LIGHT RAIL CRASHES

Since the subjective risk is equal to objective statistical risk only now of loss of vehicle control, from the aspect of the safety of tram traffic, a statistically objective risk can be analyzed. Many accidents occurred at crossings with road traffic due to non-compliance with tram priority with respect to road vehicles. Failure to comply with this rule has a significant negative impact on the safety of public transport in urban areas.

Furthermore, the investigated hazards of trams on (separate) lanes in urban areas, on crossings with road traffic and with pedestrians shows that in many cases these crossings are not signalized, and the traffic crossing should give priority to trams. The tram often passes these crossings at a speed that is like the speed on this separate lane. If a road user who wants to cross appears suddenly and does not give priority to the tram (deliberately or not), the relatively long braking distance of the tram makes a fatal crash practically inevitable [7].

The tram speed, due to its mass (empty NT 2200 in Zagreb has a mass of 41.5 tons), is important for the severity of the outcome. This situation is clearly inconsistent with the homogeneity principle of Sustainable Safety: encounters between vehicles with large differences in mass and driving characteristics must be prevented or only take place at small speed differences. The actual braking distance of a tram at 30 km/h is more than 25 m [8].

The Netherlands has no general regulations for the braking distance of this type of vehicle. Germany uses regulations [7] stipulating that the braking distance at 30 km/h should not exceed 30 m. This braking distance is considerably longer than that of a passenger car or bus, which at 30 km/h need ca. 20 m to come to a halt [7]; see Figure 3.

For a tram to achieve a braking distance like that of a car, it should drive more slowly in relevant situations (i.e., where the tram mixes with other road users). This could be enforced through technical means applying speed control system [9].

It can be concluded that there are relatively many crashes among other road traffic participants (especially pedestrians and cyclists) and trams. The large absolute number of crashes may not be high; it seems that there is a definite safety problem between trams and road traffic. This research model can be applied in the circumstances of suburban railway traffic and tram traffic in Zagreb.

Collision with trams will be more problematic due to large masses and large vehicle lengths at higher speeds. The maximum tram speed in Zagreb is limited to 50 km/h with speed limiter. Table 1 shows the braking distance and the basic parameters of all ZET trams in Zagreb essential for this research phase.

The trams partly operate on separate tracks controlled by signaling and partly in collision with road traffic and pedestrians. Separation junction in multiple levels of crossing is not feasible in all situations.

The trams partly operate on separate tracks controlled by signaling and partly in collision with road traffic and pedestrians. Separation junction in multiple levels of crossing is not feasible in all situations.

Due to the large number of fatal outcomes in collisions with other traffic participants, tram drivers are exposed to increased efforts because, according to research from Sarajevo [2], the factors of traffic environment are among the dominant factors of disturbance.

For the driver to focus more on the current traffic situation, it is necessary to allow frequent repetition operations to be carried out safely and timely without manual driver service.

Table 1

The average age and basic parameters of the trams in ZET (Zagreb Electrical Tram).

Tram model: manufacturer:	no.	The braking distance (m) for the speed of 40 km/h	Mass* of empty / full** tram (t)	The average age (year)	Air-conditioned cab	Passengers +1 driver		
						Sitting	Standing	Σ
TMK 2100: TŽV Gredelj	16	27	35.00 t / 52.00 t	18.13	YES	45+1	197	**243**
NT 2200: Crotram	140	27	41.5 t / 62.725 t	9.47	YES	41+1	241	**283**
NT 2300: Crotram	2	27	29.167 t / 41.917 t	7.26	YES	27+1	142	**170**
TMK 201* + trailer TP 591: Đuro Đaković	12 + 13	27 or 30***	18.00 t / 27.00 t	42.95 + 44.51	NO	23+1	104	**128**
Articulated TMK 301 and 354 (KT4): ČKD Praha	51	27	19.75 t / 31.275 t	31.38	YES	25+1	147	**173**
TMK 401 (T4) * + trailer TP 801 (B4): ČKD Praha	51 + 45	27 or 30***	17.30 t / 26.00 t	37.80 + 39.14	NO	20+1	103	**124**

Note 1: * for trams that are not MPVs; trailers TP are not includedNote 2:** Useful load with passengers according to EN 12663: 6 persons / m2 for 75 kg / personNote 3: *** TMK with one or two TP trailers Note 4: Braking distance for unloaded trams using the emergency brake

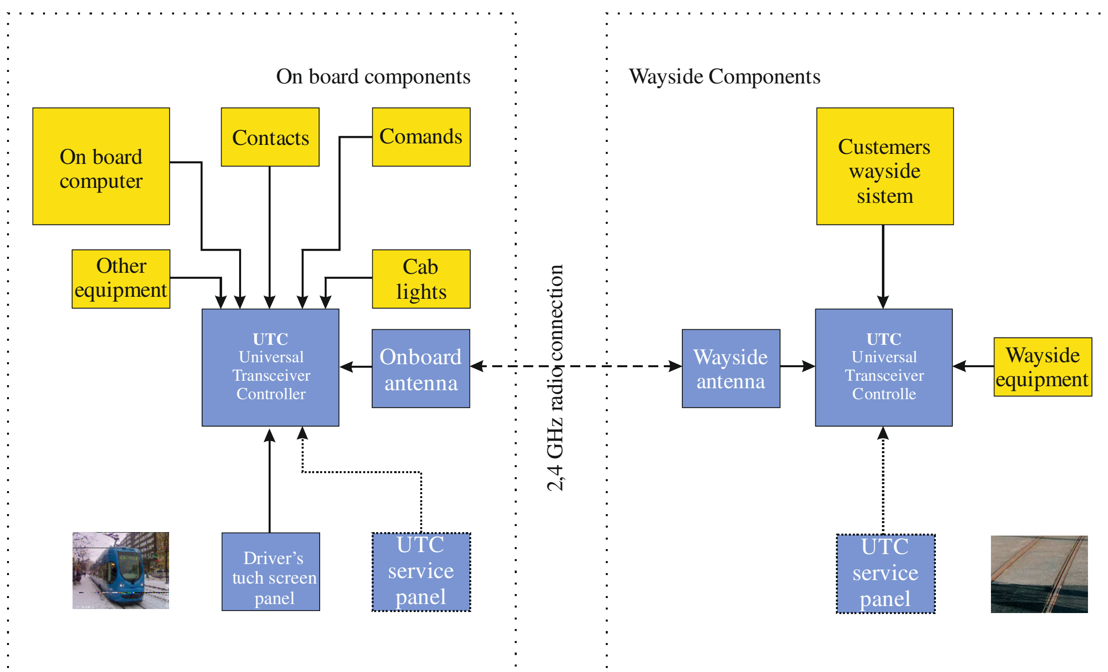

Figure 4. Tram-to-wayside communication system.

One of the options is the automatic setting of the switches (tram priority) according to a predetermined number of lines, as well as the automatic setting of signaling, both for tram traffic and for road traffic, i.e., the realization of the tram priority for traffic if all the conditions are met. According to Dewar and Olson [11], the statistically objective risk of traffic accidents for drivers in road traffic depends heavily on the time of the day and is the largest for a number of road vehicles between midnight and 6 a.m., which can be linked to Kroemer and Grandjean [12] with the negative influence of circadian rhythms at night on humans, with the exception of drivers over the age of 45 [11], for whom there is a secondary peak of statistical risk in working afternoon hours. Automated driver assistance systems will partially equal the statistical objective risk for passengers during the day, in a way that is independent of the time of day.

4 PRINCIPLE OF LOCAL TRAM PRIORITY AUTOMATION

In this chapter, one of the possible models of local automation tram priority used in the Czech Republic is presented, which, due to the decrease in the number of frequently hand-operated commands, with the reduction of workload and the increase of the performance level, also ensures traffic benefits as analyzed in Chapter 5.

Tram-to-wayside communication system is a modern sophisticated system for local transmission of data between trams and wayside systems. It is intended for data communication between any onboard equipment and any wayside equipment. Onboard equipment can be any onboard computer or Human Machine Interface. Bidirectional 2.40 GHz radio communication is used. That ensures high communication speed for tram speed of up to 100 km/h.

The system offers many flexible applications such as automatic commanding of switch points, automatic control system for tram depots, tram priority systems for traffic lights, tram localizations, passenger information systems, automatic speed-limit checking system and many others. The modification system is also applicable in Zagreb, where the commercial speed at the tramway network in 2009 was only 13 km/h [13].

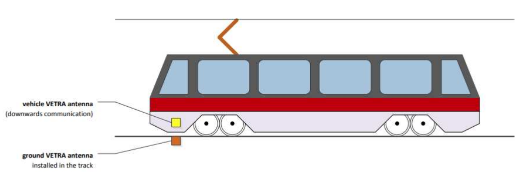

Figure 5 Antenna blocks (on train and outside).

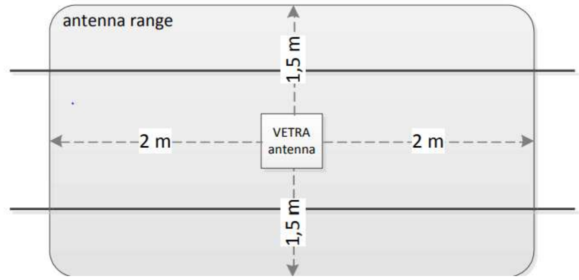

Figure 6. Outside antenna range.

Figure 4 shows the schematic layout of the communication system with the following features [14]:

- No crosstalk -Nearby antennas do not interfere;
- Fast and reliable bidirectional data communication;
- Automatically sends commands to wayside control systems;
- Easy-to-install, suitable for all trams;
- Can be installed on steel reinforcement;
- For tram speed up to 100 km/h;
- Small dimensions of the system components;
- Data are safe, all transferred data are encrypted;
- No interference with low-frequency inductive vehicle-communication systems.

4.1 Tram equipment

Equipment installed on the tram consists of:

1. UTC Universal Transceiver controller. This unit is a multifunctional unit intended for connecting all parts of equipment such as a vehicle computer, a touch screen panel for setting the switches, etc. According to Figure 4, one UTC is installed on a vehicle while others are installed in an outer cabinet. On the one hand, UTC communicates with the equipment on the vehicle while on the other hand communicates through the antenna on the vehicle with external equipment [14].

2. Antenna block on the tram is installed under the floor trams so it is visible to the terrestrial antenna. At an angle of 45° must not be metal objects, a block is installed at each end of the tram (if any driver's cabs at both ends), and at one meter from the end of the tram. Figure 5 shows the location of the antenna block on and off the vehicle.

3. Outdoor equipment - terrestrial antenna block (outside the vehicle) is placed between the rails to receive and return the information to the vehicle. Basically, both blocks are the same and differ only in the way of installation and the type of protective material in which it is incorporated and delivered. Terrestrial antenna block must be installed in the protective manhole in a location that requires communication with the vehicle. Earth antenna cable lock is connected to the outside of UTC is in the cabinet of the tracks at 1000 meters. The range of the external antenna is shown in Figure 6.

4.2 Sending information on the number of lines for the installation of driving

The arrival of a vehicle to an external antenna of track is sent to the (inductive) loop of information on the number line, which is then transmitted to the shelf and the handle rail is placed in the position that is programmed for the line.

Thanks to the communication system tram - external equipment right crossover is automatically set to the required position, unattended by the driver of the tram. The system offers three basic methods for remote control of trams:

- Central traffic control CTC (Eng. Central Traffic Control) automatic transmission number of tram lines (to send a unique number of trams UID Unique identification number) or the Line number LN
- From tram generated command direction (send UID or LN with a trip computer tram)
- Determining the direction of the driver by pressing the turn signal.

To tram driver informed about the position of automatically controlled set-reconciliation component for each crossover is an indicator of the position switch. Satisfactory safety was achieved with two independent resonant track circuits installed in the field of the instrument (Figure 7).

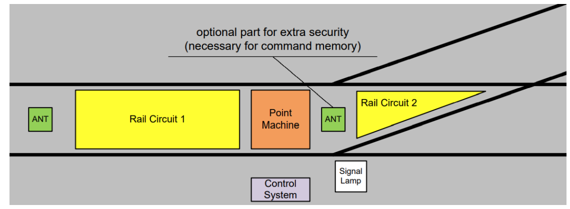

Figure 7. Configuration for automatically setting the switches according to the number of lines and/or ID of the vehicle number.

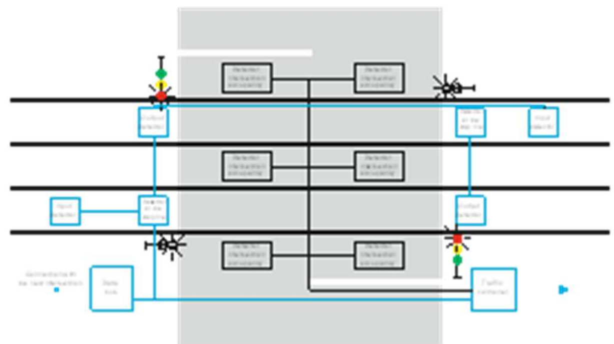

Figure 8. Scheme of automatic tram priority.

If the tram takes any of these track circuits, the device is electrically disabled to change the position. They must be used track circles and set-switches with the security certificate. Figure 7 shows the configuration for automatically setting the switches according to the number of lines LN and/or the unique number of UIDs Tram signaling system offers very high safety and availability of tram operation in areas of tram intersections and terminal stations. The system is based on combination resonant track circuits and tram-to-wayside communication system. The signaling system is equipped with standard interfaces and can be therefore, connected to any central control room via optical network or other communication infrastructure. It can be therefore, easily integrated within the existing tramway network. The system is based on the real tram priority at intersections with other traffic participants. The system is designed for safe and reliable detection of trams and other vehicles at crossings. A similar system of prioritizing trams is also applied in Athena [15]. The system reliably detects trams approaching the intersection with regulated light signaling, forwards the necessary information to traffic controller who provides full or selective priority to trams.

Figure 8 shows a system scheme for determining the traffic priorities. It also integrates the control of the speed of trams, control of the rail occupancy with other vehicles at the crossings. The system communicates between the vehicle and the external equipment bidirectionally so that tram sends the number of lines LN, the unique tram ID UID and the speeds of the vehicle are sent from the vehicle while the external equipment sends out the information about the tram position, the position of the switches, the signal status and the occupancy of the driving path as well as other programmable information. This system can be run locally (at intersections and sections with switches). The system is easy to install on the vehicle and outside the vehicle. With less refinement, it can also be integrated into the Traffic Control Center - TCC, as well as the passenger information system.

It is to be expected and should be confirmed by future research that the reduction in the number of hand-served commands on the control panel will result in a reduction in the driver's workload, an improvement in the performance level and consequently the expected lower number of traffic accidents as well as an increase in the level of safety.

5. INCREASE TRANSPORT WORK ON THE LINE

The benefits from applying the proposed model are simultaneous for both passengers and operators. One of the key parameters that determine the quality of the service offered to tram users is the travel time [17].

The cycle time on the line T (min) is defined by equation (1) where T_o (min) is the operating (travel) time on line and t_t (s) is the total time at terminals, calculated or measured in both directions:

$$T = \sum T_o + \sum t_t \qquad (1)$$

The cycle time online T (min) is defined by the basic equation of the transport process (2) on the public transport line which connects the headway of vehicles online h [min/veh] and the number of vehicles on line N:

$$T = h * N \qquad (2)$$

Furthermore, from equation (2) follows that if the same number of vehicles N are retained, and the cycle time on the line T decreases, headway h (min/veh) *must* also be reduced.

The cycle time on line T can be reduced if operating (travel) time on line T_o is reduced, in the way that all traffic lights are placed on the green light for trams (the tram priority), assuming the real total time at terminals t_t.

Consequently, the cycle speed V_c (km/h) on the same line length $2L$ (km) will increase, which is defined by equation (3):

$$V_c = 2L / T \qquad (3)$$

It will also result in an increase in the transport work of line w (sps·km/h) defined by equation (4):

$$w = C * L \qquad (4)$$

because it has increased the line capacity C (sps/h) defined by equation (5):

$$C = C_v * f \qquad (5)$$

So, with the same vehicle capacity C_v (sps/veh) and for the known number of standing and sitting places in the new tram NT 2200, and the same number of vehicles (drivers) on line N the frequency of vehicles on line f (veh/h) is higher because headway h (min/veh) is smaller.

Measurements have conducted for the new tram NT 2200, on lines no. 17 and no. 12. Measured times savings ΔT of cycle time on lines no. 12 and no. 17 in one cycle are based on the measurement of possible times savings ΔT_o of operating (travel) time, which is the sum of the duration of all red signals at traffic lights while driving as well as differences between particular times of all red traffic signals at traffic lights at stations and the average amount of all green traffic signals at traffic lights at stations [18, 19]. No. 17 is one of the four statistically most dangerous lines on which the new tram NT 2200 runs [20].

The average amount of the increased cycle speed V_{ci} = *15.42 km/h* online no. 17 contains a speed increase of 14.96 % as well as the average amount of increased operating speed V_{oi} = *18.09 km/h* contains speed increase of 16.77 % [19].

Possible increase of the average amounts of cycle speeds ΔV_c = +14.69 % as well as possible increases of the average amounts of operating speeds ΔV_o = + 16.77 % online no. 17 are the total amounts for both directions in one cycle [19].

Table 2

Comparison of possible savings of cycle times ΔT and operating times ΔT_o.

Average amounts for tram line	T_o	T_{or}	ΔT_o	T	T_r	ΔT
	(min)	(min)	%	(min)	(min)	%
no. 12:	79.33	69.87	-13.50	92.2	82.74	-11.47
no. 17:	101.7	84.59	-20.20	116.2	99.09	-17.35

Table 3

Comparison of possible increases of the cycle speeds ΔV_c and operating speeds ΔV_o on lines no. 17 and 12.

Average amounts for tram line	V_o	V_{oi}	ΔV_o	V_c	V_{ci}	ΔV_c
	(km/h)	(km/h)	%	(km/h)	(km/h)	%
no. 12:	14.29	16.20	+11.76	12.22	13.62	+10.24
no. 17:	15.06	18.09	+16.77	13.15	15.42	+14.69

The results of similar model research in which priority is given to trams and restricting other vehicles entering the "yellow line" confirm the increased cycle peed as well as the increased dynamic capacity [21].

Transport priority by trams in the City of Zagreb was also researched in 2017 [22], where two hypothetical priority scenarios were set - minimum travel time (7 % operating speed increase, 22 mil EUR investment savings) and absolute priority (41 % operating speed increase, 94 mil. EUR investment savings). The results suggested a significant space for improvement, even in the more realistic travel time scenario.

Smaller average amounts of the times savings as well as smaller average amounts of the speeds increases on line no. 12 in relation to the line no. 17 are related to the different real traffic situations on the lines, different real state of the infrastructure on the lines, different line lengths, different number of traffic lights, different number of stations as well as different number of intersections along the route of the line [18, 19].

6. DISCUSSION

Possible inaccessibility (arrangement outside of the normal arm reach) and/or poor layout at the control panel of the manually served and frequently used commands (with emphasis on grouped commands for changing of the speed as well as all related commands regarding the setting of the direction) can dominantly and negatively affect the performance of the tram drivers. Good example of a solution for this situation is multi-purpose left-hand controller for the grouped commands related to tram speed change (with integrated accelerator, braking module and “dead-man” function), which will reduce the tram driver task demands in the latest tram NT 2200. However, this is also not enough from the aspect of security.

The analysis of the tram driver’s disturbance factors in Sarajevo suggests a number of relevant disturbance factors in the context of collision with trams on the road traffic and/or their driving in the "yellow lane", which is very similar to a much more complex situation in Zagreb. Before designing a draft of a research project with the aim of proposing the final solution, it is necessary to further explore the statistically objective risk of traffic accidents in Zagreb according to the methodology of research conducted in the Netherlands. The 2013 research gave a range of characteristic static and dynamic anthropometric measures for the central 90% of male tram drivers in Sarajevo essential for the design of the control panel [23]. For a mixed male-female tram drivers’ population in Zagreb, the central 90% of the entire population should include anthropometric ranges of between 5 percentiles from the age group with the shortest female tram drivers and 95 percentiles from the age group with the tallest male tram drivers.

The conducted research suggests the need for a systematic approach to ergonomic design of the tram cab, and confirms the need for active driver assistance systems, such as a local system that will automatically set the points in accordance with the line timetable associated with the tram line number, instead of a much more expensive crossing system by remote control from one center for the whole network. The driver will supervise the automated serving segments and will also be reserved for manual command operation in case of system failure or emergency circumstances. In the proposed system, with the adaptation of the local conditions in Zagreb, it is necessary to integrate, with the tram priority, the control of the "occupancy" of the junction by road vehicles.

However, for the driver quick response to an emergency traffic situation, the factors of anthropometric space adaptation, lighting factors, thermal comfort factors, as well as the equivalent noise level and/or the accumulated daily noise must be within the recommended ranges that ensure optimum performance, not only in the NT2200 tram which makes 52% of the ZET fleet. The oldest models of trams in Zagreb without air-conditioned cabs makes 23% of the ZET fleet, and they also run during the summer, which is an example for potentially dangerous situation, because the poor values of the thermal comfort factors in tram cabs can negatively influence the tram drivers' performance and traffic safety.

The extreme measured values of thermal comfort factors from tram cabs should be simulated in the laboratory research drafts of respondents' performance measuring, by using the research equipment of several FPZ labs.

7 CONCLUSIONS

The parallel implementation of the cognitive approach to the research (tram driver's subjective disturbance factors and the tram driver's needs) at the same time with the behaviorist approach to the research (analysis of the statistical objective trams' accident risk in urban areas) has been proposed as one of the ways of reducing the impact of relevant disturbance factors from the traffic and work environment on the tram drivers.

Applying the analyzed local tram priority model will reduce the number of frequently used and manually served commands, such as related commands for setting the points and setting the direction indicator, which can affect the workload and the driver performance and thus the safety and reliability of the tram traffic. All other frequently used and manually served commands, with associated indicators and monitors, should be placed mandatory in the normal range of the arm and in the field of vision without turning the driver's head, and compulsorily within the range of anthropometric measures in the central 90% of the mixed male-female population of the tram drivers in Zagreb.

Cited results of the previously conducted research for tram line no. 12 compared with the results for tram line no. 17 have proven the possibility of significant simultaneous cycle times savings ΔT by reducing the operating times ΔT_o, both achieved by the possible implementation of tram priority via green traffic signals at traffic lights based on the local automation.

In conclusion, the application of the presented model can provide the following benefits to some extent: reduction of the workload of tram drivers (by reduction of the manually served controls on the control panel), increase of the performance level of tram drivers, increasing the cycle speed of trams, increasing the transport work of a single line with the same number of trams and drivers.

The proposed local automation of tram priority should be only one segment of the comprehensive implementation of Park-and-Ride measure in Zagreb, with the main benefits for final users: traffic will be much safer for all urban traffic participants, as well as public transport will be much faster, comfortable and attractive for tram passengers.

The claims are not questionable, but for the scientific verification of the achievement level on the example of Zagreb, concrete research should be carried out, such as self-assessment of drivers and users, field measurements, laboratory simulations, study of statistical risk factors of traffic accidents in urban areas.

Future studies should take into consideration actual tendencies in safety and health and automatization using artificial intelligence [24-26]. Modelling the supply chain and transportation systems could offer new perspectives of the accidents etiology [27, 28]. In addition, knowledge and innovation transfer between ergonomists could provide modern methods and tools for the research [29].

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Posibilul impact al automatizării priorității locale a tramaiului asupra sarcinii de muncă și performanței șoferului

Rezumat: Pasagerii din transportul public din UE nu sunt mai în siguranță decât alți participanți la traficul urban, deoarece în coliziunile cu vehicule de transport public, numărul celorlalți participanți răniți și grav răniți a crescut. Pentru reducerea numărului de accidente este necesară reducerea impactului factorilor de perturbare și a factorilor de circumstanțe nefavorabile din trafic și/sau mediu de lucru asupra conducătorului auto din vehiculele de transport public. Analiza riscului obiectiv statistic precum și analiza factorului de perturbare a șoferilor din vehiculele de transport public indică necesitatea intervențiilor în mediul de trafic și de lucru. Prin realizarea dreptului de trecere a tramvaiului prin amplasarea locală automată a macazelor și semnalizatoarelor la intersecții se preconizează să realizeze: reducerea volumului de muncă al șoferilor de tramvai, creșterea nivelului de performanță, creșterea siguranței în trafic și, în consecință, mai puține accidente de circulație. În plus, viteza tramvaiului comercial este de așteptat să crească, în consecință munca de trafic brut a fiecărei linii de transport orașului va crește, iar transportul va fi mai confortabil și mai atractiv pentru călătorii din tramvai.

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