Factors of Performance and Safety of Road Vehicle Drivers in Urban Environment

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FACULTY OF TRANSPORT AND TRAFFIC SCIENCES

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FACTORS OF PERFORMANCE AND SAFETY OF ROAD VEHICLE DRIVERS IN URBAN ENVIRONMENT

GRADUATE THESIS

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Opis zadatka:

By compiling and comparing the findings from recent scientific and professional literature, the impact of factors of the working and traffic environment to the road vehicle drivers performance will be explored. The impact of driver anthropometric adjustment to the cab dimensions, as well as the influence of changes in the Body mass index BMI with ages will be analyzed, due to proven impact of mentioned to the driver physical workload. The factors of fatigue as well as the factors of driver distraction will be briefly analyzed. Also measures for improving the performance of public city transport will be analyzed, in order to improve the safety and performance of road vehicle drivers in urban environment. It will be explored how by using the iRAP methodology and the statistical processing factors of traffic accidents the selection of the traffic accidents locations in urban environments could be simplified for which the fatigue can be a potential cause. In order to improve road safety and driver performance in urban environments guidelines will be set.

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GRADUATE THESIS

FACTORS OF PERFORMANCE AND SAFETY OF ROAD VEHICLE DRIVERS IN URBAN ENVIRONMENT

ČIMBENICI IZVEDBE I SIGURNOSTI VOZAČA CESTOVNIH VOZILA U URBANIM SREDINAMA

Mentor: Assoc. Prof. Davor Sumpor, Ph.D.

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SUMMARY

This graduate thesis presents the results of an ergonomic assessment of all relevant factors from the working and/or traffic environment affecting the performance and safety of road vehicle drivers by compiling and comparing the findings from recent scientific and professional literature. Among other factors from the working and traffic environment, the impact of driver's anthropometric adjustment to the cab dimensions, as well as the influence of changes in the BMI (Body Mass Index) with age was studied, due to the proven impact of the mentioned on the driver's physical workload. Also, measures for improving the performance of public city transport were investigated in order to improve the safety and performance of road vehicle drivers in urban environment. The factors of driver's fatigue were briefly examined. The research also included the study of how by using the iRAP methodology and the statistical processing of factors of traffic accidents, the selection of the traffic accidents' locations in urban environments, for which the fatigue can be a potential cause, could be simplified. In order to improve road safety and driver's performance in urban environments the guidelines were set.

KEY WORDS: ergonomic assessment; performance; safety; fatigue; traffic accidents

SAŽETAK

U radu su prezentirani rezultati ergonomske prosudbe svih relevantnih čimbenika iz radnog i(li) prometnog okoliša koji utječu na izvedbu i sigurnost vozača cestovnih vozila kompilacijom i komparacijom spoznaja iz recentne znanstvene i stručne literature. Između ostalih čimbenika iz radnog i(li) prometnog okoliša, analizirao se utjecaj antropometrijske prilagođenosti vozača gabaritama upravljačnice, utjecaj čimbenika promjene ITM s navršenom dobi, a zbog dokazanog utjecaja istoga na fizičko radno opterećenje vozača. Također su se analizirale mjere za poboljšanje odvijanja javnog gradskog putničkog prometa, s ciljem unaprijeđenja sigurnosti i izvedbe vozača cestovnog vozila u urbanim sredinama. Sažeto su se analizirali čimbenici umora vozača. Istražilo se kako se primjenom iRAP metodologije i statističkom obradom čimbenika prometnih nesreća može pojednostaviti selekcija lokacija prometnih nesreća u urbanim sredinama za koje umor može biti potencijalni uzrok. Odredile su se smjernice s ciljem poboljšanja sigurnosti cestovnog prometa i izvedbe vozača u urbanim sredinama.

KLJUČNE RIJEČI: ergonomska prosudba; izvedba; sigurnost; umor; prometne nesreće.

Contents

1. INTRODUCTION

The performance of road vehicle drivers takes place in a complex working and driving environment which requires drivers' continuous effort and attention. This graduate work will analyse and prove the basic hypothesis that the different and simultaneous relevant factors from the complex working and driving environment can directly and/or indirectly influence the driver's performance, such as the driver's ability factors, factors of TPR (temporary psychophysical driver's readiness) for all factors affecting the driver before the performance starts, time of day (night conditions, reduced visibility, the influence of circadian rhythms), fatigue factors, distraction factors, factors of static driver sitting/working position, factors of traffic situation, etc., indicating the importance of the continuous assessment of statistical risk factors for traffic accidents. In order to avoid the negative consequences for the road traffic safety, it is necessary to identify and continuously monitor all recent factors in the working and traffic environment that may affect the driver's performance, using the methodology, knowledge and guidance from the recent scientific and professional literature.

This graduate work has analysed how public transport vehicles such as trams and buses, due to their large masses, large vehicle lengths and longer stopping distance as well as longer braking distance, can influence the safety of other road traffic participants, which is based on the results obtained from the publicly available scientific research on traffic accidents expertise. Road safety measures were proposed to reduce the number of traffic accidents and the resulting consequences.

All the relevant factors that have influence on road vehicle drivers' performance were explored. Among other things, road vehicle driver's workload factors, workplace design as well as the relationship between the ability/capability and the task demand of road vehicle drivers were explored with suggestions to reduce the negative impact due to the human imperfection. The mutual influence of three basic groups of traffic and transport factors with their share in traffic accidents was also studied. In the human – vehicle – environment system and according to the professional and scientific literature three basic groups of factors are: traffic environment, vehicles (traffic means) and human factors (road users).

It has been also explored how by implementing tram priority via traffic lights based on local automation may increase the cycle and operating speed as well as vehicle capacity while increasing the safety of road traffic participants and the reliability of public transport, based on results from scientific research conducted on two tram lines in the City of Zagreb.

It is commonly known that the driver's fatigue represents a contributing factor in many crashes. Due to the difficulty of selecting fatigue-related road traffic accidents, a new method was proposed that can significantly assist in the selection. On the examples of road infrastructure analysis of the three traffic accidents, the efficiency of the proposed iRAP methodology was demonstrated. Detailed road crash data were given by the Ministry of the Interior of the Republic of Croatia.

The aim of this study is to identify all the relevant performance factors of road vehicle drivers which can be affected by the environmental factors, as well as to prove that by implementing several measures the road safety can be improved as well as the driver performance in urban environments. Guidelines and examples of concrete solutions for adapting the working and traffic environment to the road vehicle drivers will be given while respecting the recent ergonomic principle that the design of workplace and equipment must be optimised for human well-being, which implies comfort, safety, efficiency and productivity.

2. THE IMPACT OF PUBLIC CITY TRANSPORT ON THE SAFETY OF OTHER TRAFFIC PARTICIPANTS IN URBAN ENVIRONMENT

Public transport passengers are safer than other participants in urban traffic environment because in traffic accidents involving public transport vehicles and other vehicles, the number of seriously injured and other injured participants is much higher.

According to publicly available research from the Netherlands [1], an annual average number of casualties among the users of public transport (tram/light rail, bus, metro and train) during the period from 2000 to 2009 is one fatality and nineteen serious road injuries. The risk of public transport vehicles for other road users is much higher: during the same period there was an annual average of 41 fatalities and 138 serious road injuries. Among them, 116 are casualties of traffic accidents with buses (16 of them fatalities) and 63 of traffic accidents with a tram or train (25 of them fatalities). The casualty rate and traffic accident rate are measured by relating the number of vehicle kilometers driven by trams, buses and private cars to the number of traffic accidents or casualties. A comparison of the casualty rates shows that there are seven times more traffic accidents with a severe outcome (serious road injuries and/or fatalities) in traffic accidents with buses, than in traffic accidents with a private car, and twelve times more in traffic accidents with a tram. These ratios are even more unfavorable for fatalities: 15 times more in traffic accidents with buses and even 57 times more in traffic accidents with a tram, than in traffic accidents with a private car. In order to reduce the number of traffic accidents with a severe outcome for all traffic participants, it is necessary to reduce the impact of disturbance factors and factors of unfavorable circumstances from the traffic and/or working environment on the public transport vehicle driver.

Generally considering, due to their large masses, large vehicle lengths and longer stopping distance as well as longer braking distance, public transport vehicles such as trams and buses can have a negative impact on the safety of other road traffic participants, because the number of seriously injured and injured passengers and drivers is higher in other road traffic vehicles than in public transport vehicles.

3. FACTORS OF PERFORMANCE AND DRIVERS' COMFORT

Factors of "traffic means" and "traffic environment" according to the TCI (*Task-Capability Interface)* Fuller's kinematically open model shown in Figure 3.1 can directly and/or indirectly affect the task difficulty of the driver [2].

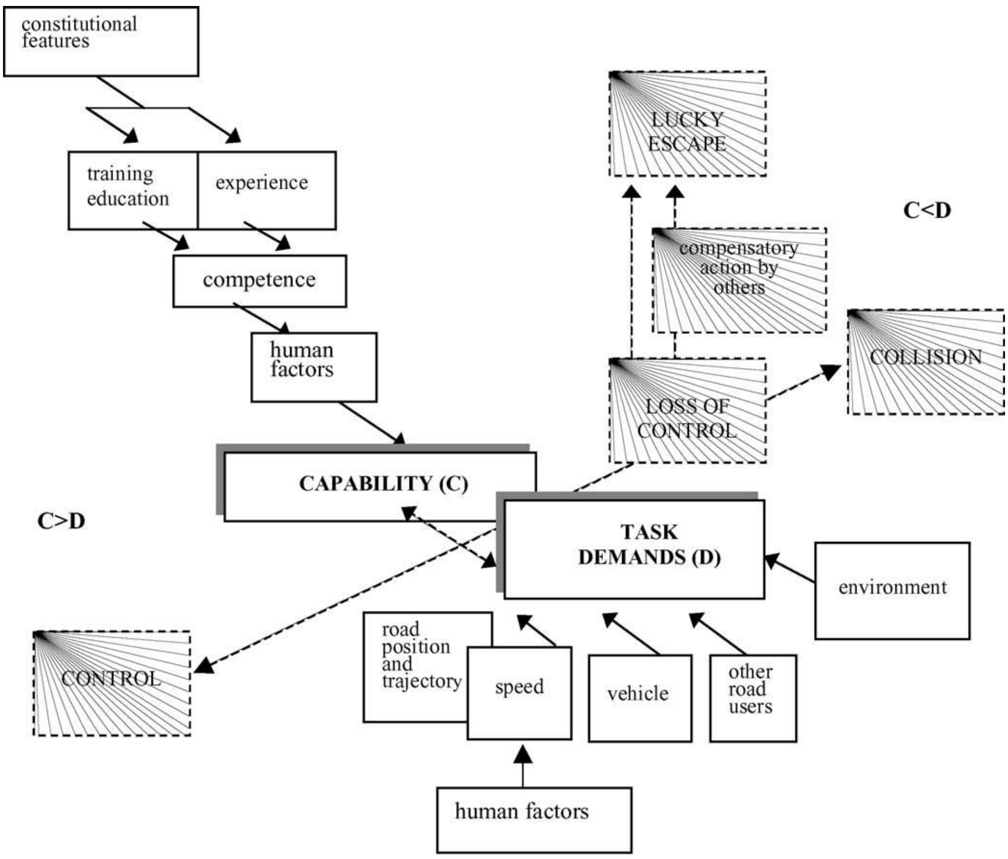

Figure 3.1 - Open kinematic TCI model of "task demand-driver's capability" interface

Source: [1]

Difficulty of the driving task can be linked with workload. The open kinematic TCI model interface is applicable regarding engineering, since input variables include three standard groups of factors common for research in the field of transport and traffic sciences: human factors, transport means and traffic or road environment. Figure 3.1 shows the relation between capability (C) and task demands (D). The first case is when the driver's capability transcends the task demand (C>D); the task can be overcome without any problems by the driver. The second case is when the driver's capability is equal to the task demand (C=D); the task can still be overcome, but the driver acts on the borders of their capability and the task does not seem so easy (subjective risk = objective risk). Third and the final case is when the driver's capability is lower than the task demand (C<D); then the task is too difficult for the driver, and possible consequences are the loss of control, collision, or maybe lucky escape. One of the solutions to how this can be prevented is that the drivers' vehicle is equipped depending on the automation level with the advance driver-assistance systems that could alert the driver or make real-time decisions for specific situations.

According to [2] the open kinematic TCI model interface has some flaws. It does not consider the possible effects of various factors on the driver prior to the start of the performance because the driver does not approach the task with the maximum capability that they theoretically have. The capability of respondents is usually predetermined by birth (genotype), but it can be improved and/or modified by environmental and growing conditions such as formal education, acquiring knowledge and skills through upbringing, work experience, additional education, environmental impact etc., which TCI open model shown in Figure 1 accepts.

Temporary psychophysical preparedness represents current physical, emotional, social and cognitive state of human body system due to several factors which could influence the performance of the task until the moment of the beginning of the performance (previous workload, influence of distraction, previous impact of environmental factors, alcohol, drugs, medicaments, stress, drowsiness and fatigue, circadian rhythms, performance motivation, emotional state etc.) [2].

To conclude, in circumstances of reduced temporary psychophysical readiness the driver does not approach the task with maximum capability which they theoretically have in ideal conditions due to the exposure of the drivers' body system to the mentioned or some other factors before the start of the performance.

In 1982 Rumar summed two studies based on the analysis of several thousand traffic accidents from Great Britain (GB) and the United States of America (USA) with a high level of matching results [3]. The results are presented in Figure 3.2 and are obtained after deep analysis of traffic accident reports. The aim was to try to establish the relative weight of vehicle, road and human factors as causes in road accidents. Upper (left) percentage is the result of the British studies and lower (right) the US studies for single, double and triple participation of all three groups of factors in traffic accidents of road vehicles.

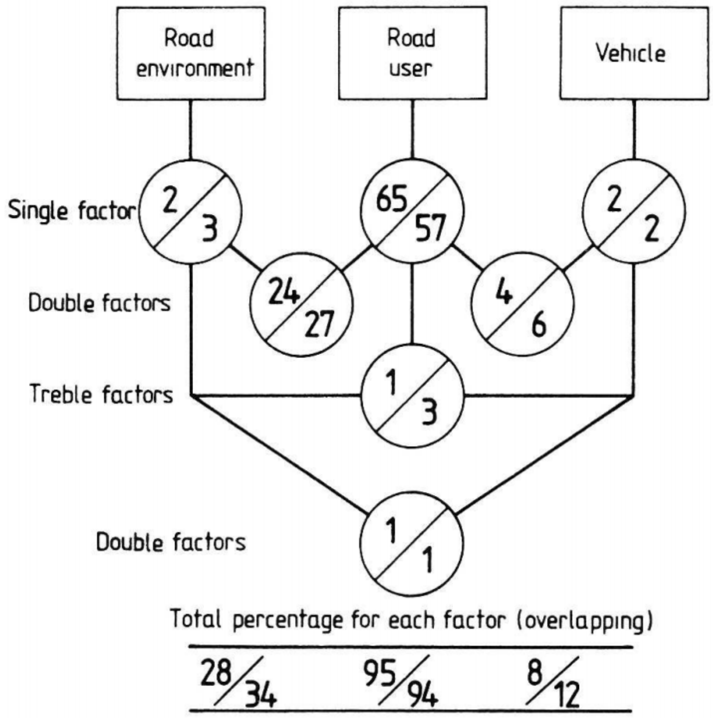

Figure 3.2 - Percentage contributions to road accidents by groups of factors

Source: [3]

According to Figure 3.2 it is obvious that the group "human factor" (road user) is a dominating contributor of road traffic accidents with a share of 95% (GB) and 94% (USA) (with overlapping). The individual contribution of the group "human factor" reaches about two-thirds of the total causes of traffic accidents (65% in Britain and 57% in the USA study). The influence of the group "human factor" dominates over other groups of factors, so that they are less noticeable. However, there are some weaknesses of this research. In case when there is no evidence of technical error in traffic accident reports the groups of experts tend to classify the cause of that traffic accident to the group "human factor", that the road user made an error that led to a traffic accident.

According to Figure 3.2 it is also obvious that the group "road environment", also known as "traffic environment", contributes with a total percentage share of 28% (GB) and 34% (USA), with all overlapping. This is a big area for implementation of many different methods in order to reduce the influence of road environment on the road driver's performance.

3.1. Analysis of respondents' body ratios in order to simplify the control panel design

The main purpose of all human body harmonic analysis, such as harmonic analysis by Zederbauer and Muftić [4], is to ensure a more simplified and more precise way of calculating other anthropometric measures, only by knowing one measured anthropometric measure, which is the standing body height h [5]. Significant five groups of factors of the human body sizes which are widely known are [7, 8, 9, 10, 11]:

- gender
- age
- ethnic differences
- socioeconomic factors
- demographic factors.

The scientists claim that the gender, age and socioeconomic factors of respondents are significantly affected by the body height, but is it possible that the same factors of participants do not significantly affect body ratios h_i/h in relation to the current standing body height h for anthropological measures h_i important for the cabin design? In a 2017 study whose results are presented in this subchapter, the participants were female and male students of the University of Zagreb and male tram drivers of the Zagreb Electric Tram (ZET) [5]. The presented results show only a smaller part of the larger scale research which includes several separate studies of male engine drivers from all regions of Croatia [6], male and female tram drivers of ZET Zagreb and male and female students of the University of Zagreb.

The construction of the harmonic circle with radius R was given by Zederbauer [4] in the way that the harmonic circle is a geometrical structure of an isosceles triangle, on whose sides there are lifted squares. Regardless of the change in circle radius, the relations between radius of circle R and the length of the sides of isosceles triangle a and b are always the same harmonic numbers. Muftić chose the diameter of the harmonic circle $2R$ for the human body height h, so that the network of canon of eight head heights h_g is associated with the diameter of the harmonic circle and the human body height. In this way the connection between harmonic numbers and anthropometric measures of the human are established, according to Equation (1) and Figure 3.3 [4].

$$2 \cdot R = h = 8 \cdot h_g \quad (1)$$

From the constructions of circle in Figure 3.3, better known as harmonic circle by Zederbauer and Muftić [4], the sizes called harmonic numbers are obtained.

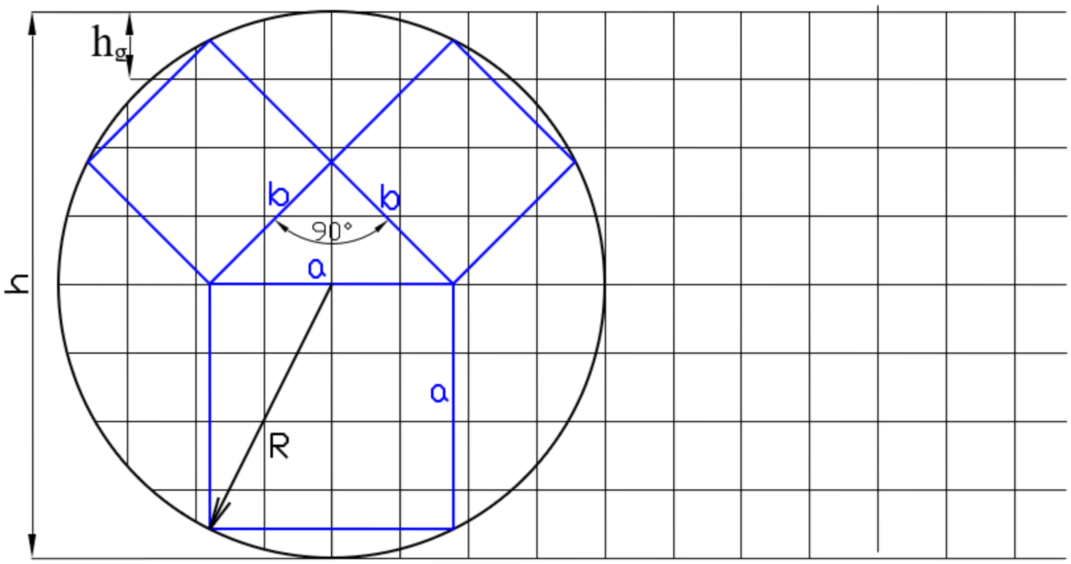

Figure 3.3 - Harmonic circle by Zederbauer and Muftić
Source: [4]

Table 3.1 - Anthropometric measures of a human as a function of the standing body height h

Length of body segment:	Label of length	Function *hi=hi(h)*:	Length of body segment	Label of length	Function *hi=hi(h)*:
Length of arm	h_r	$=\frac{25}{64}h=0.39\cdot h$	Length of upper arm	h_{ndl}	$=\frac{5}{32}h=0.156\cdot h$
Length of forearm	h_{pdl}	$=\frac{h}{8}=0.125\cdot h$	Length of hand	$h_{š}$	$=\frac{7}{64}h=0.109\cdot h$
Length of leg	h_n	$=\frac{17}{32}h$	Length of upper leg	h_3	$=\frac{9}{32}h$
Length of lower leg	h_2	$=\frac{7}{32}h$	Length of foot	h_1	$=\frac{h}{8}$
Length of the mobile part of the spine in the standing position	h_k	$=\frac{1}{3}h$	Height of foot	h_{11}	$=\frac{h}{32}$

Source: [4]

Harmonic analysis of the human shows that the functions of anthropometric sizes depend on the standing body height of the human, based on Equation (1). All functions *hi=hi(h)* which are shown in Table 3.1 should be universally valid for the young and healthy respondents of both genders with small differences [5].

Many authors [8, 10, 11] claim that the age and gender are significant factors of body stature. The development of human body dimensions reaches its maximum towards the end of the teen age or the 20s in men, while women reach this development a few years earlier. Figure 3.4 shows how body dimensions of both genders begin to decrease with age after maturity.

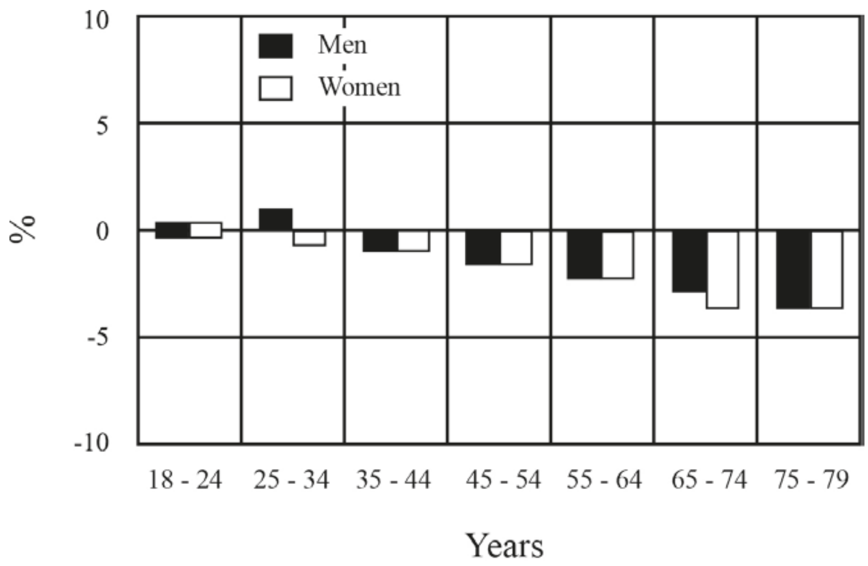

Figure 3.4 - Relative changes in body stature depending on age and gender, for men and women at the age of 18 to 79.
Source: [7]

Relative changes of the body segment ratios h_i/h with the age have been analysed on the male tram drivers from Zagreb, who were divided into three age groups [5].

The variations of the anthropometric measures in adult women and men compared to the dimensional canon of eight head heights are within the range of one module, i.e. it is considered that the total standing body height h of a human can vary within an interval of 7.5 to 8.5 head heights. It can be even 9 head heights h_g, for the so-called heroically built people [8]. This scientific claim for the value of the body ratio h/h_g between standing body height h and head height h_g has been verified and confirmed in a 2017 study on the male and female students of the University of Zagreb until the age of 29, as well as on the male tram drivers in Zagreb, divided into three age groups, whose results will be presented in this subchapter [5].

The geometric construction of the golden ratio [9] is illustrated on the right triangle shown in Figure 3.5 The standing body height *h* consists of two parts, the larger part i.e. height to the navel h_B, and the smaller part i.e. height above the navel h_C, which is shown in Figure 3.6 [5].

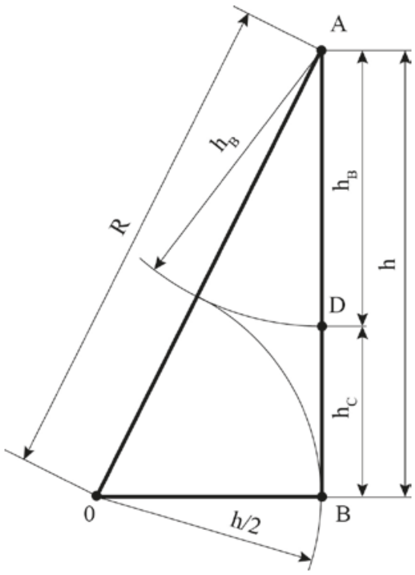

Figure 3.5 - Analysis of the human body based on the golden section

Source: [9]

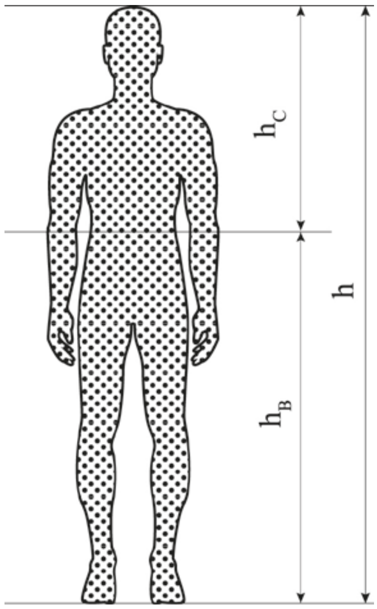

Figure 3.6 - Human body and the golden section

Source: [5]

From the right triangle ΔOAB shown in Figure 3.5 there follows [5]:

$$R = \frac{h}{2} + h_B \tag{2}$$

$$R^2 = h^2 + \left(\frac{h}{2}\right)^2 = \frac{5}{4}h^2 \tag{3.1}$$

$$R = \sqrt{\frac{5h^2}{4}} = \frac{\sqrt{5}}{2}h - \frac{h}{2} = 0.618 \cdot h \tag{3.2}$$

$$h_B = R - \frac{h}{2} = \frac{\sqrt{5}}{2}h - \frac{h}{2} = 0.618 \cdot h \tag{4}$$

$$\frac{h_B}{h} = 0.618 \tag{4.1}$$

$$h_C = h - h_B = h - 0.618 \cdot h = 0.382 \cdot h \tag{5}$$

$$\frac{h_C}{h} = 0.382 \tag{5.1}$$

$$\frac{h_C}{h_B} = \frac{h_B}{h} = 0.618 \tag{6}$$

In accordance with Equation (6) and model shown in Figures 3.5 and 3.6 it is obvious that the theoretical value of the golden section is 0.618. The study [5] presents a deviation of the real values of the body ratio h_B/h in all the groups of respondents in relation to the theoretical value of the golden section 0.618.

For all groups of respondents only a few of the most important anthropometric measures were measured, shown in Table 3.3 for the male tram drivers in Zagreb (for the entire sample, and for a sample divided into three age groups). The most important anthropometric measures for control panel design in the tram cabin are kinematic anthropometric measures of the maximum arm reach h_{mdr} and normal arm reach h_{ndr} together with the static anthropometric measure bi-acromial range (shoulder width) $h_{šr}$. The static anthropometric measures of the length of the upper arm h_{ndl} and the length of the forearm h_{pdl} were calculated using the measured values of the next three static anthropometric measures: arm length h_r, length of forearm and hand h_{10} and hand length $h_š$. The distance from the floor to the navel h_B was measured for the purpose of calculating the real value of ratio h/h_B for the golden section, for all groups of respondents [5].

According to Equations (7) and (8) taken from Kroemer and Grandjean [10], if the arithmetic mean *M* and sample standard deviation *SD* are known, then 5 centile and 95 centile for all anthropometric measures can be calculated, because 5% of the tallest and 5% of the shortest individuals of the entire sample of respondents should be excluded (in the physical dimension to which the analysis applies) [5].

$$5.0 \cdot c = M - 1.65 \cdot SD \quad (7)$$

$$95.0 \cdot c = M + 1.65 \cdot SD \quad (8)$$

The static and kinematic anthropometric measures were used for the calculation of body segment ratios h_i/h for anthropometric measure h_i in relation to the standing body height h [5].

Figure 3.7 shows typical anthropometric measures in the sagittal plane with labels by Kroemer and Muftić [5, 9].

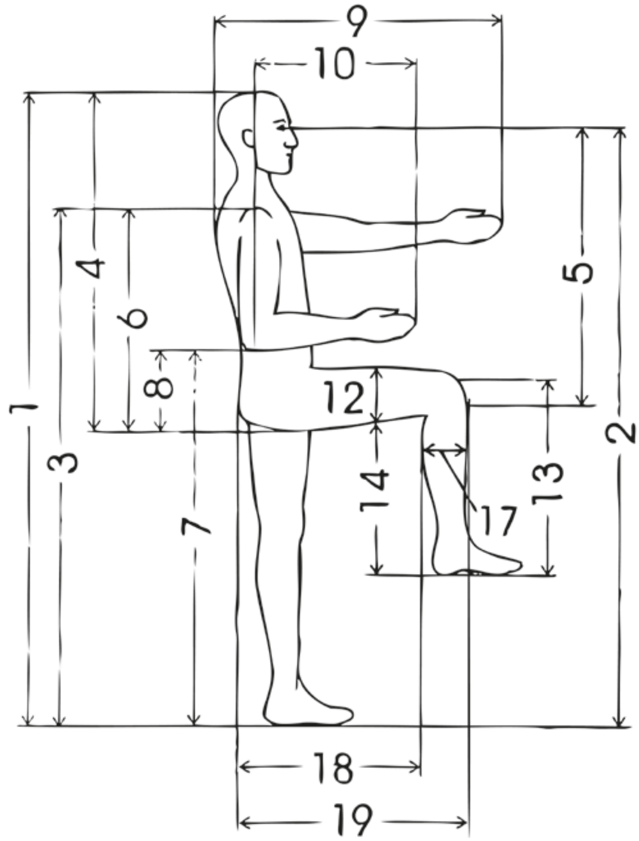

Figure 3.7 - Showing typical anthropometric measures in the sagittal plane by Kroemer

Source: [4]

The results of another study [6] confirm that gender is an important factor of body stature.

The age of fifty-one (51) surveyed engine drivers from Croatia, which are in the range from 27 to 56 years of age, significantly affects body height *h* and other anthropometric measures h_i that are functionally dependent on the body height *h* [6], which is for body height *h* confirmed by the results shown in Table 3.2.

Table 3.2 - Body height of male engine drivers in Croatia depending on age groups

Anthropometric measure	Symbol (unit)	Age groups									
		Total sample (*n = 51*)		Up to 29 (*n = 9*)		From 30 to 39 (*n = 13*)		From 40 to 49 (*n = 18*)		From 50 to 59 (*n = 11*)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Body height	*h (cm)*	178.9	5.7	177.2	6.0	180.6	6.2	178.6	6.1	178.5	4.0

Source: [6]

The values of anthropometric measures for male tram drivers in Zagreb shown in Table 3.3 partially confirm that age is a significant factor of body stature, because the largest value of arithmetic mean *M* of body height *h* is in the age group from 30 to 39 years of age [5].

Arithmetic mean of body height *h* in the age group from 50 to 59 years is not the smallest value, and possible reasons for this deviation of results shown in Table 3.3 are [5]:

- Insufficient total number of tram drivers in the sample.
- Unequal and insufficient number of tram drivers in three age groups.
- Possible impacts of demographic factors within a specific age group.

Table 3.3 - Static and kinematic anthropometric measures of male tram drivers in Zagreb depending on age

Name of the anthropometric measures or body segments	Symbol	Label by Fig. 5	Total sample		From 30 to 39		From 40 to 49		From 50 to 59	
			n=21		*n=5*		*n=8*		*n=8*	
			M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
			cm (kg*)	cm (kg*)	cm (kg*)	cm (kg*)	cm (kg*)	cm (kg*)	cm (kg*)	cm (kg*)
Standing body height	h	1	179.6	6.00	182.0	5.10	177.8	6.52	180.0	6.02
Mass*	m		95.1	17.4	94.1	16.07	91.8	16.53	98.9	20.27
Arm length (from acromion to the tip of the middle finger in vertical position)	h_r		78.2	3.49	79.0	4.36	76.6	3.16	79.3	3.06
Length of forearm and hand (from rear side of the elbow to the tip of the middle finger in horizontal position)	h_{10}	10	48.6	2.11	49.2	2.17	48.0	2.51	48.9	1.73
Length of upper arm	h_{ndl}		29.6	1.99	29.8	2.49	28.6	0.92	30.4	2.26
Length of forearm	h_{pdl}		28.6	1.43	29.0	1.73	28.4	1.69	28.5	1.07
Hand length (distance between tip of the middle finger and the first crease in the wrist)	$h_{š}$		20.0	1.02	20.2	0.84	19.6	1.06	20.4	1.06
Distance from the navel to the floor	h_B		105.0	3.99	108.6	2.30	104.3	3.11	103.6	4.57
Normal arm reach (from the rear side of the elbow to the middle of a clenched fist)	h_{ndr}		35.6	1.91	36.4	1.67	34.9	1.96	35.8	1.98
Maximum arm reach (from the rear side of the acromion to the middle of a clenched fist)	h_{mdr}		64.6	2.94	65.4	3.85	63.9	3.56	64.8	1.58
Bi-acromial range (shoulder width)	$h_{šr}$	15	39.5	2.68	38.0	3.54	40.3	2.43	39.8	2.25

Source: [5]

Table 3.4 - Body segment ratios and the golden section ratios of male and female students of the University of Zagreb and male tram drivers in Zagreb

Body segment ratios or golden section ratios	Male students up to 29 years of age				Female students up to 29 years of age				Male tram drivers in Zagreb from 30 up to 59 years of age			
	n=39				*n=48*				*n=21*			
	M_r	SD_r	*min.*	*max.*	M_r	SD_r	*min.*	*max.*	M_r	SD_r	*min.*	*max.*
h_B/h	**0.61**	0.015	0.58	0.66	**0.60**	0.013	0.57	0.62	**0.59**	0.015	0.55	0.61
h_C/h_B	**0.63**	0.040	0.52	0.72	**0.66**	0.036	0.61	0.76	**0.71**	0.045	0.64	0.83
h_C/h	**0.39**	0.015	0.34	0.42	**0.40**	0.013	0.38	0.43	**0.42**	0.016	0.39	0.45
h/h_g	**8.10**	0.660	6.73	9.37	**8.38**	0.481	7.43	9.26	**8.06**	0.340	7.50	8.75
h_r/h	**0.44**	0.017	0.40	0.47	**0.43**	0.013	0.41	0.47	**0.43**	0.012	0.41	0.46
h_{mdr}/h	**0.36**	0.020	0.33	0.40	**0.36**	0.016	0.32	0.40	**0.36**	0.015	0.33	0.39
h_{ndr}/h	**0.20**	0.014	0.16	0.24	**0.20**	0.010	0.16	0.22	**0.20**	0.008	0.18	0.21
$h_{šr}/h$	**0.20**	0.019	0.16	0.23	**0.20**	0.018	0.17	0.24	**0.22**	0.015	0.20	0.24

Source: [5]

Results in Tables 3.4 and 3.5 show that all mean values M_r of the golden section ratios h_B/h for all groups of respondents (for both genders and for all age groups of tram drivers) deviate very little from the theoretical value of the golden section which is 0.618. The largest range of variations of the golden section ratios h_B/h around the mean arithmetic value M_r is for the male students of up to 29 years of age, from the minimal 0.58 up to the maximal 0.66 [5].

Table 3.5 - Body segment ratios and golden section ratios of male tram drivers in Zagreb depending on age

Body segment ratios or golden section ratios	Male tram drivers from 30 up to 39				Male tram drivers from 40 up to 49				Male tram drivers from 50 up to 59			
	n=5				*n=8*				*n=8*			
	M_r	SD_r	*min.*	*max.*	M_r	SD_r	*min.*	*max.*	M_r	*SDr*	*min.*	*max.*
h_B/h	**0.60**	0.009	0.59	0.61	**0.59**	0.009	0.57	0.60	**0.58**	0.019	0.55	0.60
h_C/h_B	**0.68**	0.026	0.64	0.71	**0.70**	0.025	0.66	0.74	**0.74**	0.058	0.66	0.83
h_C/h	**0.40**	0.009	0.39	0.41	**0.41**	0.009	0.40	0.43	**0.42**	4.50	0.40	0.45
h/h_g	**8.13**	0.354	7.78	8.71	**8.06**	0.423	7.50	8.75	**8.01**	0.271	7.57	8.38
h_r/h	**0.43**	0.015	0.42	0.46	**0.43**	0.012	0.41	0.45	**0.44**	0.008	0.43	0.45
h_{mdr}/h	**0.36**	0.016	0.34	0.38	**0.36**	0.018	0.33	0.39	**0.36**	0.014	0.34	0.39
h_{ndr}/h	**0.20**	0.010	0.19	0.21	**0.20**	0.009	0.18	0.21	**0.20**	0.007	0.19	0.21
$h_{šr}/h$	**0.21**	0.016	0.19	0.23	**0.23**	0.010	0.22	0.24	**0.22**	0.015	0.20	0.24

Source: [5]

The results in Tables 3.4 and 3.5 show that all mean values M_r of the body ratios h/h_g for all groups of respondents deviate very little from the theoretical value based on the canon of eight head heights h_g which is 8. There is a small difference between the mean arithmetic value of the body ratio for male students (h/h_g = 8.1) and the mean arithmetic value of the body ratio for female students (h/h_g = 8.38). The largest range of variations of body ratios h/h_g is around the mean arithmetic value M_r for male students up to 29 years of age, from minimal 6.73 up to a maximum of 9.37 (variations gain value of 2.64 head heights). The differences of the mean arithmetic values of body ratios h/h_g for tram drivers in relation to the theoretical value $h/h_g = 8$ decrease depending on age; for male tram drivers from 50 up to 59 years of age, the body ratio h/h_g is 8.01 [5].

The results shown in Tables 3.4 and 3.5 confirm that there is no big difference between the mean arithmetic values of body ratio h_r/h (ratio of arm length and body height) depending on gender (male and female students), age (three age groups of male tram drivers) and occupation (students and tram drivers) [5].

Mean arithmetic values of body ratio h_r/h of all groups of respondents shown in Tables 3.4 and 3.5 are almost the same with the mean arithmetic values of body ratio h_r/h of all four age groups for fifty one (51) surveyed engine drivers from Croatia, which were in the range from 27 to 56 years of age in 2015 [6]; and also, those are almost the same with the mean arithmetic values of body ratio h_r/h of 68 female students from the University of Zagreb in 2016 (another sample from the same population) [11].

Mean arithmetic values of body ratios $h_{mdr}/h = 0.36$ (ratio of maximum arm reach and body height) and $h_{ndr}/h = 0.2$ (ratio of normal arm reach and body height) of all groups of respondents shown in Tables 3.4 and 3.5 are completely the same with the mean arithmetic values of body ratios h_{mdr}/h and h_{ndr}/h of all four age groups for fifty one (51) surveyed engine drivers from Croatia [6], and also, those are completely the same with the mean arithmetic values of body ratios h_{mdr}/h and h_{ndr}/h of 68 female students from the University of Zagreb in 2016 (another sample from the same population) [11]. Generally considering, kinematic anthropometric measures, maximum arm reach h_{mdr} and normal arm reach h_{ndr} are linear functionalities depending on the standing body height h [6], and this fact can be the reason why those body ratios do not depend on the changes of body height depending on age [5].

The most important results of this study are that the body ratios h_{mdr}/h and h_{ndr}/h can be used for simplified calculation of values of anthropometric measures h_{mdr} and h_{ndr} only by knowing the value of the body height *h*, during the control panel design in tram cab or train cab, because real mean arithmetic values of body ratios $h_{mdr}/h = 0.36$ and $h_{ndr}/h = 0.20$ do not depend on gender, age and occupation for adult respondents from Croatia [5]. Quick and simplified calculation of normal arm reach h_{ndr} is very important, because frequently used commands on the locomotive, railcar or tram control panel need to be arranged mainly within the normal reach of the arm, using multi-purpose controllers for serving several important and frequently used functions by one hand, whenever possible [12].

The static anthropometric measure bi-acromial range (shoulder width) $h_{šr}$ has to be measured for all respondents divided into age groups, from the target population of drivers, and the mean arithmetic value of body ratio $h_{šr}/h$ cannot be used for simplified calculation of the value of anthropometric measure $h_{šr}$ only by knowing the value of body height *h* [5]. The available studies [13] also indicate very weak correlations ($r = 0.42$) between bi-acromial range (shoulder width) and body height *h* in males (r = 0.42), which means that there are no linear functional dependences $hšr=hšr(h)$.

It is worth mentioning that the largest part of the measured participants are not harmonic beings. Just a few respondents have body dimensions in accordance with the golden section and harmonic analysis by Zederbauer and Muftić based on the canon of eight head heights h_g [5]. There was an insufficient total number of tram drivers in the sample as well as unequal and insufficient number of participants in three age groups. Same research should be conducted on female tram drivers since the population of tram drivers of the ZET operator in Zagreb is mixed male-female [5].

3.2. Correlation dependence of lumbar moment on the body mass index

Suburban trains are part of the public city traffic system along with trams and buses. The factors of physical workload of the tram and engine drivers can also be excessive body mass *m* in relation to height *h* expressed by the amount of the body mass index (*BMI*) as well as inadequate design of the driver cab, control panel and seats not matching the scope of anthropometric measures from the target population in Croatia. The factors of anthropometric unadjusted working environment from the cabin, when interacting with anthropometric measures of engine drivers, can affect the task difficulty, increasing the workload of drivers while driving, reducing the performance of engine drivers, as well as reducing the safety of the transport process [14].

According to the Fuller kinematic TCI model "the ability of drivers - demand tasks" [1] the "tasks demand" is significantly affected by selecting the speed of vehicle by engine drivers. The possible influence on the task difficulty (i.e. workload) is the placement, arrangement and accessibility of the frequently used and manually served commands to change the speed on the control panel, such as multipurpose controller (with integrated braking module, accelerator module and "dead man" function), which is commonly used in the newer tram cabs and newer locomotive cabs in Croatia [14].

Only seven static and kinematic anthropometric measures important for the engine and tram driver's control panel design were selected from the 25 measured in an older study from 2015 [6], for a sample of 51 male engine drivers from all parts of Croatia [14].

Finding of the more realistic and more accurate functional dependence of the lumbar moment in case of engine drivers $M_{ly} = M_{ly}(BMI)$ at the level of vertebra L4/L5 on the body mass index *BMI* is a subject of ergo-assessment in this subchapter, in accordance with the basic research hypothesis that the lumbar moment M_{ly} predominantly linearly depends on the body mass index *BMI* [14].

The *BMI* expressed in Formula (9) is an important ergonomic assessment parameter since it contains two most important statistical anthropometric measures; body mass *m* and standing height *h* [14].

$$BMI = \frac{m}{h^2} \tag{9}$$

Research from 2012 [15] presents how the physical workload of engine drivers in the static sitting working position expressed through the amounts of lumbar moment $M_{ly} = M_{ly}\ (BMI)$ at the level of vertebra L4/L5 can be intensively influenced by the design of the control panel (driver cab), regarding the poor organization of frequently used commands within maximal arm reach. Lumbar moment M_{ly} has functional dependence with amount of *BMI* index $M_{ly} = M_{ly}\ (BMI)$ of high strength, with correlation coefficient $r = 0.806$ [14].

It is important to note that instead of calculating for $n = 50$ random respondents from the sample in 2012 [15] for the static and kinematic anthropometric measures h_i calculated from the standing height *h* using harmonic analyses by Muftić and Zederbauer [4], the improved accuracy of calculation in papers which followed in 2015 [12, 14] have been realized by regression function $M_{ly} = M_{ly}\ (BMI)$ obtained on the basis of really measured static and kinematic anthropometric measures h_i for body segments outside the balance seating position [14].

But the most important kinematic anthropometric measures for control panel design such as normal arm reach h_{ndr} and maximum arm reach h_{mdr} were in all the previous research in 2015 measured to the tip of the middle finger [12, 14], not to the centre of the clenched fist, which is not quite right, since the frequently and manually served commands on the control panel (switches, buttons and controllers) are being manually served with a clenched fist or mostly clenched fist in reality [14].

As many as 82% of the 50 surveyed engine drivers from a random sample in 2012 were overweight or obese [15]; also as many as 80.39% of the 51 surveyed engine drivers from a different random sample in 2015 were overweight or obese [6], regarding the numerical value of *BMI* ($BMI \geq 25$). The studies carried out during 2011 in Slovenia [16] targeting 245 employees at the railways indicate 66.9% overweight or obese workers, with no significant differences between the two groups of workers regarding the nature of their work (white or blue-collar workers) [14].

Table 3.6 contains calculated and measured values of the seven static and kinematic anthropometric measures which were measured in 2015 [14].

Table 3.6 - Ranges and values of seven static and kinematic anthropometric measures for the entire randomly selected sample n=51

Static or kinematic anthropometric measure	Symbol / measuring unit	Remark	Amount
h – Measured **standing height** in balanced standing posture	$\bar{h}$ / cm	Calculated - Expression (10)	178.9
	Δh / cm	Range of measured for $n = 51$	167 – 188
	SD_h / cm	Calculated - Expression (11)	5.7
m – Measured **mass**	$\bar{m}$ / kg	Calculated - Expression (10)	92.0
	Δm/ kg	Range of measured for $n = 51$	58.9-124
	SD_m / kg	Calculated - Expression (11)	14.1
h_{ndr} – **Normal arm reach** or working distance, from rear side of elbow to the center of the clenched fist	$\bar{h}_{ndr}$ / cm	Calculated - Expression (10)	35.5
	Δh_{ndr} / cm	Range of measured for $n = 50$	31.0 - 39.0
	SD_{hndr}/ cm	Calculated - Expression (11)	2.0
h_{mdr} – **Maximal arm reach** or length of reach, from the rear side of the acromion to the center of a clenched fist	$\bar{h}_{mdr}$ / cm	Calculated - Expression (10)	64.7
	Δh_{mdr} / cm	Range of measured for $n =51$	57.0 - 73.0
	SD_{hmdr}/ cm	Calculated - Expression (11)	3.7
$h_{š}$ – **Hand length**, from wrist (the first crease) to the tip of the middle finger	$\bar{h}_{š}$ / cm	Calculated - Expression (10)	20.0
	$\Delta h_{š}$ / cm	Range of measured for $n =51$	18.0 - 23.0
	$SD_{hš}$ / cm	Calculated - Expression (11)	1.1
h_r - **Arm length**, from the tip of the acromion to the tip of the middle finger (in vertical position)	$\bar{h}_r$ / cm	Calculated - Expression (10)	77.6
	Δh_r / cm	Range of measured for $n = 51$	71.0 - 86.0
	SD_{hr} / cm	Calculated - Expression (11)	3.4
$h_{p+š}$ - **Length of forearm and hand** (from rear side of the elbow to the tip of the middle finger)	$\bar{h}_{p+š}$ / cm	Calculated - Expression (10)	48.2
	$\Delta h_{p+š}$ / cm	Range of measured for $n = 51$	43.0 - 52.0
	$SD_{hp+š}$ / cm	Calculated - Expression (11)	1.9

Source: [6]

According to Wilson and Norris from 2005 [17] and the guidelines of *Rail Safety and Standards Board* from Great Britain the actual priorities during scientific research that can be related to the safety and the group of factors “human factor” include, among others, the design of the driver cab and the environment.

The arithmetic means or the mean value *M* of individual static and kinematic anthropometric measures $\overline{h}_i$ from Table 3.6 have been calculated according to Expression (10) [14].

$$M = \overline{h}_l = \frac{h_1 + h_2 + .. h_n}{n} = \frac{1}{n} \cdot \sum_{i=1}^{n} h_i \tag{10}$$

Standard deviation SD_i of individual static and kinematic anthropometric measures h_i from Table 3.6 have been calculated according to Expression (11) [14].

$$SD_i = \sqrt[2]{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (h_i - \overline{h}_i)^2} = \sqrt[2]{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \Delta h^2} \tag{11}$$

Knowing the standing height *h* and body mass *m*, using the Donskij-Zacijorskij method [18] it is possible to calculate the amounts of single segmental masses m_i for hands, forearms, and upper arms in $n = 51$ respondents, using regression Equation (12) and with determined regression factors B_o, B_1 and B_2 [14].

$$m_i = B_0 + B_1 \cdot m + B_2 \cdot h \ [kg] \tag{12}$$

The positions of mass centres m_i are calculated according to Table 3.7, measured from the upper border of the body segments [14].

Table 3.7 - Mass centres in the percentage of the function of the body segment length

Body segment	Distance (%)
Head and neck	50.02
Upper torso	50.66
Middle torso	45.02
Lower torso	59.59
Hand	36.91
Thigh	45.49
Lower leg	40.49
Foot	44.14
Upper arm	44.98
Forearm	42.74

Source: [19]

Body segment gravities F_{gzi} have been calculated according to Expression (13), and the amounts of lumbar moments M_{ly} according to Expression (14) have been obtained by the reduction of all the gravities F_{gzi} from segmental masses m_i into the origin of the coordinate system xy in Figure 3.8 [14].

$$F_{gzi} = m_i \cdot 9.81 \tag{13}$$

$$M_{ly} = \sum_{i=1}^{n} F_{gzi} \cdot x_i \tag{14}$$

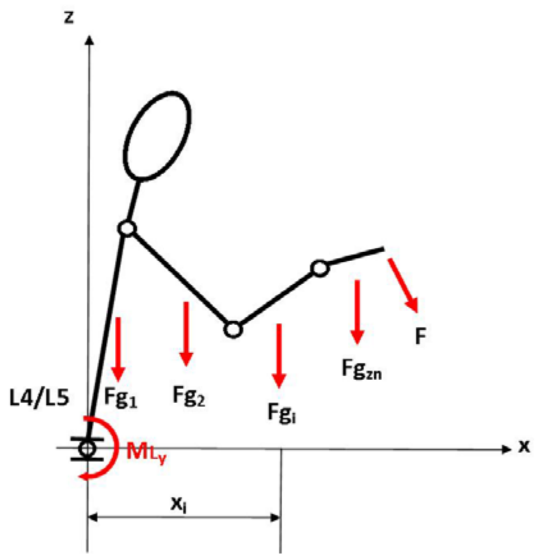

Figure 3.8 - Two-dimensional stick model of the respondent in sagittal plane

Source: [20]

In compliance with the considerations of Mairiaux et al. [21], or Muftić et al. [4], the origin of the coordinate system x y represents also the point of reduction L4/L5 of the lumbar moment M_{ly} to the level between the fourth (penultimate) and fifth (last) lumbar vertebra in the mobile part of the spine viewed from above downwards [14].

Figure 3.9 shows the least favourable hypothetical static equilibrium working position of stick biomechanical 2D model of an engine driver in sagittal plane [22], only with both arms beyond the equilibrium position and horizontally extended in the zone of maximal reach [14].

Lumbar moment M_{ly} according to regression function (15) has an acceptable correlation dependence $M_{ly}=M_{ly}(BMI)$ of medium strength with correlation coefficient $r = 0.719$, close to the border value of r for a high strength [14].

$$M_{ly} = 0.663 \cdot BMI + 6.0115 \quad (15)$$

Regression function (15) refers to the hypothetical static working position of an engine driver in sagittal plane according to Figure 3.9 [14].

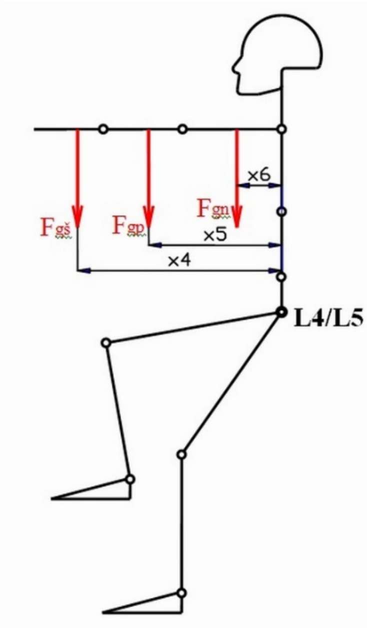

Figure 3.9 - Stick biomechanical 2D model of an engine driver in sagittal plane, in the least favourable hypothetical static equilibrium working position

Source: [22]

Regression function (15) is less linear, but much more realistic and based on the really measured static and kinematic anthropometric measures of engine drivers, since normal arm reach and maximum arm reach were measured to the centre of the clenched fist [14].

Results present how the physical load of engine drivers in the static sitting working position expressed through the amounts of lumbar moment $M_{ly}= M_{ly}(BMI)$ at the level of vertebra L4/L5 can be intensively affected by the design of the control panel (driver cab), regarding poor organization of frequently used commands, if they are placed within maximal arm reach [14].

In assessing the physical effort of engine drivers in the hypothetically least favourable static working position according to Figure 3.9, and in interaction with the increased body mass *m* in relation to the standing height *h*, it is recommended to use the regression function $M_{ly}=M_{ly}(BMI)$ according to Expression (15), which has been obtained based on the measured static and kinematic anthropometric measures of engine drivers from the random and sufficient sample, since normal arm reach and maximum arm reach were measured to the centre of the clenched fist, not to the tip of the middle finger such as in past research, because of the fact that most of the frequently and manually served commands at the control panel (switches, buttons and controllers) are being served with a clenched fist or mostly clenched fist in reality [14].

Obviously, the physical load of suburban train and tram drivers in a static sitting position can be affected by:

- Layout and availability of frequently used hand-operated commands (the same must be within normal arm reach).
- Value of the body weight regarding the standing body height of the respondent measured by BMI (subjects with a higher body mass with the same body height and the same static sitting position are loaded with a greater amount of lumbar moment M_{ly}).

4. THE IMPACT OF THE PRIORITY OF TRAMS ON THE SAFETY OF ROAD TRAFFIC IN ZAGREB

The City of Zagreb is the capital city of the Republic of Croatia with a population of more than 790,000 which also makes it the largest city in the country [23]. It is located south of the Medvednica Nature Park, divided into two parts by the Sava river; the north part is Zagreb and the south part is New Zagreb. The City of Zagreb is a well-developed economic city in the Republic of Croatia thanks to its good geographical position which makes it a very important transport hub that connects Central Europe, the Mediterranean and Southeast Europe [24].

Zagreb City road network is the most developed in relation to the network of other transport branches. It consists of roads, streets, and city avenues as well as highways that tangent the peripheral parts of the City. Due to the increasingly intensive development of road transport and traffic, motorisation rate is approximately 450 vehicles per 1,000 inhabitants [23]. Passengers are used to the comfort and reliability provided by the private cars which is why the occurrence of traffic congestion in the city is frequent, especially in the morning and the afternoon peak periods because of migration of people to/from work [25]. It is therefore, very important to encourage passengers to use other forms of transport such as public transport.

Public transport in Zagreb is organised predominantly by tram and bus lines. There are a total of 19 tram lines and 149 bus lines in the City of Zagreb. In 2017 a total of 287,712 passengers were transported in public transport, from which 197,078 passengers were transported by tram and 90,634 were transported by bus [23]. This indicates that the dominant type of vehicle in Zagreb public transport is the tram. Possible reason why this is the case is good coverage of public transport network shown in Figure 4.1.

Chapter 2 explained the negative impact of public transport vehicles (such as trams and buses) on the safety of all other road traffic participants. In a situation when a traffic accident occurs, the number of seriously injured and injured passengers and drivers is higher in other road traffic vehicles than in public transport vehicles. In this Chapter it will be explained that some specific improvements in public transport can lead to increased safety of road traffic participants to a certain extent.

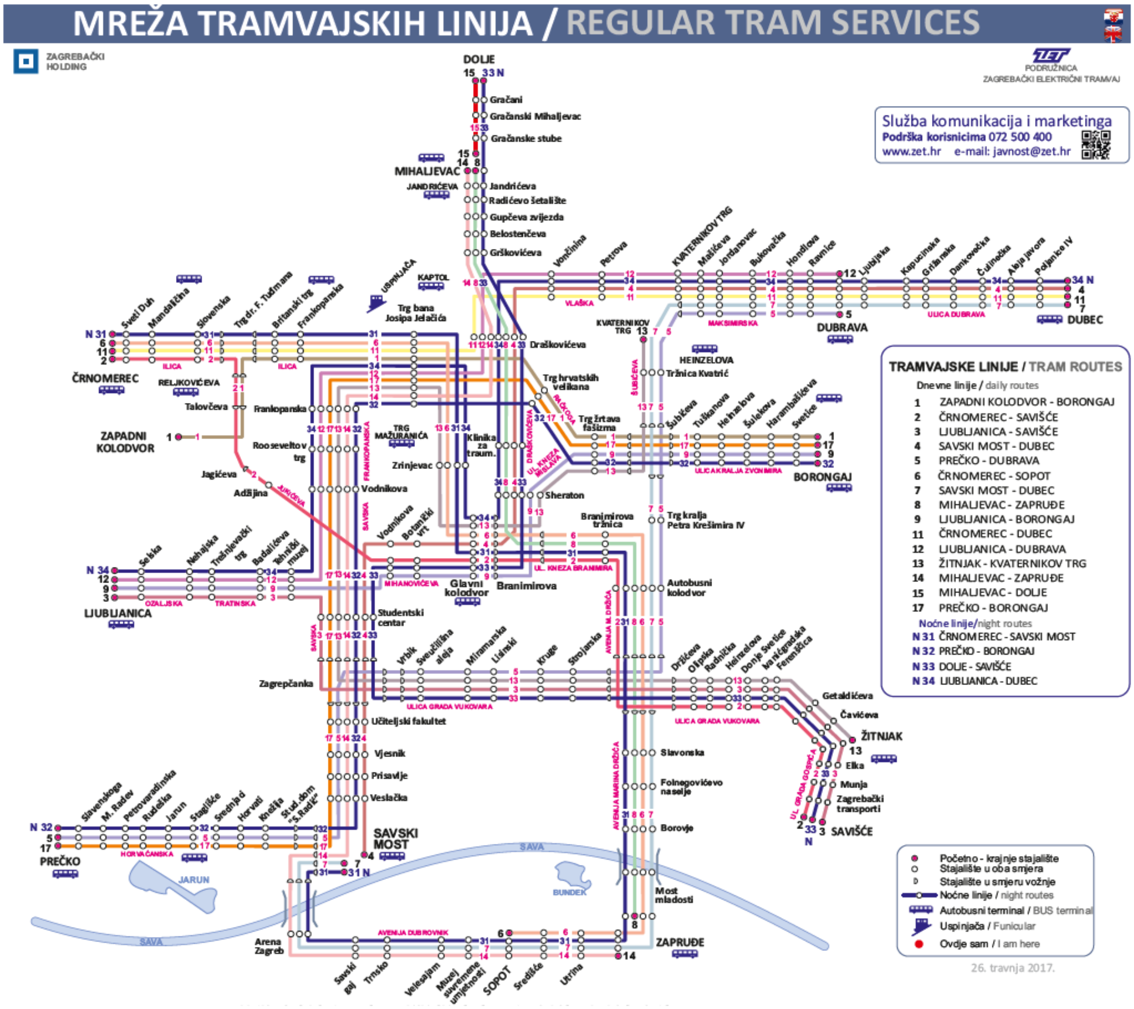

Figure 4.1 - Zagreb tram network

Source: [26]

A weak point of public transport is constant interference of tram vehicles with other types of vehicles, which is especially problematic in the morning and the afternoon peak periods when the occurrence of traffic congestion is frequent. Trams are held up by private cars that want to park/exit from a parking lot located next to the lane dedicated for public transport vehicles, turning vehicles and vehicles that illegally use their lane, jeopardizing road safety [27]. All the mentioned leads to possible tram delays and overloads in peak periods which consequently causes a reduction in the cycle speed of trams and thus the attractiveness of public transport becomes remarkably lower. The cycle speed on the tramway network in 2009 in the City of Zagreb was 13 km/h [28].

One of the many possible solutions to ensure the increasing of the cycle speeds V_c *(km/h)* and operating speeds V_o *(km/h)* of trams in Zagreb, as well as increase in the vehicle capacity

C_v *(sps/veh)* of a single line with the same number of trams and drivers in one shift can be achieved by the possible implementation of tram priority via traffic lights based on the local automation.

The basic principles of tram priority signalling systems are [31, 32]:

- Passive traffic signal priority: Predetermined signal plans are used, and traffic lights are set to turn green based on an average tram speed. Local automation at crossings with traffic lights is not necessary.
- Active traffic signal priority: Gives priority to the approaching tram that has already sent a signal to the traffic signal controller.
- Unconditional traffic signal priority: Once the safety traffic parameters are met, the priority is immediately assigned to the tram that has submitted the priority request.

There are four types of active traffic signal priority systems [29]:

- dedicated priority – phasing changes
- longer green time
- phase and timing adjustment
- intelligent transport system approach.

All the three above-mentioned principles have their own advantages and disadvantages. Passive traffic signal priority is the simplest since the cycle/phase duration is defined according to the average vehicle speed. Active traffic signal priority is more effective than the passive traffic signal priority because it is based on a kinematic response. Unconditional traffic signal priority is rarely used to optimize the movement of public transport vehicles because it is more applicable for emergency service vehicles. The main problem of all traffic signal priority systems is additional waiting for other traffic participants. The big question arises to whom priority should be given in a situation when at least two public transport vehicles approach the traffic light intersection at the same time [31, 32].

It should be noted that the tram driving path can be usually set [30]:

- Manually by setting the points outside of vehicle (with a hand tool).
- Manually by setting the points by serving the electrically operated switches from the tram cab.
- By local automation, which is a compromise between price of investment and quality of solution.

- By remote control from one point (centre), which is the most expensive solution.

Research conducted on tram lines No. 12 [30] and No. 17 [31] in Zagreb have proven possible realistic saving of the operating (travel) time ΔTo and of the saving the cycle time ΔT, according to the assumption that all tram lights should be green due to tram priority via traffic lights.

The measurements were conducted using the stopwatch – pencil – record list method in the early shift during the morning peak load as well as in the middle shift during the afternoon peak load for all the seven days of the week, and for the new tram NT 2200. The measured time savings ΔT of cycle time on lines No. 12 and No. 17 in one cycle are based on the measurement of possible time savings ΔT_o of the operating (travel) time, which is the sum of the duration of all red signals at the traffic lights while driving, as well as the 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 [33, 34].

Operating (travel) time T_o is one of the key parameters that determine the quality of the service offered to tram users [29]. Cycle time T *(min)* is defined by Equation (16) where ΣT_o *(min)* is the total operating (travel) time on the line and Σt_t *(min)* is the total time at terminals, calculated for both directions [33, 34]:

$$T = \Sigma T_o + \Sigma t_t \qquad (16)$$

Cycle time T *(min)* is defined by the basic Equation of the transport process (17) on the public transport line which connects the headway of vehicles h *(min/veh)* and the number of vehicles N on the tram line [33, 34].

$$T = h \cdot N \qquad (17)$$

Moreover, from Equation (17) follows that if the same number of vehicles N are retained, and cycle time T decreases, headway h *(min/veh)* must also be reduced [33, 34].

Cycle time T can be reduced if the operating (travel) time To is reduced, in the way that all traffic lights are set to the green light just before the tram arrives (the tram priority), assuming the real total time at terminals t_t [33, 34].

Operating (travel) speed V_o *(km/h)* on the same line length $2L$ *(km)* will increase if the operating (travel) time T_o is reduced, which is defined by Equation (18) [33, 34].

$$V_o = \frac{2L}{T_o} \qquad (18)$$

Consequently, the cycle speed V_c *(km/h)* on the same line length *2L (km)* will increase if the cycle time *T* is reduced, which is defined by Equation (19) [33, 34].

$$V_c = \frac{2L}{T} \quad (19)$$

It will also result in an increase in the transport work of line *w (sps·km/h)* defined by Equation (20)

$$w = C \cdot L \quad (20)$$

because it has increased the kinematic line capacity *C (sps/h)* defined by Equation (21) [33, 34].

$$C = C_v \cdot f \quad (21)$$

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 *N* on lines No. 12 and No. 17 the frequency of vehicles on line *f (veh/h)* is higher because headway *h* (*min/veh)* is smaller [33, 34].

The results from both studies shown in Table 4.1 and Table 4.2 are different in relation to each other. The average amount of the increased cycle speed V_{ci} = *13.62 km/h* on tram line No. 12 contains a speed increase of *10.24%,* while cycle speed V_{ci} = *15.42 km/h* on tram line No. 17 contains a speed increase of *14.96%*. The average amount of the increased operating speed V_{oi} = *16.20 km/h* on tram line No.12 contains a speed increase of *11.76%*, while operating speed V_{oi} = *18.09 km/h* on tram line No. 17 contains a speed increase of *16.77%*. Possible increase of the average amounts of cycle speeds as well as possible increase of the average amounts of operating speeds on both tram lines are the total amounts for both directions in one cycle [33, 34].

Table 4.1 - Comparison of possible increase of the cycle speeds ΔVc and operating speeds delta Vo on lines no. 17 and no. 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

Source: [33, 34]

Table 4.2 - Comparison of possible savings of cycle times ΔT and operating times

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

Source: [33, 34]

Smaller average amounts of the time savings on line No. 12 and line No. 17 as well as smaller average amounts of the speed increase are different in relation to each other because of 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 and position of stations as well as different number of intersections along the route of the line [33, 34].

The results of similar research in which priority was given to trams and the restriction for other vehicles entering the "yellow line" was included, confirm the increase of cycle speed as well as the increase in kinematic capacity [32].

Traffic signal priority for trams in the City of Zagreb was also researched in 2017 [33] where two hypothetical priority scenarios were set. First, with minimum travel time (7% operating speed increase, 22 mil. EUR investment savings) and second for absolute priority (41% operating speed increase, 94 mil. EUR investment savings). Significant space for improvement, even in the more realistic travel time scenario has been suggested by the results.

The cited results of the previously conducted research for tram line No. 12 [30] compared with the results for tram line No.17 [31] have proven the possibility of significant simultaneous cycle time 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.

Generally considering, the application of the tram priority in urban environment by using the local automatic setting the points and signals for trams on the traffic light intersections can provide economic, traffic safety as well as ergonomic benefits and improvements to some extent. Applying the studied 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 tram driver's performance and thus the safety of all other traffic participants in the urban environment, with the emphasis on the vulnerable groups of traffic participants. Also, trams would become more accessible means of transport and passengers would use it more effectively because of the increase in the operating speeds.

5. SAFETY ASSESSMENT BY IRAP METHODOLOGY OF CHARACTERISTIC LOCATIONS OF ROAD TRAFFIC ACCIDENTS IN ZAGREB

Today’s fast paced way of life affects all aspects of our everyday life, including driving. According to the World Health Organization (WHO) approximately 1.35 million people die each year as a result of road traffic accidents [34]. Large proportion of these crashes are due to drowsiness and fatigue because more and more people world-wide sit behind the wheel after insufficient and poor-quality sleep due to lifestyle factors. Many researchers estimate that the share of traffic accidents related to fatigue or sleepiness of drivers is up to 20% [38, 39, 40].

The most common causes of traffic accidents except fatigue are [34]:

- speeding
- driving under the influence of alcohol and other psychoactive substances
- distracted driving
- reckless driving
- factors from the traffic environment (unsafe road infrastructure)
- factors from the vehicle (unsafe vehicle)
- others.

According to statistics about traffic accidents in the Republic of Croatia for the year 2018. a total of 33,402 traffic accidents occurred, with speed unsuited for environmental conditions on the road as the most common cause of traffic accidents [35].

Driving while tired can lead to traffic accidents with serious injuries and fatalities because fatigue leads to impairment of driving performance manifesting itself in diminished steering performance, slower reaction time, reduced ability to keep enough headway and increased tendency to mentally withdraw from the driving task [42, 43]. Fatigue also has an effect on driver’s motivation to perform the task. Interaction and communication with the surrounding environment deteriorates and the person gets irritated more quickly and reacts more aggressively toward other people and things [36]. Drivers may try to compensate for the performance-decreasing effect by increasing the task demands mentioned in Chapter 3 (e.g. driving faster, reducing headway, etc.) in order to increase the alertness or by decreasing task demands (e.g. slowing down, increasing headway, etc.) [37].

Five major factors that cause fatigue in general and driver fatigue are [36]:

- lack of sleep
- bad quality sleep
- internal body clock (circadian rhythm)
- time-on-task (time spent driving)
- monotonous tasks
- individual personal characteristics (age, psychophysical driver readiness) and medical condition.

Sleep-related fatigue refers to the circadian rhythms of the human body that regulate the state of sleepiness and alertness. Human body has the strongest need for sleep between 10 PM-12 PM, while the ability to stay awake reaches its peak between 7 PM-9 PM and the lowest between 4 AM-5 AM which is shown in Figure 5.1 [38]. Driving between 2 AM and 5 AM increases the risk of traffic accidents by 5 to 6 times [39]. Circadian rhythms also lead to wakefulness in the early afternoon, and accordingly, most of the incidents occur between 12 AM-6 AM and 2 PM-4 PM [40]. Furthermore, according to Garbarino et al., young adults are involved in two-thirds of all sleepiness-related crashes, especially those occurring late at night or early in the morning [41].

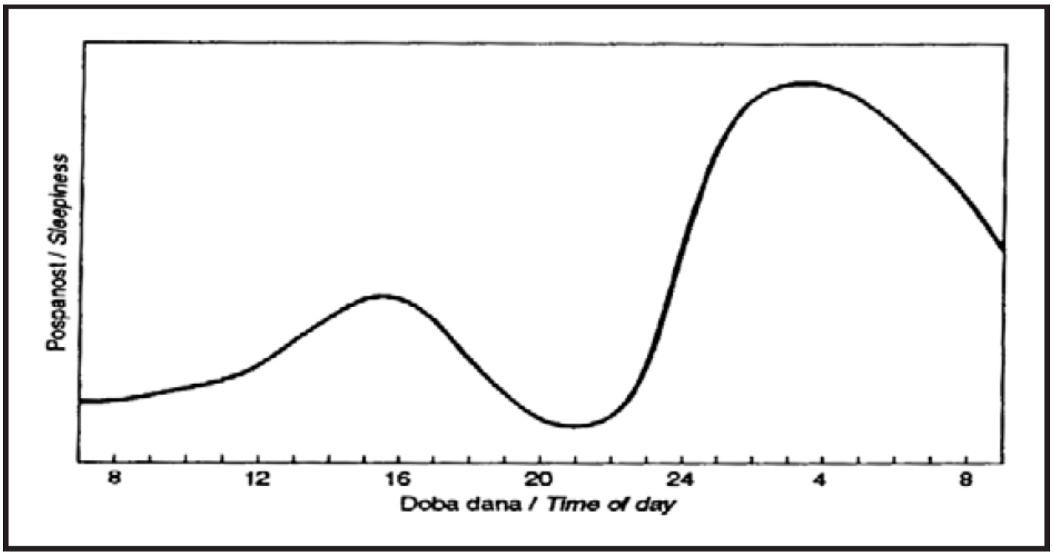

Figure 5.1 - Variations of sleepiness throughout the day

Source: [42]

In most cases it is difficult to determine if fatigue was the cause of traffic accident due to the complexity and variety of its characteristics [43]. After traffic accident has happened, often the drivers do not want to admit that they had fallen asleep while driving and that they are guilty of causing a traffic accident. Also, unlike the situation with alcohol-related traffic accidents where the drivers are tested for alcohol impairment at the scene of the road traffic accident using a special device that analyses the alcohol level in the driver's breath, there is currently no available measurable test to quantify the levels of sleepiness at a crash site.

However, in the United Kingdom (UK) and similarly in the USA fatigue-related crashes have been identified using the following criteria [40, 52, 53]:

- The vehicle has run off the road (UK).
- There are no skid marks or braking traces (UK).
- The driver could see the point of run-off or the object hit prior to the crash (UK).
- Witnesses may report lane drifting prior to the crash (UK).
- Traffic accident occurs during late night/early morning or mid-afternoon (USA).
- The crash is likely to be serious (USA).
- A single vehicle leaves the roadway (USA).
- The crash occurs on a high-speed road (USA)
- The driver does not attempt to avoid a crash (USA).
- The driver is alone in the vehicle (USA).

As previously mentioned, after the traffic accident expertise, it is very difficult to reliably select the traffic accidents that are caused by fatigue of road vehicle drivers. The research topic in this chapter is a methodology that significantly helps in selecting these specific locations of traffic accidents. This methodology is called International Road Assessment Program (iRAP). The iRAP methodology can quickly and objectively detect the static safety of the road infrastructure elements. This graduate work will present on an example of three traffic accidents that occurred in the City of Zagreb selected by statistical analysis by characteristic filters (criteria) how by using the iRAP methodology the factors of road infrastructure from the group of "traffic environment" factors can be completely excluded as the cause of traffic accidents. The more accurate selection of road traffic accident that are caused by driver fatigue will help researchers from other scientific areas to select and explore the characteristic factors of fatigue-related traffic accidents, in order to suggest measures to reduce the fatigue effect on the driver's performance.

IRAP is an international road assessment program for the promotion of safer road infrastructure with a view of rescuing life and preventing serious injuries to road traffic participants. So far, over 1.3 mil. km of road network in the world has been risk mapped by partners using iRAP methodology. The purpose of risk maps is to give an objective view of where people are being killed or seriously injured on a road network and where their crash risk is the greatest. The iRAP methods are used and adopted by national governments, state and local authorities, mobility clubs and private sectors. The United Nations (UN), WHO, the FIA Foundation and other leading institutions recommend using the iRAP methodology. The iRAP methodology for saving lives has been developed by the world's leading road safety researchers and organisations. Collaboration with partners in the development of new products that meet the growing need for increased traffic safety allows for a reduction in traffic accidents with fatalities and seriously injured road traffic participants. The tendency is to achieve Vision Zero (a multinational road safety project aimed at achieving a system without deadly or severely injured traffic participants). The iRAP's free online software for risk mapping called ViDA, located at http://vida.irap.org is available in multiple international languages [44].

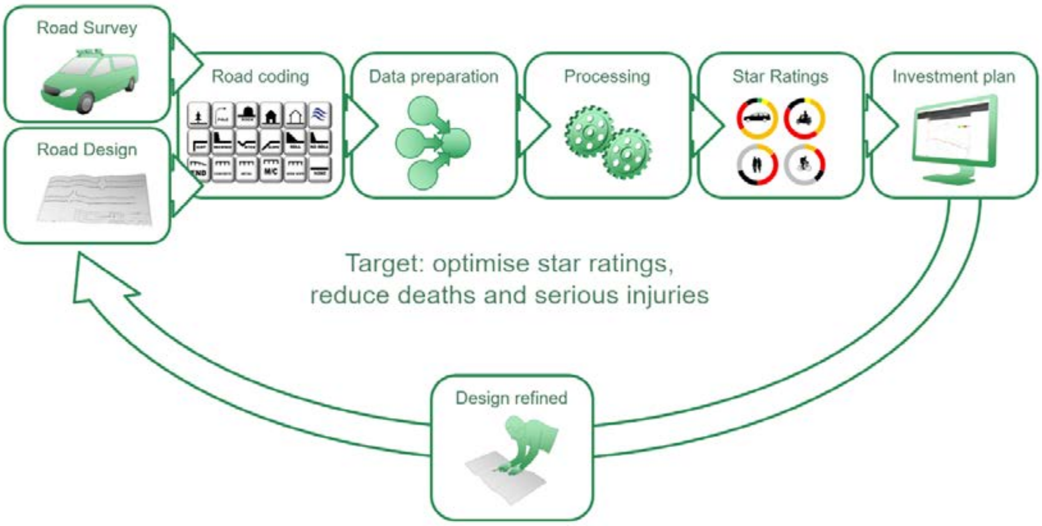

Figure 5.2 - iRAP Star Rating process

Source: [44]

Figure 5.2 represents all different steps for the star rating process necessary for road safety assessment. Road coding consists of the key road infrastructure features that are assessed during a typical road inspection. Visual representation of some of the key road infrastructure features that are assessed during road inspection are shown in Figure 5.3. Road risk is measured for every 10 metres of road and calculated for every 100-metre segment. Over 50 attributes are determined for each segment of the road in online software ViDA.

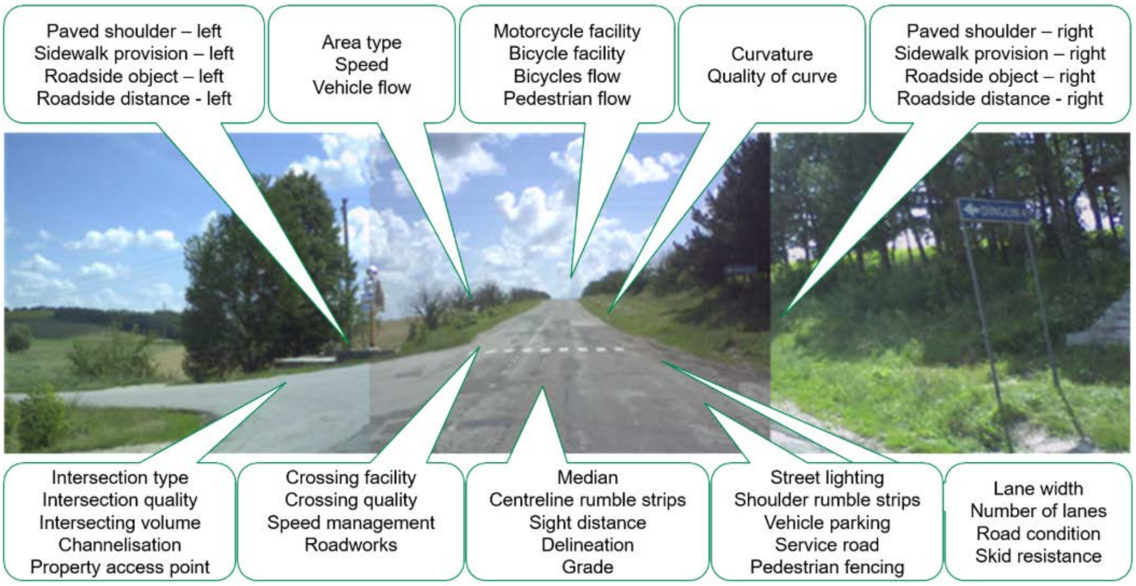

Figure 5.3 - Key road infrastructure features (attributes)

Source: [44]

When it comes to road safety assessment the focus is on identifying and recording the road attributes which influence the most common and severe types of crashes, based on scientific evidence-based research. The Star rating score (SRS) represents the measure of risk which is "built-in" the road for individual road users. One-star road is the least safe and five-star road is the safest, but also the most expensive. Figure 5.4 shows that over 50% of road network across 54 countries has a one- or two-star rating by road user type. Three-star or better roads for all road traffic users is a key for saving lives and preventing serious injuries. The ultimate goal for the future is the building of safe roads with safe speeds on which safe vehicles travel and transport safe people [44].

The main groups of attributes of road infrastructure elements on which the safety assessment is based are [44]:

- roadside
- mid-block
- intersections
- flow
- VRU facilities and land use
- speeds.

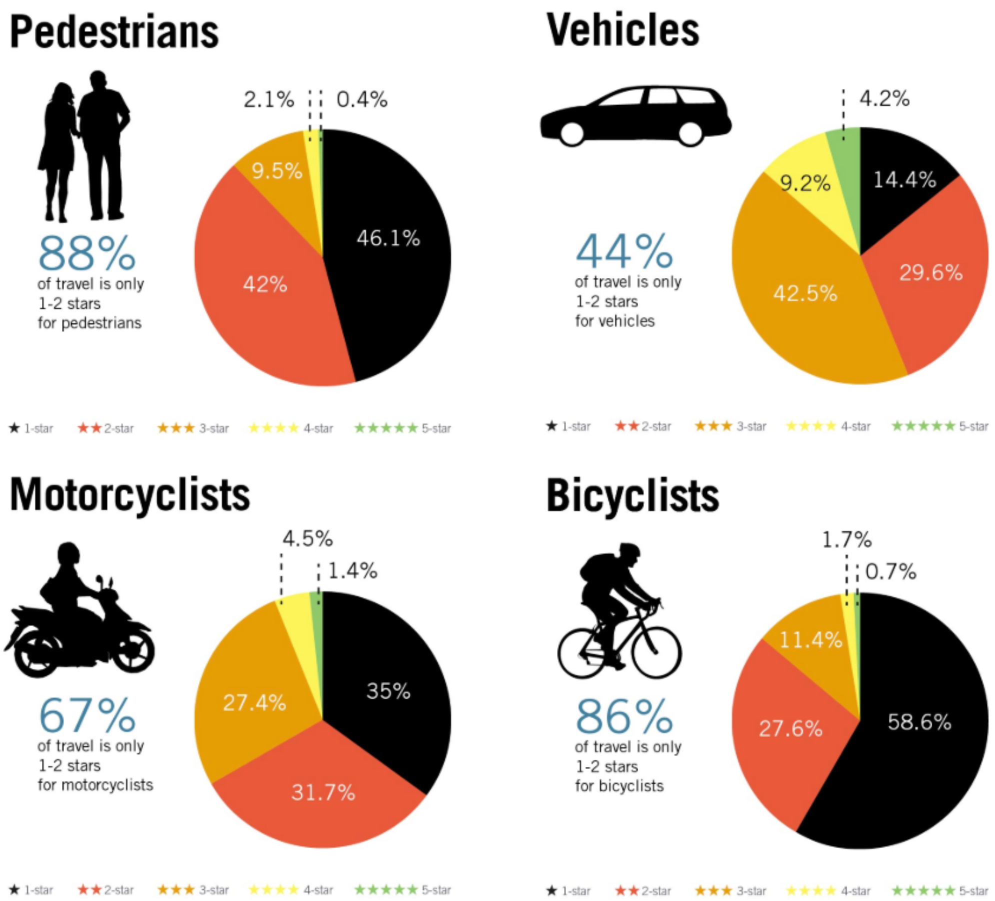

Figure 5.4 - Star ratings by road user type based on a 358,000 km sample of roads across 54 countries

Source: [44]

Figures 5.5, 5.6 and 5.7 show the location of traffic accidents in which only one road traffic vehicle was involved (private car). They are considered to be the cause of driver's fatigue because they were identified and selected using previously mentioned criteria from the UK and the USA; they occurred early in the morning or late at night and road safety assessment by iRAP methodology was made so that the uncertainty of road infrastructure as a cause of road traffic accident could be excluded. All traffic accidents occurred in the City of Zagreb. It is worth mentioning that during the selection of traffic accidents it was considered that the drivers were not under the influence of alcohol, psychoactive substances, medicaments and that they were not using smartphone or radio (influence of distraction). The information about road traffic accidents were given by the Ministry of the Interior of the Republic of Croatia (MUP RH) and are shown in Tables 5.2, 5.4 and 5.6. It is worth mentioning that police reports of road accidents are the main source of data used for this research and that there is concern about the accuracy and reliability of the provided data. The results from road safety assessment of the road infrastructure elements by iRAP methodology are presented in Tables 5.1, 5.3 and 5.5.

Figure 5.5 - The location of traffic accident No. 1 with GPS coordinates 45°49.741, 15°55.338

Source: [45]

Table 5.1 - Star rating score for traffic accident No. 1

Star Ratings for the existing road:				
Road user	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists
Star Rating Score (SRS)	7,59	8,8	NA	NA
Star Rating	3	3	NA	NA

Table 5.2 - Information about traffic accident No. 1

Road	255 Kustošijanska street	**Traffic accident No.**	32546
Date	24 November 2017	**GPS coordinates**	45°49.741, 15°55.338
Day of the week	Friday	**Time**	9:00 PM
Injuries	Death	**Type of traffic accident**	Vehicle hit in the roadside object
Circumstances	Other driver's mistakes	**Number of vehicles participated**	1
Road characteristics	Straight road	**Road surface**	Dry-clean
Speed limit (km/h)	50	**Visibility**	Night
Male drivers	1	**Female drivers**	0

Figure 5.6 - The location of traffic accident No. 2 with GPS coordinates 45°47.653, 15°56.786

Source: [45]

Table 5.3 - Star rating score for traffic accident No. 2

Star Ratings for the existing road:				
Road user	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists
Star Rating Score (SRS)	6,1	10,18	NA	NA
Star Rating	3	3	NA	NA

Table 5.4 - Information about traffic accident No. 2

Road	Zagrebačka avenue	**Traffic accident No.**	22735
Date	31 August 2016	**GPS coordinates**	45°47.653, 15°56.786
Day of the week	Wednesday	**Time**	1:20 AM
Injuries	Death	**Type of traffic accident**	Vehicle left the roadway
Circumstances	Speed unsuited for environmental conditions on the road	**Number of vehicles participated**	1
Road characteristics	Straight road	**Road surface**	Dry-clean
Speed limit (km/h)	60	**Visibility**	Night
Male drivers	1	**Female drivers**	0

Figure 5.7 - The location of traffic accident No. 3 with GPS coordinates 45°49.034, 16°02.358

Source: [45]

Table 5.5 - Star rating score for traffic accident No. 3

Star Ratings for the existing road:				
Road user	Vehicle occupants	Motorcyclists	Pedestrians	Bicyclists
Star Rating Score (SRS)	11,31	15,99	NA	NA
Star Rating	3	2	NA	NA

Table 5.6 - Information about traffic accident No. 3

Road	Branimirova street	**Traffic accident No.**	4583
Date	24 February 2013	**GPS coordinates**	45°49.034, 16°02.358
Day of the week	Sunday	**Time**	5:40 AM
Injuries	Death	**Type of traffic accident**	Vehicle left the roadway
Circumstances	Speed unsuited for environmental conditions on the road	**Number of vehicles participated**	1
Road characteristics	Straight road	**Road surface**	Dry-clean
Speed limit (km/h)	60	**Visibility**	Night
Male drivers	0	**Female drivers**	1

All three traffic accidents occurred late at night or early in the morning where vehicle left the roadway, while in one road traffic accident the vehicle hit the roadside object. One person (the driver) in each traffic accident was involved and died at the scene of the road traffic accident or immediately afterwards. Two drivers were male while one was a female driver.

The results from safety assessment by iRAP methodology of three characteristic locations of road traffic accidents show that all of them are rated with highly ranked rating of 3-star for static safety of the road infrastructure elements. Road infrastructure of the three examined scenes was not the dominant cause of the road traffic accidents, due to high ratings by iRAP methodology. The factors of traffic infrastructure in the group of “traffic environment” factors can be completely excluded as a cause of the investigated traffic accidents. It is important to note that all three selected locations of road traffic accidents share the possible cause of the adverse effect of circadian rhythms since they occurred late at night or early in the morning. Therefore, assuming technical correctness of the vehicles involved in the investigated traffic accidents the main cause should be found among the group “human factor” (road user), which is highly likely to be driver fatigue.

Using the iRAP methodology to evaluate the static safety of the road infrastructure, it is possible to:

- Assess the static safety of road infrastructure and probability of occurrence of traffic accidents (caused by traffic environment factors).
- To propose countermeasures to increase the static safety of road infrastructure and improve star ratings.
- Make it easier to locate traffic accidents that are probably caused by the fatigue of road vehicle drivers.

6. DISCUSSION

Ergonomic assessment of all relevant factors from the working and/or traffic environment is part of a complex ergonomic approach to the human (driver) – traffic environment – vehicle system analyses. The weakest link of the mentioned system is the human being (driver) due to their imperfection and flaws. In order to increase traffic safety, the human being must be in the centre and the basic principle for adapting complete working and traffic environment. In this chapter the guidelines and examples of concrete solutions for adapting the working and traffic environment to the road vehicle drivers in urban environment are proposed.

In order to adapt the working and traffic environment to the road vehicle drivers, we need to consider not only the environment in which they are located but also the environment in which other participants of the road traffic system are located (i.e. trams due to proven negative impact on the safety of other road vehicles as well as other traffic participants) which can directly or indirectly affect one another and thus the overall traffic safety.

In this graduate work, based on the findings from recent scientific and professional literature, it has been demonstrated that the process of designing the control panel in the trams and trains can be simplified by knowing only a few measured anthropometric measures. The most important anthropometric measures for control panel design in the tram cabin are kinematic anthropometric measures maximum arm reach h_{mdr} and normal arm reach h_{ndr} together with static anthropometric measure bi-acromial range (shoulder width) $h_{šr}$. It has been proved that the body ratios h_{mdr}/h and h_{ndr}/h can be used for simplified calculation of values of anthropometric measures h_{mdr} and h_{ndr} only by knowing the value of the body height h, during the control panel design in tram cab or train cab, because real mean arithmetic values of body ratios $h_{mdr}/h = 0.36$ and $h_{ndr}/h = 0.20$ do not depend on gender, age and occupation. For this reason, a simple measure such as adjusting the control panel design in public transport vehicles is proposed, which includes the layout and availability of frequently used commands served by hands which should be positioned within the normal arm reach h_{ndr} in the field of view without turning the head.

The possibility of quick and simplified calculation of normal arm reach h_{ndr} is very important, because frequently used commands on the locomotive, railcar or tram control panel need to be arranged mainly within the normal arm reach h_{ndr}, using multi-purpose controllers for serving several important and frequently used functions by one hand, whenever possible.

Knowing the scientific fact that the lumbar moment M_{ly} predominantly linearly depends on the body mass index *BMI* (in consequences when frequently used commands are placed within maximal arm reach h_{mdr}), the above-mentioned measure would allow ergonomic adjustment to the human in order to reduce the negative impact of the higher amounts of the driver's *BMI* index and poor adjustment of frequently used commands served by hands which can directly affect the physical load of tram and engine drivers.

The same benefit can be achieved by implementing the tram priority, which, apart from the reduction of the tram driver's workload, could increase the tram driver's performance level by reducing the number of manually served commands on the control panel. Also, reducing the impact of disturbance factors and factors of unfavourable circumstances from the traffic and/or working environment on the public transport vehicle driver, in addition to all the above proposed, the safety of all other traffic participants in urban environment would increase to some extent with the emphasis on the vulnerable groups of traffic participants.

Apart from the safety benefit, it has been also proven how by implementing tram priority via traffic lights based on local automation may increase the cycle and operating speed as well as vehicle capacity while increasing the safety of road traffic participants and reliability of public transport. Also, trams would become a more accessible means of transport and passengers would use it more effectively.

Due to rapidly increasing share of traffic accidents related to fatigue or sleepiness of drivers in the total number of road traffic accidents, along with inability to measure fatigue level at a crash site indicates the importance of identifying and selecting these specific types of road crashes while simultaneously removing the factors of road infrastructure from the group of "traffic environment" factors as a cause of traffic accident.

By using iRAP methodology:

- It can quickly and objectively detect static safety of the road infrastructure elements and remove them as a possible cause of road traffic accident.
- To propose measures to increase the static safety of road infrastructure.
- Significantly helps in selecting locations of traffic accidents which are caused by driver' fatigue.

Accumulated active, as well as passive fatigue most commonly in monotone scenarios during the night-time, may result in reducing the temporary psychophysical driver's readiness, so that the driver does not approach the performance with maximum capacity which they theoretically have.

Driver fatigue countermeasures may be directed at drivers, transport companies, roads or vehicles. Increasing the driver's awareness of the risk of being involved in a fatigue-related crash may be increased by educating them from the very beginning in primary schools as well as in kindergartens. Transport companies could regulate night shifts by introducing longer and frequent breaks which has proven to have influence on the driver's performance. Road infrastructure measures to reduce fatigue-related crashes include upgrading roads or building new ones in order to ensure 3, 4 or 5-star standards by implementing measures such as road safety barriers to prevent drivers from driving off the road, improving delineation (signs, lines, and lighting) or by managing (reducing) speed limits. Road vehicles should be equipped with different modern technologies that will assist the driver or completely replace the driver (depending on the levels of driving automation from "no automation" to "full automation"). During the moments when the driver cannot intervene at a satisfactory level of performance with respect to the required level of safety (because of the current low level of their psycho-physical readiness, they do not use the capability they theoretically have) or in a traffic situation when the driver's capability is lower than the task demand (C<D), then the task is too difficult for the driver, vehicle could issue a warning sign or make decisions and perform actions independently.

7. CONCLUSION

In this graduate work the basic hypothesis has been proven as follows: it is necessary to identify and continuously monitor different and simultaneous relevant factors from the working and/or traffic environment that may affect the driver’s performance as well as the safety of the city transport in urban areas.

To this end, several different measures have been proposed in order to improve road safety and driver’s performance using the methodology, knowledge and guidance from the recently available scientific and professional literature, the benefits of which have been analysed and described in detail in this graduate work. All the proposed measures have respected the recent ergonomic principles of adapting the working environment to the users. The optimal ergonomic working principles are satisfactory if they are at such a level of quality that the drivers do not have the need to subjectively think or feel as effort, but exclusively deal with their operational tasks that are complex, stressful and require high psycho-physical readiness.

In this graduate work has been proven how public transport vehicles such as trams, buses and trains, due to their large masses, large vehicle lengths and longer stopping distance as well as longer braking distance, can have a negative impact on other road traffic participants, because the number of seriously injured and injured passengers and drivers is higher in other road traffic vehicles than in public transport vehicles.

In this graduate work has been also proven how by using iRAP methodology the locations of traffic accidents that are probably caused by the driver's fatigue can be selected.

For the final study conclusion, the results of a larger scale research should not be limited only to factors from the working and traffic environment mentioned in this graduate work. In the future works and papers, great attention will be paid to driver’s fatigue and distraction factors inside and outside of driver’s cab, because they are among the major risk factors associated with road traffic accidents in the urban areas.

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List of Symbols and Measuring Units

Symbol	Definition (measure unit)
BMI	Body Mass Index (kg/m^2)
C_v	Vehicle capacity (sps/veh)
f	Frequency of vehicles on tram line (veh/h)
F_{gzi}	Body segment gravities (N)
h	Standing body height (cm)
h	Headway (min/veh)
h_1	Foot length (cm)
h_{10}	Length of forearm and hand (cm)
h_{11}	Height of foot (cm)
h_2	Length of lower leg (cm)
h_3	Length of upper leg (cm)
h_B	Distance from the navel to the floor (cm)
h_C	Height above the navel (cm)
h_g	Head height (cm)
h_k	Length of the mobile part of the spine in the standing position (cm)
h_{mdr}	Maximum arm reach (cm)
h_n	Leg length (cm)
h_{ndl}	Length of upper arm (cm)
h_{ndr}	Normal arm reach (cm)
$h_{p+š}$	Length of forearm and hand (cm
h_{pdl}	Length of forearm (cm)
h_{pdl}	Length of forearm (cm)
h_r	Length of forearm and hand(cm)
$h_š$	Hand length (cm)
$h_{šr}$	Bi-acromial range/shoulder width (cm)
L	Line length (km)
m	Mass (kg)
M_{ly}	Lumbar moment (Nm)
n	Sample size ( )
N	Number of vehicles on tram line ( )
R	Radius (cm)
T	Cycle time (min)
T_o	Operating (travel) time (min)
t_t	Time at terminals (min)
V_c	Cycle speed (km/h)
V_o	Operating (travel) speed (km/h)

List of Abbreviations

BMI	**Body Mass Index**	Indeks tjelesne mase
C	**Capability**	Sposobnost
D	**Task demand**	Težina zadaće
EU	**European Union**	Europska unija
GB	**Great Britain**	Velika Britanija
IRAP	**International Road Assessment Program**	Međunarodni program procjene sigurnosti cestovne infrastrukture
ITM	Body Mass Index	**Indeks tjelesne mase**
max	**Maximum**	Maksimum
min	**Minimum**	Minimum
MUP RH	**Ministry of the Interior of Republic of Croatia**	Ministarstvo unutarnjih poslova Republike Hrvatske
TCI	**Task-capability interface**	Sučelje sposobnosti zadatka
UK	**United Kingdom**	Ujedinjeno Kraljevstvo
UN	**United Nations**	Ujedinjeni narodi
USA	**The United States of America**	Sjedinjene Američke Države
WHO	**World Health Organisation**	Svjetska zdravstvena organizacija
ZET	**Zagreb electric tram**	Zagrebački električni tramvaj
TPR	**Temporary psychophysical readiness**	Privremena psihofizička spremnost

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