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- Provide international dissemination of knowledge and contributions to the science and practice in the field of traffic and transportation
- Promote and exchange information and knowledge in the transportation research arena and its application
- Explore the new trends in development and invention related to the efficiency, reliability, safety and economically and ecologically sustainable transportation.

TTTP provides conditions and positive environment for the new idea promotion, exchange research results and achievements accomplished by the scientific community from academia and transportation industry.

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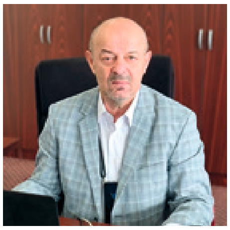

FROM THE EDITOR

Dear readers,

It is my pleasure to present to you the 13th printed and electronic issue of the magazine " Traffic and transport theory and practice – TTTP ", with its 11 authorised articles in the area of traffic and transport engineering.

Papers in this issue are focused on the topics of traffic safety within urban safety, smart cities and sustainable urban mobility, as well as contemporary information and communication technologies in the area of traffic and transport process regulation. There is a special attention on articles that emphasize the importance of stationary traffic from the aspect of analysis and management of urban movement as a whole. Protection and safety of vulnerable participants in traffic still dominates, and as such is important in the part of implementation of the present decade of road traffic safety for 2021-2030 where urban safety dominates as a strategic goal. At the same time, we also publish an article determining safety aspects and performance of electric vehicles and the influence of new vehicles and alternative fuels at the quality of live in urban areas. We are happy that in this issue there is also a contribution from the Prime Minister of the Republic of Srpska Government, a professor at University of East Sarajevo, with two papers reflecting on the European recommendations for sustainable urban mobility.

The magazine has ensured an open access to previous issues on its own website (www.tttp-au.com) which provides wider population of researchers to publish and protect the copyright of their papers.

Editor-in-Chief
Prof Danislav Drašković, PhD Eng.

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ORIGINAL SCIENTIFIC PAPER

Component-Based Object Recognition Algorithm

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Abstract: The paper presents an approach to object recognition based on the hypothesis of representing objects using a set of geometric primitives and relations between them. The goal of the paper is to develop a method for object recognition in the environment, which allows to recognize objects based on their description. For this purpose, the following tasks are solved: the recognition of a set of geometrical objects (primitives), the estimation of relations between primitives and the search of correspondences between the found primitives and relations and the defined templates (descriptions objects). The set of geometric primitives is selected taking into account the nature of the subject area of the objects to be recognized. The paper presents object recognition examples through the use of the method proposed. As a result, the operability of the proposed object recognition method is confirmed. An object description method has been developed. For experiments, the images of primitives were used generated in the Blender 3D, as well as photos of primitives from the kid's toy constructor. The primitive detection model was trained on a training sample consisting of 1000 artificial images and 50 real images. The research results can be applied in algorithms for recognizing traffic participants as well as traffic signaling objects

Key words: object recognition, object detection, recognition by components, computer vision, relation encoding, recognition algorithm.

INTRODUCTION

Recognition algorithms have found wide applications, including industrial applications such as equipment condition monitoring, product quality control [1], [2], text digitization [3], staff authentication [4], etc. Object recognition approaches are based on feature extraction of recognition objects, their search in new data and class assignment [5]. Based on the extracted features, an object prototype is built. A prototype provides an "average" representation of an object. In modern deep learning-driven algorithms object features are automatically extracted based on labeled examples from the training dataset.

I. Biederman proposed the theory that humans use a set of geometric features and the relations between them to recognize objects [6]. Biderman's theory is based on the assumption that every object can be represented by a set of geons (a set of geometric shapes). Each geon is described by a set of non-accidental properties that remain the same when the angle of view is changed [5], [6]. The evolution of such recognition approaches can be traced in [7], [8]. The recognition task can be defined as determining the necessary set of geometric primitives and their relations to recognize objects, selecting and training a model to recognize primitives and developing rules for relation estimation and recognition based on primitives and relations.

A set of geometric primitives can be defined taking into account the nature of the subject area and the task to be solved. A distinctive feature of the approach is that the number of geometric features and relations is finite. Three-dimensional shapes represent the examples of primitives, i.e. prism, sphere, torus, etc. (shape features). The examples of relations are spatial relations between primitives (above, below, farther, closer, etc.), contact, scale, distance, etc.

Described below object recognition approach is based on two assumptions: 1) any object can be represented as a finite set of geometric primitives connected to each other by a finite set of relations; 2) the recognition of a known (described) object can be performed as a search for a set of object primitives, connected with each other by a set of known relations.

Recognition performance depends on a number of parameters, such as metrics, the quality and size of the training dataset, and the nuances of the recognizable objects. In order for a sufficient dataset to be collected, several iterations of data collection are typically taken, incl. dataset preparation, training and model comparison. [9]. When the number of recognizable classes increases, a decrease in recognition accuracy can be observed, which is discussed in [10] and confirmed by empirical observations. Based on that, we can make assumptions about the application restrictions of recognition algorithms and, hence, develop an algorithm that solves some recognition problem for a new application, which requires time and resources.

At the moment, the most common tool for object recognition is convolutional neural networks [11], which have replaced the non-neural-based recognition algorithms (such as Haar cascades [12], HOG [13], DPM [14]). In this case, it is not quite reasonable to talk about the advantages of some methods over the others, because the recognition algorithm (as well as other parameters such as loss function, optimizer, etc.) is selected for a particular problem [15] (same method can show good and poor performance depending on its application).

PRIMITIVE DETECTION

In order for the objects to be recognized in the image, sets of primitives and relations will be used. The set of primitives may depend on the subject area of objects and take into account the nature of this area, for example, outdoor lighting maintenance [16] (a variety of mounts, shapes, textures, etc.).

To investigate the possibility of recognition by components, it is assumed that objects can be constructed from a set of primitives that includes different prisms and cylinders.

For the experiment, we use the SSD300 VGG16 neural network model. The base network is VGG16. On top of the base network, convolutional layers are added to extract features at different scales. Anchors are placed on feature maps and allow the model to generate bounding box predictions for objects at different scales and aspect ratios. Anchor frames are predefined rectangles of different sizes and ratios placed at different scale levels of feature maps. Synthetic and real images are used to train the neural network.

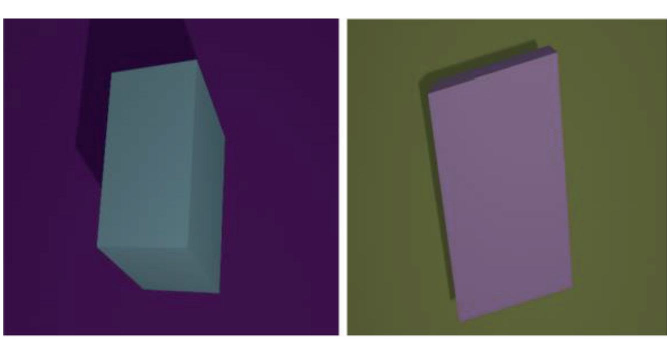


Fig. 1 – Example of synthetic images from the training dataset

The training was carried out for 18 epochs using 1000 synthetic images (800 - for training, 200 - for validation), after which an early stopping function was triggered.

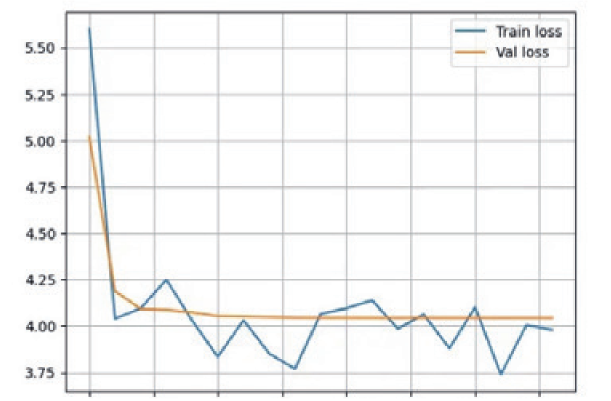
An example of synthetic images is shown in Fig. 1.

Then, the model was trained on mixed data for 14 epochs (50 images of real objects + 1000 synthetic images).

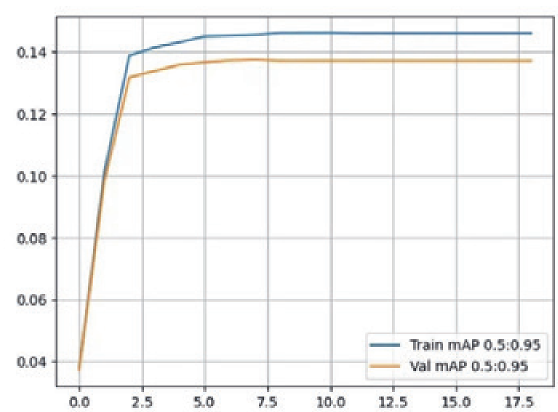
SGD optimizer was used for training. The learning rate was reduced to 0.0001 to get better convergence and avoid overtraining. Momentum is 0.9. Weight decay is 0.0005.

The loss function consists of two components: Bounding box regression loss and Classification loss.

The training plots are shown in Fig. 2 and 3.



a



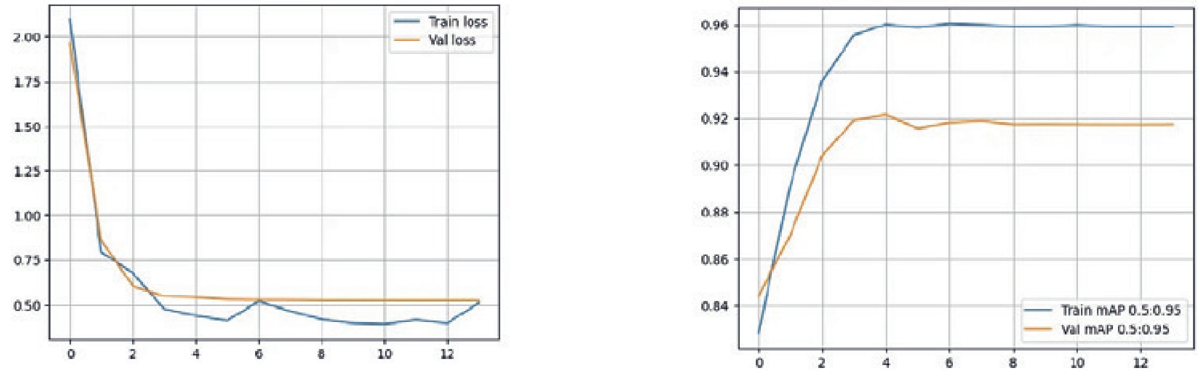
b

Fig. 2 – Training plots for 1000 synthetic images
(*a* – training loss, *b* – mAP)

Adding real data to synthetic data leads to an increase in accuracy.

Primitive recognition examples are shown in Fig. 4. As can be seen from the figure, false positives are observed. Therefore, the results require filtering by confidence.

As a result, we get primitive coordinates, which will be used to estimate relations.



a *b*

Fig. 3 – Training plots for 50 real images + 1000 synthetic images (*a* – training loss, *b* – mAP)

Table 1 – Models mAP (mean average precision)

Data	mAP 0.50:0.95	mAP 0.50	mAP 0.75
Synthetic only	0.038	0.077	0.038
Synthetic and Real	0.157	0.336	0.126

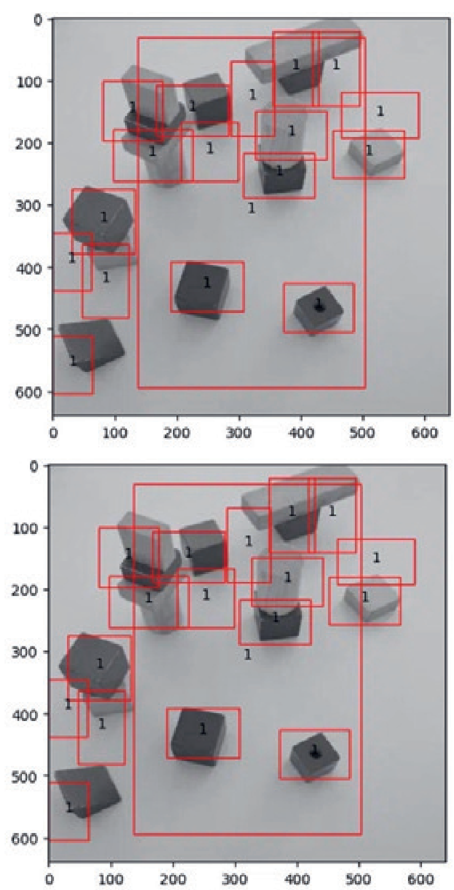


Fig. 4 – Example of recognized primitives

ESTIMATION OF RELATIONS BETWEEN PRIMITIVES

To specify relations between primitives, the representation of objects in the form of graphs is well applicable, where primitives are nodes of the graph, and relations are edges of this graph [5]. In practical implementation, it will allow to store information about recognized objects in explicit form in graph databases.

We use the following labels: A – rectangular prism, B – triangular prism, C – cylinder. In this case, the scene description can be represented as in Fig. 5a.

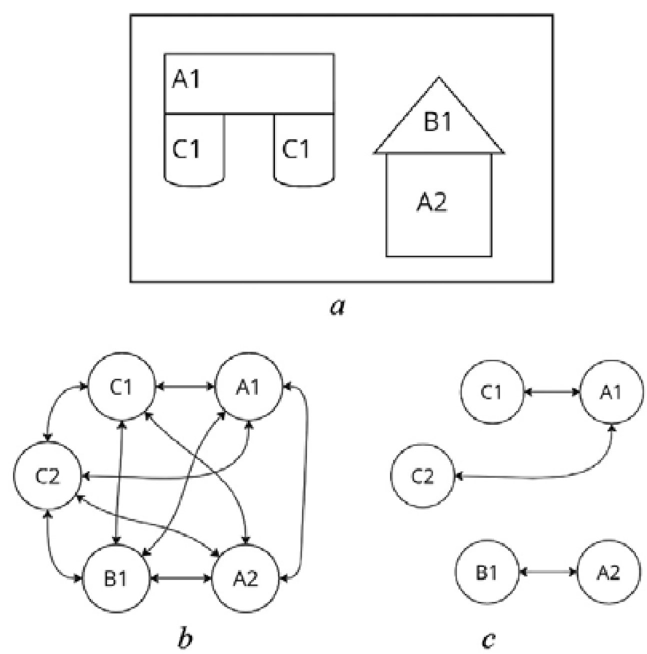


Fig. 5 – Schematic representation of the scene (*a* – scene, *b* – hypothesis generation, *c* – relation estimation)

Fig. 5b shows that the list of possible relations between all primitives may be redundant for recognizing an object; therefore, we limit relation set to the relations between contacted primitives.

Using the example of Fig. 5a, we use the following set of relations in two-dimensional space: on the left, on the right, above, below, and intermediate states. As a result, we obtain the following possible variant of the recognized object shown in Figure 6a.

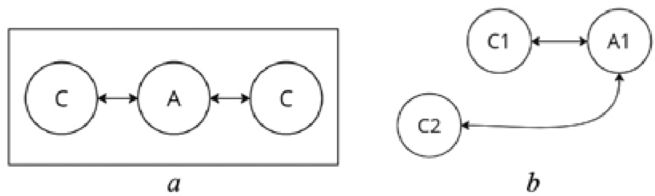


Fig. 6 – Known object and hypotheses of possible objects in the scene (a- known object, b- possible variant of the object in the scene)

Table 2. Relation encoding.

Relation	Letter code	Number	Binary code	Gray's code
Contact + on top	a	0	000	000
Contact + top right	b	1	001	001
Contact + on the right	c	2	010	011
Contact + bottom right	d	3	011	010
Contact + at the bottom	e	4	100	110
Contact + bottom left	f	5	101	111
Contact + on the left	g	6	110	101
Contact + top left	h	7	111	100

To describe the relations between primitives, we introduce their encoding. For encoding, we use Gray's code, an analog of binary coding, each value of which differs from the previous and from the next one by one bit. To describe the relations, eight encoded states need to be introduced, as shown in Table 1 and Fig. 3. Thus, much different relations will have a difference of 2 bits, and neighboring relations will have a difference of 1 bit.

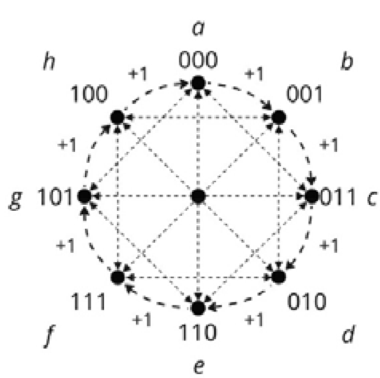


Fig. 7 – Graphical representation of relation encoding (+1 shows the direction of rotation when switching from one state to another)

Thus, the process of object recognition is reduced to the description of known objects and further search for matches in the scene. For example, there is a description of a «house» represented by primitives in Fig. 8, Formula 1.

$$House = \overset{e}{BA} \quad (1)$$

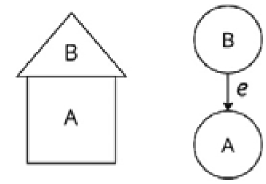


Fig. 8 – Description of the «house» represented as primitives and relations between them.

In such a description of the object, it is necessary to specify that changing the order of primitives when writing should lead to a change of the relation between them to the opposite, e.g., Formula 2.

$$\overset{e}{BA} = \overset{a}{AB} \quad (2)$$

Consider the scene with the objects shown in Figure 9a. The representation of the scene as primitives is as shown in Figure 9b.

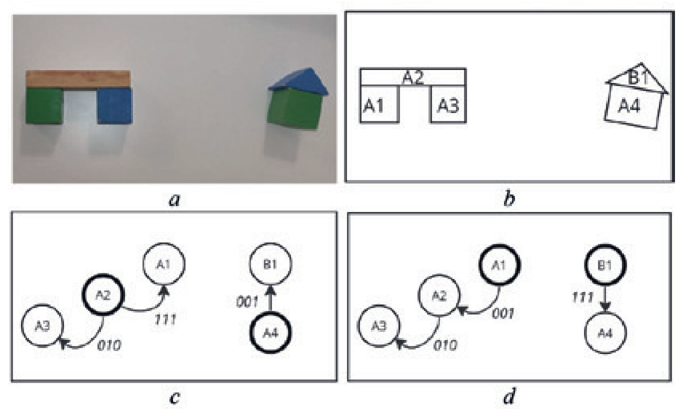


Fig. 9 – Example of a relation estimation between primitives (*a* – scene, *b* – scene representation as primitives, *c* and *d* – relation estimation with different start primitives)

Next, a start primitive has to be selected for recognition. From the start primitive along the chain, relations are estimated between primitives; an example is shown in Figures 9c and 9d. Considering situations when objects in the scene are rotated relative to the description, as, for example, in Figure 9a, it is necessary to check matches by rotating the object in the scene. To do this, a unit is added to or subtracted from all the object relations, and, if a match is found, the object is detected.

The example of recognition for Figure 9c looks as follows:

$$\overset{b}{A1B1} \overset{-1}{\Rightarrow} \overset{a}{A1B1} = House \quad (3)$$

By rotating the relations by one step, a match with the searched object is found.

Similarly, a recognition example is presented for Figure 5d. In this case, the primitive B1 is chosen as the start element and a permutation of the primitives with a change of relations is also applied for recognition.

$$B1\overset{f}{\frown}A1 \overset{-1}{\Rightarrow} B1\overset{e}{\frown}A1 = A1\overset{a}{\frown}B1 = House \tag{4}$$

As a result, the following steps of the algorithm can be defined (Figure 10).

Step 1. Extraction of a set of primitives from an image (e.g., as in [17]);
Step 2. Estimation of relations between primitives in the scene;
Step 3. Partitioning of the set of primitives into isolated groups. Further steps are performed for each group separately;
Step 4. Checking sufficiency of primitives in the group to contain known objects. If there are enough primitives, go to step 5, if not, go to the next group;
Step 5. Choosing a start primitive, relative to which the chain of relations will be estimated;
Step 6. Constructing a relation graph sequentially from each primitive to all adjacent primitives;
Step 7. Matching search by combinations of primitives and relations, taking into account possible object rotation. If a match is found, add the object to the set of detected objects, remove primitives from the set of primitives. If a match is not found, go to the next combination.
Step 8. If not all the groups are checked, go to step 4, otherwise output the set of detected objects.

Fig. 10 – Component-based object recognition algorithm

IMPLEMENTATION AND APPLICATION OF COMPONENT-BASED OBJECT RECOGNITION ALGORITHM

JSON language has been used for the description of objects and relations between them (listing 1). Consider the scene shown in Figure 11a. The found primitives and the relations between them are presented in listing 2. The recognition result is shown in Fig. 11a.

As can be seen from the above recognition example, the proposed component-based object recognition algorithm can be used to detect objects in an image.

Listing 1. Description example of the object «house» (v1 – description variant, nodes – primitive set, edges - relations)

```
"house": { "v1": {
        "nodes": {
        "A1": {"name": "square_prism"},
        "B1":{"name":"triangular_prism"}},
        "edges": {
        "a1": {"from": "A1", "to": "B1",
                "data": null}
        }}}
```

Listing 2. Object recognition example (possible_objects - hypothesis about objects in the image, boxes - coordinates of bounding boxes of detected primitives, relations - relations between detected primitives, version - version of hypothesis description; detected_objects - verified hypotheses about the presence of an object in the image, box - bounding box of the object, class - a certain class of object based on primitives and relations between them).

```
{'arc_0': {'boxes': {'A0': [516, 416, 109, 102],
        'A1': [605, 348, 282, 60],
        'A2': [700, 417, 99, 103]},
        'relations': {('A0', '011', 'A2'),
                ('A1', '010', 'A2')},
        'version': 'v1'},
 'house_1':{'boxes':{'A3':[1167,424,152,115],
        'B4':[1179,352,160,82]},
        'relations':{('A3','000','B4')},
        'version': 'v1'}}
detected_objects:
{'arc_0': {'box': [462, 318, 287, 150],
        'class': 'arc'},
 'house_1': {'box': [1091, 311, 168, 170],
        'class': 'house'}}
```

As can be seen from the above recognition example, the proposed component-based object recognition algorithm can be used to detect objects in an image.

CONCLUSION

The paper presents an approach to object recognition based on the hypothesis that objects can be recognized using primitives and relations between them. An approach to primitive recognition, object description, and relation encoding for two-dimensional image space is presented; object recognition examples in an image are demonstrated. The proposed recognition approach allows to recognize new objects without the need to retrain the algorithm on a new training dataset. To expand the list of recognized objects, it is necessary to expand the database of known objects with the description of a new object or a class of objects. The implementation of the approach will reduce the risks of recognition quality deterioration when the number of recognized object classes increases and reduce labor costs for adapting recognition algorithms for new objects.

The research results can be applied in algorithms for recognizing traffic participants as well as traffic signaling objects.

By comparing the behavior of an identified traffic participant with the detected traffic signaling, its condition can be corrected and the traffic situation managed.

With an appropriate mobile communication network for data transmission and distance monitoring of traffic participants, their speed and distance from each other can be corrected and safe traffic flow can be organized.

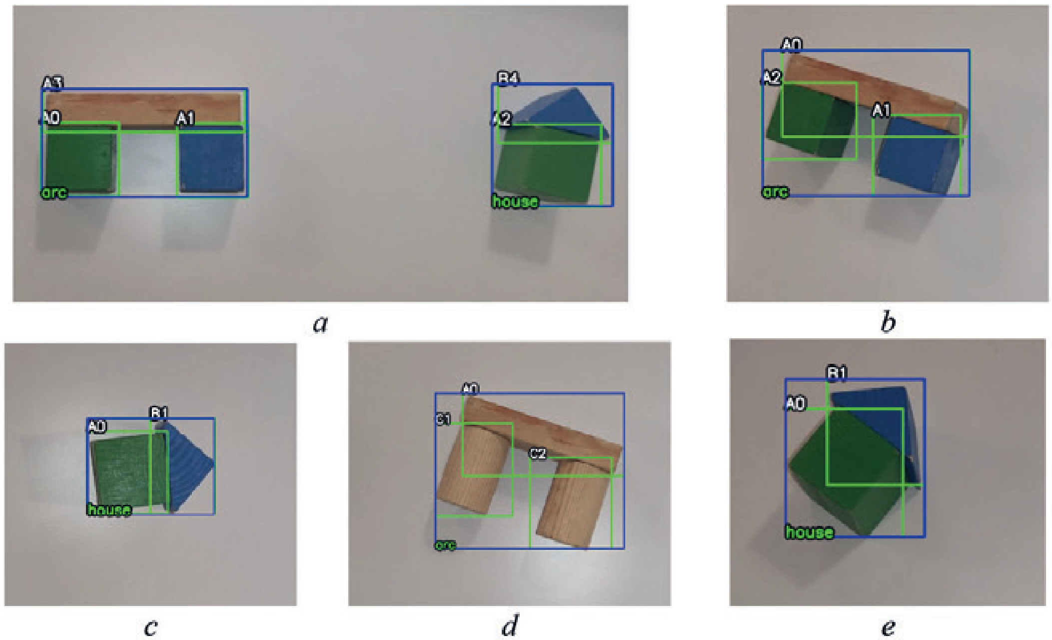


Fig. 11 – Object recognition example using component-based object recognition algorithm

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ORIGINAL SCIENTIFIC PAPER

The Concept of Mobility and Global Challenges in Road Transport by 2050

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Abstract: After collecting and processing of the facts, it is evident that today, 2.6 million posts of drivers remain unfilled in the countries covered by the survey with a tendency that this estimated number shall increase to 3 million. In data processing, the official data of the International Road Transportation Union IRU have been used which are explicitly showing that a trend of «vacant» jobs and mobility challenges have been observed in all regions, except Eurasia. The least affected countries are Mexico and Argentina with 8.6% of truck driver vacancies, the exception being China, where the system is stable. In the paper, we deal with the issue of mobility in countries outside the EU, especially the countries of the Western Balkans where we have determined that the trend of drivers leaving for the EU is on the rise and will be especially instigated by continuous economic recovery of global GDP growth, persistent tensions in the supply and demand of road freight and decrease in available workforce of drivers as well as training and qualification challenges. To obtain the results of the work, we set the first hypothesis «lack of professional drivers is a global problem that directly affects the GDP», as well as the second hypothesis «EU directives and the lack of standards harmonisation in the countries outside the EU cause job positions of motor vehicle drivers being uncovered» In order to understand the set hypotheses, our work included extensive research and experience, whereas the methods used include: inductive and deductive methods, methods of analysis and synthesis, methods of abstraction and concretization, methods of generalization and specialization, method of classification, method of description, method of compilation and comparative method. With the protocols, road transport operators have committed to become carbon neutral by 2050 through the IRU Green Compact , the summary provides an overview of this research, focusing on the scenarios assessed and the recommended way forward. In short, which optimization model is the best for road transport operators to make Europe carbon neutral by 2050 on one hand and on the other, to meet the standards of the EU Directives on the mobility of workers, professional competences, skills and abilities, so to make the profession of a professional driver attractive for young people, and also to facilitate and remove the existing barriers that are visible. In conclusion, we confirmed and proved the set hypotheses with proposal for the measures at different levels and recommendations to eliminate or stop negative trends through comprehensive coordination.

Key words: drivers mobility, EU Directives, IRU, road operators, CPC,

JEL classification: F02, L91, R4, R5

STARTING BASIS FOR CONSIDERATION OF GLOBAL CHALLENGES IN ROAD TRANSPORT

ANALYSIS OF MOBILITY AND FILLING OF POSTS OF MOTOR VEHICLE DRIVERS

The IRU survey on drivers shortage was distributed by IRU[1] members to their road transport companies. The results for 2021 were collected between October 2021 and January 2022 and 1,524 companies from 25 countries responded (including passenger and freight companies).

For each topic (shortage of drivers, percentage of female drivers, percentage of young and old drivers, average age) the results show the average, weighted by the number of drivers of each company and the weight of the country in terms of employees in road transport[2] / transportation and storage employees compared to the regional average.

The share of unfilled driver positions is based on the answers to the questions "How many drivers do you currently employ?" and "How many unfilled driver positions do you currently have?". The forecast for 2022 is based on the respondents' own forecasts (answers to the questions "Indicate the expected number of drivers you will need next year (assuming business as usual)" and "How many of these driver positions will you be unable to fill (due to lack of drivers)?" "). The number of unfilled driver positions is based on the total number of drivers working for logistics companies and dispatchers, provided by national road transport associations (IRU members), and the percentage of unfilled driver positions (the number of drivers is considered to correspond to the number of driver positions that have been filled) . The share of unfilled positions is calculated based on the companies that responded to the survey.

In the case of freight, these are mainly road freight companies (for hire and reward), as there were very few dispatchers/companies that responded to the survey. Considering that for this type of company the percentage of unfilled positions could be lower than for operators of road freight transport for hire and reward (i.e. transport on short distances), the total number of indicated unfilled positions could be slightly higher than the actual figure.

Over 2.6 million jobs for professional motor vehicle drivers were unfilled in 2021[3] in the countries covered by the survey and the shortfall is expected to increase in 2022. Truck driver shortages increased in 2021 in all regions surveyed except Eurasia. It was strongest in Eurasia and Turkey, where 18% and 15% of driver jobs were unfilled in 2021, respectively.

Mexico and Argentina are the least affected, with 8.6% of truck driver vacancies. Transport companies predict that the shortage of truck drivers will continue to grow in 2022. The only exceptions will be China and Argentina, where they will remain practically stable. This will be fueled by continued economic recovery (global GDP growth forecast at 4.2% for 2022, even if economic growth will slow compared to 2021), persistent tensions in road freight supply and demand and a reduction in available driver workforce (due to demographic factors, as well as difficult working conditions and training and qualification challenges).

Eurasian companies expect 26% of truck driver jobs to remain unfilled in 2022. This exceeds the 2019 level (24%), while the shortfall is expected to reach 14% in Europe, 11% in Mexico and 18% in Turkey. Globally, the shortage of truck drivers remains a structural problem and is expected to be a factor limiting the growth of the road freight industry in 2022[4].

In all regions, less than 3% of truck drivers are women, except in China (5%) and the USA (8%). The share of female drivers remains very low in all regions, especially compared to the overall benchmark of the transport industry: over 8% of transport workers are women in general, and even over 20% in some regions (Eurasia, Europe and America).

In the bus transport segment, even if the share of female drivers was slightly higher in Europe compared to freight transport, the representation of women fell from 16% in 2020 to 12% in 2021. The entire transport industry is struggling to attract young people. There were encouraging signs in Mexico and China, where 19% and 17% of truck drivers were under the age of 25. In the rest of the countries, the share of young drivers was below 7%. The situation is particularly difficult in the passenger segment, where the share was below 3% in both Europe and China. The main reasons for such low numbers are the aging population, the minimum legal age for entering the profession, which in some countries goes up to 21 and even 26, along with the attractiveness of the profession. The pandemic has also negatively affected the number of new young drivers entering the profession in many countries. Given the large percentage of older drivers approaching retirement, the driver shortage will continue to grow dangerously, if no action is taken.

OBLIGATIONS TO REDUCE HRAMFUL GAS EMISSIONS AND THE ROADMAP UNTIL 2050

Starting from the fact that supply chains, and thus GDP, are dependent on professional relation, filling of job vacancies, we are facing, on the other side, with signed international agreements and clear roadmaps towards "decarbonization". The EU's targets for reducing emissions from road traffic introduce new target values

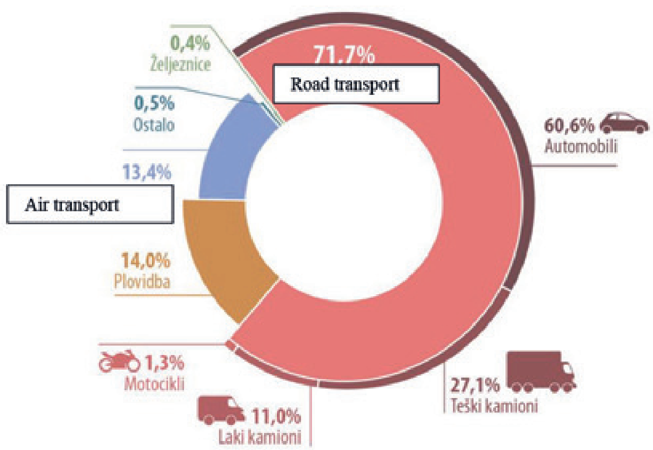
[1] IRU | World Road Transport Organisation - IRU is a world organization for road transport, 3,5 million operators and logistics around the world.

[2] Full link to 2023 Driver Shortage Survey: https://www.research.net/r/drivershortage2023

[3] In the scope of countries surveyed: United States. Mexico, Argentina, Europe (Spain, Italy, France, UK, Ireland, Germany, Poland, Romania, Belgium, Netherlands), Eurasia (Russia, Uzbekistan, Ukraine), Turkey, Iran, China

[4] Full link to 2023 Driver Shortage Survey: https://www.research.net/r/drivershortage2023

for CO2 emissions, in order to reduce harmful emissions from new passenger cars and light commercial vehicles (vans). The new legislation paves the way for zero CO2 emissions for new cars and light commercial vehicles from 2035. The transitional emission reduction targets for 2030 are 55 percent for cars and 50 percent for vans - light trucks. Parliament and EU member states have reached an agreement on the final form of the rules. Other measures and targets the EU intends to complement the CO2 targets for cars and vans - light trucks with: a new emissions trading system (ETS) for road traffic and buildings, increasing the share of renewable transport fuels, abolishing tax credits for fossil fuels and revising the law on infrastructure for alternative fuels for the purpose of expanding capacity.



Picture 1. Analysis of the harmful gas emissions by types of transport[5]

Based on the data of the European Agency for Ecology, we have determined that road traffic is marked as the carrier with 71.7% of negative data on the emission of harmful gases, out of which 27% comes during the transport of goods and bus transportation of passengers, while 73% is the result of individual use of cars and vens.

The European Union has adopted strategic documents that, in the roadmap until 2050, refer to the spheres of reforms in individual and public transport, to reforms and transformations in the domain of logistics, macro-micro distribution, as well as costs for introduction of a new approach.

The roadmap until 2050 requires major transformations in the domain of "green logistics" and "green distribution" and includes a series of changes that will take place in order to improve these sectors. In addition to the key principles of the concept that we discussed in the next chapter, we will mention sustainability, as rail transport of passengers and goods, we expect the goal of reducing CO2 emissions by more strongly directing flows towards rail transport. The concept of mobility, derived from the European mobility strategy, foresees an increase in the volume of railway traffic by 200% by 2050 and strengthening of the role of railways in the total volume of transport.

THE CONCEPT OF „EU MOBILITY PACKAGE" IN FUNCTION OF FILLING THE POSTS OF DRIVERS IN ROAD TRANSPORT SYSTEMS

To obtain the results of the work, we set the first hypothesis "lack of professional drivers is a global problem that directly affects the business of transport operators and the GDP itself", as well as the second hypothesis "EU directives and the lack of harmonization of standards with countries outside the EU cause the non-coverage of positions of motor vecihle drivers".

In order to understand the set hypotheses, our work included extensive research and experience, we used inductive and deductive methods, methods of analysis and synthesis, methods of abstraction and concretization, methods of generalization and specialization, method of classification, method of description, method of compilation, as well as comparative methods. With the protocols, road transport operators have committed to become carbon neutral by 2050 through the IRU Green Compact[6], the summary provides an overview of this research, focusing on the scenarios assessed and the recommended way forward.

In short, what is the best optimization model for road transport operators, on one hand, to make it carbon neutral in Europe by 2050, and on the other, by meeting the standards of the EU directives on the mobility of workers, professional competences, skills and abilities, make the occupation of a professional drivers attractive to young people, that is, to facilitate and remove the existing barriers that are visible.

Shortage of truck drivers since over 2.6 million truck driver jobs were unfilled in 2021 in the countries covered by the survey[7].

With the package on drivers mobility, the European Union has largely defined restrictive measures and limitations in terms of working hours, breaks, tachographs, advanced second generation tachographs, secondment of workers, cabotage and the justification period.

The implementation of new frameworks is being prepared in the field of extending the probation period from current 28 to 56 days, as well as restrictions on the operation of the towing and towed vehicle for up to 8 weeks.

[5] Source: Evropska agencija za ekologiju, 2022. (European Environment Agency's home page (europa.eu))

[6] IRU Green Compact | IRU | World Road Transport Organisation

[7] The scope of the countries include: United States (various methodologies), Mexico, Argentina, Europe (Spain, Italy, France, UK, Germany, Poland, Romania, Lithuania, Belgium, Netherlands), Russia, Turkey, Iran, China. Unfilled truck driver jobs calculated based on the total number of truck drivers in each country, and the share of unfilled positions reported in responses from road transport companies (more details in the methodology).

The aforementioned changes and modifications have already entered into force and with clear application deadlines as a contribution to the concept of driver mobility, we are also introducing "more flexible activities in supply chains", so that loading and unloading time is significantly shortened to 30 minutes, that is, to 5 minutes for automated processes.

The majority of countries decide to change the dimensions of freight vehicles, so in Denmark, Norway, Germany, Spain, measures of up to 60 tons of total vehicle weight are introduced, and the length is extended to 26 meters, etc. At the proposal of the associations, new categories are introduced in driver's licenses, for example 4.25 tons, and the age limit for drivers is lowered to 17 years of age.

The aim of the measures within the mobility concept is to facilitate, improve, optimize, eliminate congestion, relieve supply chains and other by 2050.

The position of a professional driver is irreplaceable until 2050, with corrections and application of new technological solutions, the share and percentage will be reduced but unchanged in absolute value. They want to make the workplace more attractive and acceptable, so the strategic documents of the EU emphasize the need for disincentive measures, as in the example of Spain, which banned the work of drivers during loading and unloading, and also by affirmation in the strategic documents fines for empty driving are introduced.

Employers are requested to organize the work of drivers with mandatory vacations at the latest after three weeks in the place of residence, to reduce the percentage of night driving hours through the strategy of night jumps, and to facilitate the return to the operational headquarters.

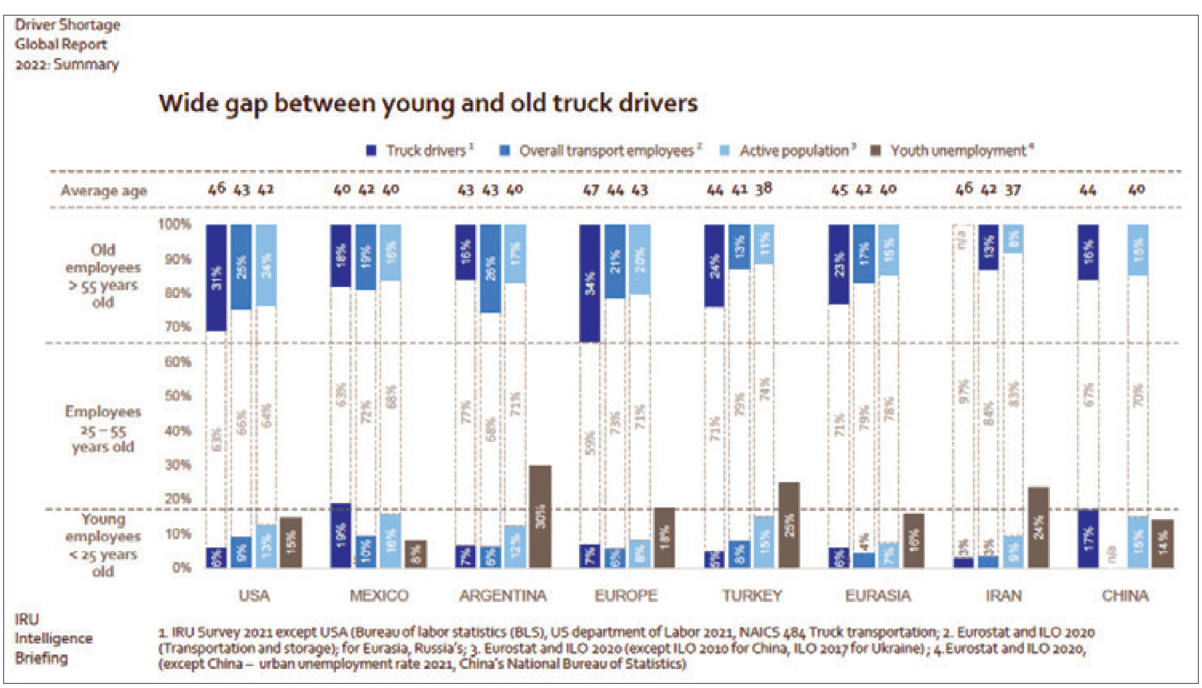
The strategic document "mobility package", in the first phase, includes the reform of the rules for professional drivers. However, we are also aware of the fact that the concept of mobility and global challenges in road traffic by 2050 currently records a shortage of about 230,000 jobs in the position of motor vehicle driver.

Based on the research, it was determined that the difference between old and young drivers is one of the causes of vacant seats, where it can be seen that Europe and America face a high percentage of 34% of drivers over 55 years old.

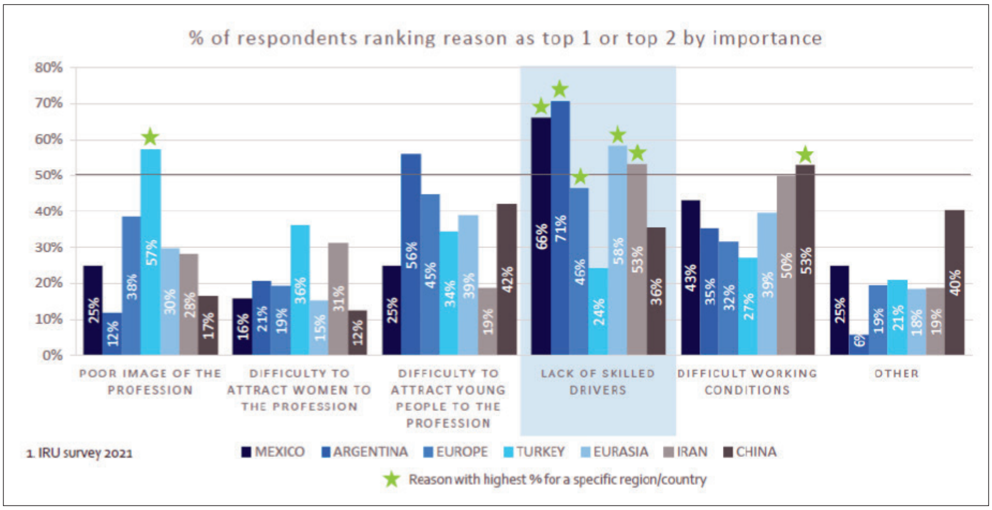
It is clear that the over-55 age limit dominates the markets with the largest driver shortage, and is too large compared to the share of young truck drivers, meaning the shortage will increase in the near future as there will not be enough young drivers to cover the aging drivers who are leaving for retirement. The most difficult cases are Europe and Iran. Europe has the highest average driver age (47), and more than one third of the driving population is over 55. Moreover, the proportion of young drivers is very low (only 7% of drivers are under 25). Iran also has a high average age (46), and the lowest proportion of young drivers among the regions surveyed (3%). On the other hand, Mexico and Argentina have a low level of share of old drivers over 55 (18% and 16%, respectively), which is aligned with the total active population and, in the case of Mexico, accompanied by a high share of young truck drivers (19%).

As was the case in 2020, operators from all regions/countries surveyed (except Turkey and China) continue to see a lack of qualified drivers as the most important reason explaining the driver shortage affecting them.

On the other hand, when asked about the most necessary measures to solve the shortage and attract more



Picture 2. Analysis of drivers age breakdown / https://www.research.net/r/drivershortage2023



Picture 3. Main reasons for truck drivers shortage (according to the surveyed operators) / https://www.research.net/r/drivershortage2023

people to the profession, operators agree that priority should be given to measures to improve the working conditions of drivers:

- Fairer remuneration of employees
- Greater investments in safe parking spaces and supporting infrastructure,
- More decent and higher quality treatment of drivers at departure/arrival points,
- Shortening and eliminating waiting - more flexible delivery time,
- Elimination of the driver's physical effort (manual loading, etc.)

Transport companies are concerned about the complex approach to training, so they are in favor of a simpler approach. In other words, there is a high demand to facilitate access to the profession through incentive subsidies or payment of training costs and training. Another parameter that has been highlighted is the return of the image to the profession.

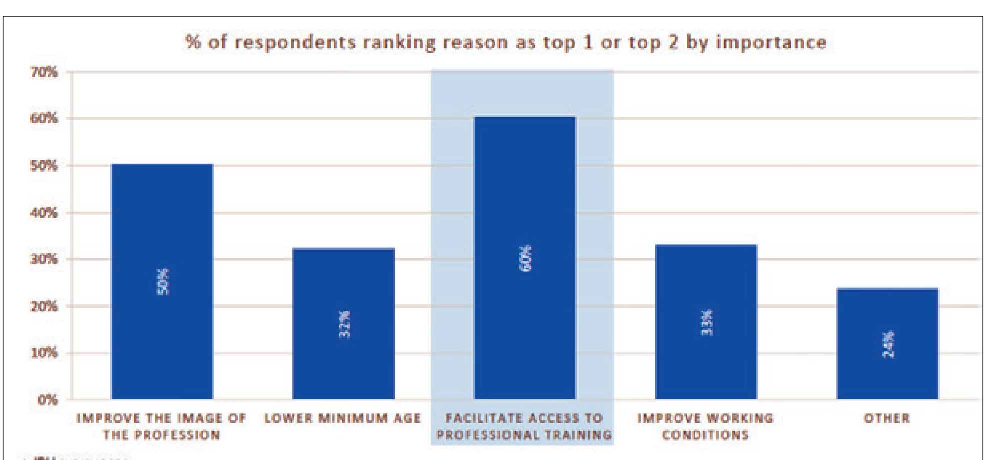
In Europe, the shortage of bus drivers is steadily increasing, but is still expected to remain far from pre-pandemic levels in 2022. It has risen from 5% to 7% in 2021, and is expected to increase further to 8% in 2022. This is the reuslt of the increased demand which is expected in 2022 because the restrictions of mobility are mitigated and reduction of existing drivers due to:

Bus drivers change their profession because the activity lost in the pandemic shall not resume, fewer young drivers are trained and enter the profession, due to low activity, restrictions limit the training capacity and the attractiveness of the profession.

THE MOBILITY CONCEPT AND GLOBAL CHALLENGES IN ROAD TRANSPORT BY 2050

SHORT TERM CONCEPTS OF MOBILITY

When we talk about different concepts of mobility development in road transport, we point out that short-term and long-term goals are set, road transport faces minor and major challenges. We are currently witnessing demands in road transport aimed at sustainable solutions, starting from closer plans, so this year activities are directed towards shaping sustainable mobility solutions such as:



Picture 4. Main reaons for shortage of bus drivers

1. INTRODUTCION OF ELECTRIC VEHICLES (EVs)[8]: During the year 2024, the direction towards stimulating the procurement of electric vehicles, certainly the rise of sales will also contribute to the new technologies in the field of batteries, the increased radius of autonomy and the development of infrastructure.

2. SUPPORT INFRASTRUCTURE FOR ELECTRIC VEHICLES: Relevant ministries in decision-making bodies are considering different models for development of support infrastructure, primarily filling stations for electric vehicles, but also other forms of environmentally friendly fuel.

By defining the directions of development, locations, level and quality of infrastructure is in direct proportion to "introduction of electric vehicles". Some of the recognized and well-known models are state, public-private and private investment in infrastructure.

Strategic TENT "network of European corridors", capitals, urban environments and other strategic zones, and intersections are in the highest rank.

3. MOBILITY DIVISION (MaaS)[9]: In the last decade, there has been an expansion, sharing of mobility with an emphasis on "cars". Some states and cities have regulated and defined a legal framework in which disincentive measures are aimed at lower capacity utilization coefficients of private driving units. The goal of these tasks is to reduce congestion, more rational and optimal use of the capacity of personal driving units. And the money from the disincentive measures, which is collected, is directed towards the improvement of the infrastructure from the construction of bicycle paths, the definition of "zero tolerance CO2" zones and the like.

Mobility sharing is in direct correlation with digitization, defining user platforms that enable the realization of the road plan, the number of users, optimization of consumption and with emphasis on stimulating electric vehicles as a mobility sharing concept. On the other hand, modifications and technologies in the domain of "two-wheelers" have given birth to new forms and more technologically advanced light, collapsible and mobile vehicles. The challenges that are current today are the definition of legal frameworks for sharing mobility. The currently available data indicate that the average occupancy rate per car is around 1.6, which must certainly change.

4. SUSTAINABLE CITY PLANNING MANAGEMENT: Places with highest concentration of inhabitants, the process of creating a megapolis began in the last decades of the last century, and today the reality is that majority of inhabitants are located in cities, and closer goals certainly mean moving toward planning of sustainable city urbanism. We are facing correction of urban errors, lack of management space, i.e. priorities are defining sustainable zones, paths for cyclists, directing macro and micro-distributive flows, improvement of city traffic towards an efficient system, with large capacities in a short period of time, switching to environmentally friendly systems powered by electricity. In the individual system, the focus is on planning of sustainable pedestrian zones and in administrative and cultural centers, on public transport system that connects city areas, such as residential with business zones.

5. VEHICLES WITH NO DRIVERS – AUTONOMOUS VEHICLES: The development of the concept of vehicles with no drivers is not new, but in short term it represents a binding potential that is primarily used to connect airport terminals with the city center and experiences from large cities such as Paris and others, give us the right to consider this concept as binding.

The development and testing of the potential of autonomous vehicles is proven in the delivery of goods, which will be discussed later, the so-called "last mile".

The concept aims to optimize the connection of airport facilities with the city center, significantly improve traffic flow, reduce congestion and optimize transport systems.

Testing of the use of autonomous cars and flying vehicles continues with testing and technical-technological safety and security data.

EUROPEAN CONCEPT OF MOBILITY AND CHALLENGES IN ROAD TRANSPORT

The European Union, as well as all other countries in Europe, have more or less agreed on strategic documents based on sustainable mobility guidelines and have adopted strategic policies within which the foundations of the "green agenda" are defined, with a clear framework for their implementation until 2050.

The concept of mobility and global challenges in road transport by 2050 covers a wide range of topics, from economic recession, high business costs, market instability to problems in finding transporters, challenges are especially pronounced in the time of global supply chain disruptions.

The starting point is decarbonization of transport, the increase in the number of environmentally friendly hybrid to electric vehicles globally could increase fivefold by 2025, electromobility aims to achieve net-zero emissions in road transport.

Governments around the world are adopting programs and plans with the aim of improving overall road safety, with the EU's long-term goal of achieving a zero fatality rate by 2050.

1. Efficiency: Optimizing delivery routes and times can significantly reduce costs and increase customer satisfaction.

2. Technology: The use of advanced technologies like GPS tracking and route management software can

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8 https://odrzime.rs/digitalna-infrastruktura-i-povezanost/trendovi-odrziva-mobilnost-u-2024/.

9 https://odrzime.rs/digitalna-infrastruktura-i-povezanost/trendovi-odrziva-mobilnost-u-2024/.

improve the accuracy and speed of delivery.

3. Sustainability: Electric vehicles and bicycles are becoming increasingly popular for "last mile" delivery in urban areas, reducing emissions.

4. Adaptability: Flexibility in delivery times and the ability to choose a pick-up location are important to provide better customer service.

The outstanding problem is the development of infrastructure for a sustainable concept of the "green agenda" until 2050, which is multidimensional and complex, with unknown variables, and a specific time frame, the problem of financing is a challenge that must be addressed much deeper than a roadmap. Cooperation and coordination require all holders of executive functions of governments in Europe to support investment in research and development of new technologies with common strategies.

DIGITIZATION AND AUTONOMOUS VEHICLES

The basis of the European concept of mobility is digitization of processes and documentation in logistics processes, with the aim of reducing costs, automating activities and actions, improving efficiency. A digitized approach will facilitate distribution of goods by the year 2050 in collection and door-to-door delivery with autonomous vehicles.

We expect that digitalization and application of advanced technologies would completely transform transport activities especially in initial and final logistics operations, increasing the efficiency of transport systems, eliminating unnecessary waiting costs, delays, empty rides, reducing the total costs of logistics systems and improving overall road safety.

The concept of mobility leads to major changes in distribution of goods, autonomous vehicles will form the backbone of the distribution of goods, we can also include "drones" in this grouping, that could significantly contribute to reducing the number of traffic accidents.

By 2050, the reforms will include regulatory measures, primarily legal regulations, which must be adapted to enable the use and wider application of autonomous vehicles. Reforms include technical and technological standards, and also adaptation of other traffic regulations.

CONCLUSION

The concept of mobility challenges in road transport is going in two directions, in one direction the strategic commitment of the EU is to make it carbon neutral by the year 2050, and the other direction is to fulfill the standards of the EU directive on the mobility of workers, professional competences, skills and abilities to make the profession of a professional driver attractive to young people, that is, to facilitate and remove the existing barriers that are visible.

The position of a professional driver is irreplaceable until 2050, with corrections and application of new technological solutions, currently in order to solve the shortage and attract more people to the profession of motor vehicle drivers, operators agree that priority should be given to measures to improve the working conditions of drivers:

- fairer remuneration of employees,
- greater investments in safe parking spaces and supporting infrastructure,
- more decent and better treatment of drivers at departure/arrival points,
- shortening and eliminating waiting - more flexible delivery time,
- elimination of physical effort of the driver (manual loading, etc.).

Transport companies are concerned about the complex approach to training, so they are in favor of a simpler approach.

The European Union has adopted strategic documents that, in the roadmap until 2050, refer to the spheres of reforms in individual and public transport, to reforms and transformations in the domain of logistics, macro-micro distribution, as well as costs for introduction of a new approach.

The Roadmap until 2050 requires major transformations in the domain of "green logistics" and "green distribution" and includes a series of changes that will take place in order to improve these sectors. In addition to the key principles of the concept that we discussed in the previous chapter, we will mention sustainability, as rail transport of passengers and goods, we expect the goal of reducing CO2 emissions by directing flows more strongly toward rail transport. The concept of mobility, derived from the European mobility strategy, foresees an increase in the volume of railway traffic by 200% by 2050, and the strengthening of the role of railways in the total volume of transport.

The outstanding and stated problem is the development of infrastructure for a sustainable concept of the "green agenda" until 2050, at the very least it is multidimensional and complex, with unknown variables, and a specific time frame, the problem of financing is a challenge that must be addressed much deeper than a hodogram. Cooperation and coordination require all holders of executive functions of government in Europe to support investment in research and development of new technologies with common strategies.

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ORIGINAL SCIENTIFIC PAPER

Smart Mobility in Smart Cities

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Abstract: Contemporary urbanization trends today are defined in accordance with the principles of sustainable development, aiming to create a balance between the need for increased mobility, economic progress, and environmental protection in cities. The increase in the world's population therefore requires a new way of optimizing human movement and the transportation of goods. The concept of smart mobility emerged alongside smart cities. Smart cities represent urban environments where information and communication technologies are applied to increase the efficiency of the urban system, leading to constant exchange of information with the population to improve the level of services available in the city and enhance the quality of people's lives. The concept of smart mobility represents a system that collects and processes data in real-time using various information and communication technologies to optimize travel, ultimately leading to reduced traffic congestion, emissions of harmful gases, increased traffic safety, and improved efficiency and effectiveness of the transportation system. This paper will define the concepts of smart cities and smart mobility, and through examples of good practices, implemented solutions of the smart mobility concept in European cities will be presented. Furthermore, the paper will also address the challenges of implementing smart mobility systems that may arise due to the complexity of transportation systems in cities.

Keywords: smart mobility, ITS, ICT, sustainability, city

INTRODUCTION

The global population is characterized by a trend of continuous growth, and according to the United Nations (UN), it was estimated to have reached 8 billion in November 2022. The latest projections suggest that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100 (United Nations, 2022). Such rapid growth without adapting the management of human and goods transport poses a significant challenge for the further development of cities and countries. The increase in the world's population itself represents one of the main demands for creating a new perspective on optimizing people mobility and freight transport.

The concept of urbanization includes the spatial expansion of existing cities, the emergence of new urban centres, and the increase in the proportion of the population living in cities. The urbanization process itself has a significant impact on the transportation system. As an increasing number of people migrate to cities for better living conditions and economic opportunities, the demands for transportation and better management of the existing transportation system become more pronounced. This phenomenon necessitates a change in the current system regarding infrastructure, traffic demand and supply management, introduction of new transportation modes, etc. Understanding the impacts of rapid and increasing urbanization is crucial for achieving sustainable development and creating a sustainable transportation system.

The process of urbanization can be described through the following phenomena (Rodrigue, 2024):

Increasing traffic congestion: If not managed properly, urbanization leads to a significant increase in the number of motor vehicles on the road network, ultimately resulting in traffic congestion and parking issues. This leads to decreased productivity from an economic standpoint, as well as increased environmental pollution. For these reasons, it is essential to address the problem of traffic congestion through the introduction of smart mobility, utilizing intelligent transportation systems (ITS), alternative modes of transportation, etc.

Increasing pressure on public transport: The rapid process of urbanization can also overwhelm existing public transport systems. This issue manifests in an excessive number of passengers in systems designed to operate at a required level of service with a smaller number of passengers. Due to increased traffic congestion, vehicles often experience delays. All these problems lead to a decrease in the level of service provided. With the increase in the number of passengers using public urban transport, it is necessary to adapt the system to the new needs of the population. Some possible implementations include the introduction of Bus Rapid Transit (BRT) systems, Light Rail Transit (LRT) systems, or metro systems.

Infrastructure challenges: The urbanization process itself leads to increasing demands for investments directed towards transportation infrastructure to keep up with both the heightened economic growth and the population growth of the urban area. The construction and maintenance of existing infrastructure become more difficult during the urbanization process. To ensure that infrastructure development meets user needs, it is desirable to introduce various ITS and Information and Communication Technologies (ICT) to increase the efficiency of transportation infrastructure while also enhancing traffic safety to a high level.

Changes in travel patterns: Increased concentration of people in urban areas directly affects the alteration of their travel planning and behaviour from origin to destination. Traffic management in this case aims to encourage travel using sustainable modes of transportation, whether it be walking, cycling, scooters, or the increasing use of public transport. Indirectly, by providing alternative modes of transportation, the need for car ownership is reduced.

Social aspect: With the increase in urbanization, there arise problems related to a certain segment of the population who, for various reasons, are unable to own a vehicle or drive one. This refers to the fact that all people have a need for mobility, and their needs must be met. This issue is addressed through the construction of a transportation system with a high degree of accessibility.

When all characteristics of the urbanization process are considered, it is evident that the process significantly affects the transportation system as a whole, particularly the people mobility. It is essential for the transportation system to be shaped in a way that it can keep up with the increasingly rapid process of urbanization and to adapt the mobility of the population in a timely manner through the implementation of new solutions aimed at achieving smart mobility.

THE ROLE OF SMART MOBILITY IN SMART CITIES

Smart cities represent urban environments where ITS and ICT are applied to increase the efficiency of urban systems. In this process, there is a continuous exchange of information with the population aimed at improving the level of services available in the city and enhancing people's quality of life. Smart mobility is one of the most important systems in a smart city. The concept of smart mobility involves a system that collects and processes real-time data using various ICT to optimize travel, ultimately leading to reduced traffic congestion, emissions of harmful gases, increased traffic safety, and improved efficiency and effectiveness of the transportation system (Brčić et al, 2018; CEPT, 2024).

Smart mobility is based on the following principles:

- Flexibility, which means offering multiple travel options to passengers so they can choose what works best in a given situation;
- Efficiency, ensuring travel to the destination with minimal delays and in the shortest time possible;
- Integration, planning routes from door to door regardless of the mode of transportation used and
- Clean technology, transitioning from polluting vehicles to those with zero emissions.

Two more aspects of smart mobility are accessibility and social benefit, meaning it should be accessible to

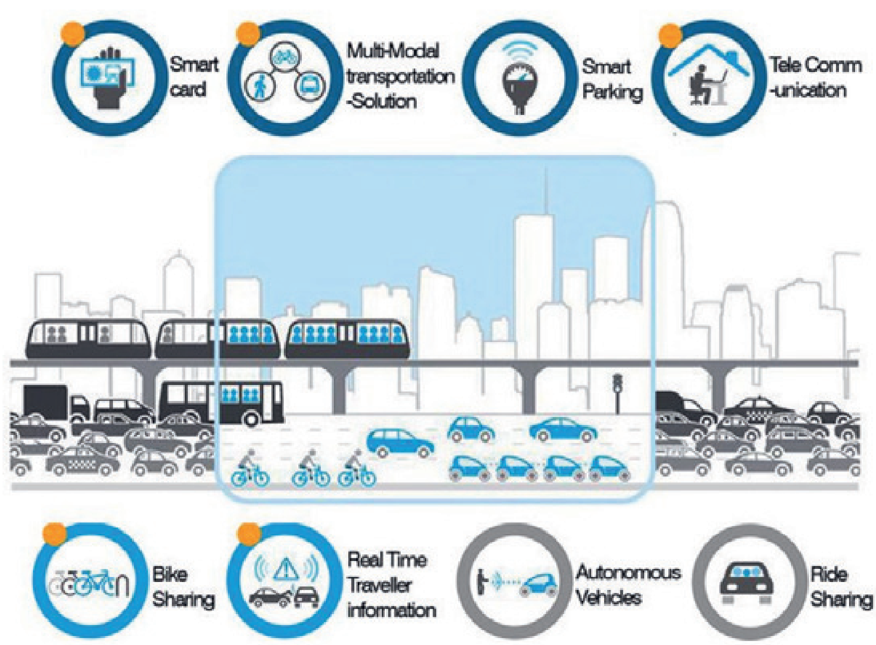

Figure 1. The smart mobility concept (CEPT, 2024)

everyone and provide a better quality of life (Gabelica, 2019).

Smart mobility encompasses the integration of a variety of different technologies, whose interconnectedness into one system enables data collection for the purpose of innovation and improvement of the transportation system as a whole. Some key aspects of smart mobility are (Butler et al., 2020):

Intelligent infrastructure: Smart mobility relies on infrastructure equipped with modern sensors, cameras, and communication technologies for data collection and real-time traffic management. This includes smart transportation systems that involve adaptive traffic signals, as well as travel route planning based on existing traffic conditions in real-time to reduce traffic congestion and travel times.

Autonomous vehicles: They are equipped with modern sensors, artificial intelligence (AI) and ICT. This type of vehicle eliminates the human factor in traffic.

Carpooling and carsharing systems: These two systems are just examples of possible solutions. These systems reduce the need for private car ownership while providing flexible and affordable transportation options.

Electric vehicles: They represent just one of the alternatives to vehicles with internal combustion engines. The increasing use of electric vehicles significantly contributes to reducing the negative impacts of traffic in terms of emissions of harmful exhaust gases.

Mobility as a Service (MaaS): This concept integrates a variety of transportation solutions into one system (e.g., public passenger transport, bike, scooter, and car rental). These systems typically operate through one or more digital platforms. MaaS offers a wide range of solutions for trip planning, facilitates payment for transportation fares, and increases the level of service of the transportation system, its affordability, and sustainability.

The role of smart mobility lies in enabling significantly easier and more efficient use of all aspects of the transportation system by users, while also facilitating traffic demand management in urban environments. To achieve this, it is necessary to change the perspective on people mobility because what is crucial for smart mobility is that there are certain advantages for both traffic participants and the administrative part of traffic management (Figure 2).

With adequate planning, urban areas can become more efficient, functional, and sustainable from a transportation perspective. Introducing smart mobility into the existing transportation system leads to improvements in its efficiency, resulting in benefits that can be observed from an economic standpoint as well. The development of smart mobility creates space for the existence of simple, accessible, and sustainable modes of transportation (Bıyık et al., 2021).

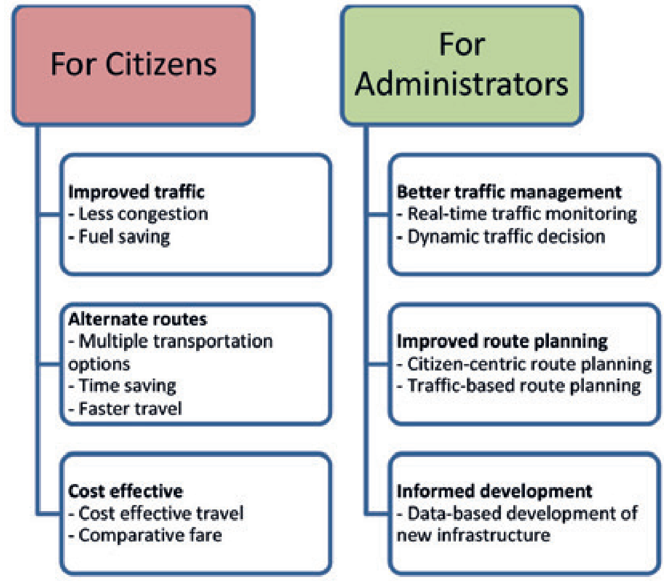

Figure 2. Need and importance of smart mobility (Paiva et al, 2021)

EXAMPLES OF SMART URBAN MOBILITY SOLUTIONS

The using of modern technologies significantly transforms traffic systems in cities that have started implementing smart mobility in recent years. In this chapter, it will be described examples of good practices in implementing smart mobility solutions. These solutions aim to improve the quality of life for citizens, reduce negative environmental impact, and enhance the planning and efficiency of public transportation, decrease traffic congestion, as well as citizen dissatisfaction. The entire concept of smart mobility aims for a transportation system that is highly flexible and practical based on intelligent management.

Helsinki (Finland): For a while now, the city of Helsinki has been investing significant resources in developing sustainable transportation, with a strong focus on public transport and other alternative modes. In terms of modal split, passenger cars account for 36% of trips, public transport for 25%, and walking and cycling for 39%. One of the tasks and goals of implementing the Whim application is precisely to reduce the share of passenger cars and increase the use of public transport and alternative modes of transportation in modal share. The application was launched in 2017, and by the end of 2018, the number of users had exceeded 70,000. The aim of implementing this application is to connect different modes of transportation through one platform. The application itself enables easy trip planning by providing access to public transport schedules, taxi booking, and even car and bicycle rental services. Depending on the type of monthly subscription, the application offers various service options, as certain categories include the costs of using taxi services and renting cars or bicycles.

Research on the travel characteristics of Helsinki residents has shown that users of the Whim application tend to use public transport and taxi services more frequently and use passenger cars less compared to residents who do not use the application. Although the average daily mobility does not differ significantly between the two categories of residents, the conclusion is that besides significant changes in travel redistribution, the significance of the application lies in easier trip planning and realization (Maas Alliance, 2024).

Milton Keynes (England): Research has shown that Milton Keynes, a city with around 280,000 inhabitants, has a very low usage rate of public transport (6%) and cycling (3%) for commuting purposes. The reasons for this situation include poor cycling infrastructure and low-quality public transport services. To increase the number of trips taken using public transport, it is necessary to modernize the system with services that provide users with real-time information and to simplify the payment system. The high level of motorization and neglect of the development of other modes of transport have led to the dominance of cars in the transportation system (Milton Keynes Council, 2018).

Predictions indicate an increase in traffic demand in the future, hence the need for radical changes in traffic management and the introduction of modern systems to achieve smart mobility. One idea to increase the share of passenger trips using public transport is to improve the level of service with the help of the MotionApp application, launched in 2017. The idea revolves around designing an application that provides users with real-time information about the system in a simple way, enables payment, and simultaneously offers easier use and information about parking systems alongside public transport. Specifically, the application collects data on the occupancy status of parking garages and, through an interactive system, facilitates easy finding of available parking spaces (Valdez et al., 2018).

The MotionApp application collects data through a system of sensors, as well as through feedback from users of the application. The data it gathers include public transport vehicle schedules, their exact real-time locations, traffic congestion information, and parking lot occupancy data. The goal of collecting this information is to provide participants in traffic with useful information to facilitate trip planning and increase the efficiency of all modes of transportation. Bus performance has shown a significant improvement, with journey numbers increasing by 6%, and the proportion of customers satisfied with the overall service increasing. Bus punctuality has also improved, with up to 90% of non-frequent buses now running on time. Additionally, the average minimum travel times by public transport to key services for Milton Keynes residents have dropped by 15% (Milton Keynes Council, 2018). The application is just one part of a broader program called MK:Smart, which aims to make the city one of the leading smart cities in the United Kingdom (UK). The initiative oversees the development of the 'MK Data Hub', which enables and manages data related to energy and water consumption, transport data, social media, specialized apps, and other data sources.

Barcelona (Spain): Over the past decade, Barcelona has invested significant funds in reducing traffic congestion and developing and implementing a sustainable transportation system. One measure to achieve smart mobility is the implementation of a bike-sharing system called Bicing. The implementation of this system, along with investment in cycling infrastructure, has enabled a large portion of daily trips to be made by bicycle. Currently, there are 428 bike rental stations in the city, with 105,545 active Bicing system users (Wolnjak, 2023). Due to the observed imbalance in the number of bicycles available for rental in different zones depending on the altitude, the system has been expanded to include electric bike rental services, which can more easily handle the terrain variations in the city. In line with the trend of smart mobility development, an application has been developed for system users to reserve bicycles, make payments, and easily find the nearest available bike (Castells, 2020). With the development of micro mobility, the system also offers electric scooter rentals as part of its services.

The public transport system in Barcelona is a complex system consisting of several subsystems (bus, metro, and tram). To facilitate the use of these systems, they have been integrated into a single fare system, meaning that one type of ticket can be used for any of the mentioned systems or their combination. Additionally, to simplify trip planning, a real-time passenger information system has been implemented. This system provides passengers with necessary information through an application, inside vehicles, as well as at public transport stops.

In addition to the mentioned initiatives, there are several other projects in Barcelona aimed at achieving smart mobility, such as incentives for using electric vehicles (purchase subsidies, free parking, electric vehicle charging station construction, etc.). Barcelona has implemented a smart parking system where sensors collect information to help users find available parking spaces more easily and direct drivers to the nearest available spot. Additionally, shared mobility systems such as Carsharing and Carpooling have been successfully operating in the city for some time, reducing the reliance on owning private vehicles. When it comes to sustainable smart mobility, Barcelona is perhaps best known for its urban neighbourhoods called "Superblocks." These residential areas contain a network of streets reserved exclusively for pedestrians and cyclists, with only a small portion designated for motor vehicles.

Copenhagen (Denmark)

Copenhagen stands as one of the global leaders in the realm of smart mobility solutions. Renowned for its dedication to sustainable transportation, the city has introduced a variety of pioneering initiatives to encourage cycling, walking, and the use of public transport. Among these initiatives, the development of cycling infrastructure emerges as a key smart mobility solution. Additionally, Copenhagen has successfully integrated its public transport systems, boasting an extensive network of buses, trains, and metro lines that operate under a unified ticketing system. This integration ensures seamless and convenient access to public transport for both residents and visitors alike. Furthermore, Copenhagen has installed real-time information displays at bus and train stops, enabling passengers to access up-to-date arrival times for their next bus or train. Additionally, the city has embraced various smart traffic management solutions aimed at alleviating congestion and enhancing traffic efficiency. Copenhagen's intelligent traffic management system continuously monitors traffic patterns and dynamically adjusts traffic signals to optimize flow and minimize congestion. Moreover, the implementation of a smart parking system equipped with sensors has revolutionized parking in the city. By detecting available parking spaces and guiding drivers to the nearest spot, this system reduces the time spent searching for parking and effectively mitigates congestion. Moreover, Copenhagen has implemented various smart mobility solutions aimed at enhancing safety and accessibility. These include pedestrian and cyclist detection systems installed at key intersections, as well as the introduction of low-floor buses and tactile paving. By prioritizing sustainable transportation modes and optimizing transportation efficiency, Copenhagen's smart mobility initiatives not only improve the quality of life for residents but also position the city as a global leader in reducing greenhouse gas emissions and addressing climate change (Wolnjak, 2023).

Glasgow (Scotland)

The role of ITS is indeed crucial in the transformation of cities into smart digital societies. Cities can address traffic challenges effectively, thereby improving traffic efficiency. ITS provides users with valuable information such as real-time traffic updates, local amenities, public transport schedules, and seat availability, enabling commuters to plan their journeys more efficiently. This not only reduces travel time but also enhances safety and comfort for passengers. The application of ITS has gained widespread acceptance and usage across many countries worldwide. ITS is not only utilized for managing traffic congestion and providing real-time information but also plays a crucial role in enhancing road safety and optimizing infrastructure utilization. A notable example of effective ITS implementation is observed in the city of Glasgow (Choudhary, 2019).

In Glasgow, ITS provides regular updates to daily commuters regarding public bus schedules, timings, seat availability, the current location of buses, estimated time of arrival at specific destinations, next bus stop locations, and the passenger density inside buses. The entire application of ITS relies on data collection, analysis, and utilizing the insights from the analysis in traffic management operations, control, and research. Location data plays a crucial role in these processes. In the application of ITS systems, sensors, information processors, communication systems, roadside messages, GPS updates, and automated traffic prioritization signals play crucial roles. The Traffic Management Centre (TMC) serves as a vital component of ITS, operated by the transportation authority. It functions as a technical system where data is collected and analysed for real-time operations and traffic control management, as well as providing information about local vehicles.

The entire process consist of data collection, transmission, analysis and travel information.

Data collection: It relies on various hardware devices that form the foundation for ITS functions. These devices primarily record data such as traffic volume, surveillance footage, vehicle speed and travel duration, location information, vehicle weight, delays, etc. These hardware devices are linked to servers typically located at data collection centres, which store vast amounts of data for subsequent analysis.

Data Transmission: This part of process involves transmitting collected data from the field to the TMC, and subsequently relaying analysed information from the TMC back to travellers. Traffic-related notifications are communicated to travellers via the internet, SMS, or on board vehicle units.

Data Analysis: The data collected and received at the TMC undergoes several processing steps. These include error rectification, data cleaning, data synthesis, and adaptive logical analysis. This refined collective data is further analysed to predict traffic scenarios, providing appropriate information to users.

Traveller Information: Travel Advisory Systems (TAS) are utilized to provide transportation updates to travellers. These systems deliver real-time information such as travel time, travel speed, delays, road accidents, route changes, diversions, and work zone conditions. This information is disseminated through various electronic devices including variable message signs, highway advisory radio, internet platforms, SMS, and automated cell notifications.

ITS represents a win-win situation for both citizens and city administrators. It ensures safety and comfort for citizens by providing real-time information and efficient transportation services. At the same time, it offers city administrators easier maintenance and surveillance of transportation systems, enabling them to make data-driven decisions for optimizing traffic flow and enhancing overall urban mobility.

CHALLENGES IN THE TRANSITION TO SMART MOBILITY

Considering the complexity of existing transportation systems, the implementation of smart mobility faces the following challenges (Pavia et al., 2021):

Infrastructure issues: During the implementation of smart mobility, certain challenges arise regarding infrastructure, mainly concerning how to adapt the existing transportation infrastructure to new needs. With the increasing popularity of autonomous vehicles and electric vehicles, there is a need to build infrastructure tailored to these vehicles. This includes constructing charging stations, implementing advanced communication and information technologies, etc.

Last Mile Connectivity: This problem primarily pertains to public transport systems, specifically how to facilitate door-to-door travel. To overcome this issue, it is necessary to reorganize the public transport system according to passengers' needs and integrate it with other modes of transportation.

Security and Privacy: The demand for interconnected devices and the swift accumulation of extensive personal data raise significant privacy issues concerning data exchange between devices and users. Additionally, the interconnected nature of devices renders the entire network susceptible to external attacks and breaches.

Governance: The expansion of smart mobility has broadened the reach of traditional transportation systems to encompass additional stakeholders, including technology companies and service providers. The involvement of these new participants requires revised policies and regulations governing smart mobility. It is essential to integrate existing traffic laws seamlessly to address the requirements of smart mobility solutions.

Initial Adoption: A significant challenge in smart transportation is raising awareness among potential users to encourage adoption. Many solutions are still in early stages of development, lacking substantial evidence of their precise objectives and benefits.

Dynamic Routing and Transportation Mobility: Efficient solutions require dynamic routing systems capable of estimating users' travel demands and optimizing available resources to deliver solutions. This process relies on sophisticated software and technological advancements.

Network Management and Monitoring: Smart mobility systems consist of a multitude of smaller elements and subsystems that need to be organized and integrated into a cohesive system. The primary challenge often encountered in this context is the cost associated with implementing and maintaining these systems.

Data Acquisition and Integration: Collecting data from diverse sources with varying security and privacy protocols presents a challenge. Managing the vast volumes of real-time data generated by connected devices is a complex task.

Legal Challenges: The engagement of various stakeholders such as payment companies, governments, city administrations, public-private transportation entities, users, and others underscores the need for a clearly defined legal framework and supportive policies to facilitate smart mobility initiatives.

This chapter highlights just some of the potential challenges that may arise during the implementation of smart mobility systems. To ensure that the implemented system operates at a high level and thereby meets the needs of traffic participants and the goals for which these solutions were implemented, close collaboration is required between city administrations, traffic participants, and potential investors.

CONCLUSION

This paper presents the key elements and characteristics of smart mobility, as well as the challenges encountered during the implementation of smart mobility systems in cities. It also highlights examples of best practices in the application of smart mobility across Europe to achieve a sustainable transportation system. From intelligent infrastructure and autonomous vehicles to mobility as a service, the smart mobility system encompasses a wide range of interconnected elements into one system to optimize the transportation system and improve levels of service for its users.

The benefits offered by smart mobility are undeniable, as evidenced by the reduction of traffic congestion, decreased environmental pollution, and improved safety for traffic participants, increased accessibility, and easier travel planning. Smart mobility enables the creation of a healthier and safer living environment for both city residents and tourists.

With advancements in autonomous vehicles, electric vehicles, MaaS systems, ITS and ICT, there is even greater potential for innovation and progress in transportation. While there are certain challenges associated with the implementation of smart mobility systems, there is also significant scope for the development of modern transportation systems aimed at meeting all societal needs and enhancing the quality of life for future generations.

Two key concepts that will influence the development of smart mobility in the near future are freight transportation and a significant shift towards MaaS service for passenger transport. In both cases, the Internet of Things (IoT) and Artificial Intelligence (AI) will play an increasingly important role in the future development of smart mobility concepts in cities.

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ORIGINAL SCIENTIFIC PAPER

Protection of Pedestrians from Collisions With Motor Vehicles

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Abstract: New vehicle models must be homologated in accordance with EC regulations on pedestrian protection. In this article, an analysis of traffic accidents and pedestrian injuries was presented first, as a result of expert examinations, and then appropriate solutions are presented for the design of the front part of the vehicle with the aim of reducing serious injuries. The severity of injuries caused by a vehicle hitting a pedestrian depends mostly on the speed of the vehicle and the shape of the front part of the vehicle. Relevant indicators of vehicle collisions with pedestrians point to inappropriate speed and late detection of pedestrians by the driver. Current technology offers active prevention of vehicle collisions with pedestrians and mitigation of the consequences of a collision if one occurs. The tendency of the development of pedestrian protection is set on the development of combined active-passive protection. Based on the pedestrian protection criteria, the method of optimizing passive systems and the method of testing protection in accordance with European regulations is presented. These are, first of all, lift-up engine bonnet, the windshield and the pedestrian airbag, which can reduce fatal injuries. The Euro NCAP program publishes the results of testing new vehicle models with regard to pedestrian protection. This increases social awareness of the importance of using technology to protect pedestrians.

Keywords: pedestrian injury, vehicle design, integrated pedestrian protection, HIC criterion, pedestrian protection test.

INTRODUCTION

Vehicle collisions with pedestrians are the cause of numerous fatal injuries. The most common driver mistakes that cause pedestrians get hurt are inappropriate speed and late spotting of pedestrians, and not respecting the pedestrian right of way, while the most common mistakes of pedestrians are improperly crossing the road and crossing the road while a red light sign at a traffic light was on. The article first presents the analysis of traffic accidents and injuries to pedestrians, as a result of the conducted expert examinations, and then presents appropriate solutions for the design of the front part of passenger vehicles with the aim of protecting and reducing pedestrian injuries.

In order to increase the protection of pedestrians, the advanced technology offers active prevention of a vehicle hitting a pedestrian and mitigating the consequences of a collision if it occurs. Active systems use technologies to recognize the danger of a vehicle hitting a pedestrian. Vehicles are equipped with sensors and cameras to warn of danger, and in case of lack of timely reaction of the driver, they brake and stop automatically.

If a collision occurs, passive systems reduce injuries to pedestrians, especially to the head and legs. These are, firstly, raising the bonnet and airbags for pedestrians, which can reduce fatal injuries. The combination of active and passive systems provides the greatest protection for pedestrians, considering the available energy of these systems. Such integrated protection provides more protection options and reporting to the traffic rescue service (eCall). Pedestrian protection tests are carried out on new vehicle models in the process of their homologation. The Euro NCAP program publishes the results of tests on new vehicle models and on pedestrian protection. This increases social awareness of the importance of pedestrian protection.

CHARACTERISTICS OF A VEHICLE COLLISION WITH A PEDESTRIAN

The vehicle-pedestrian collision contacts are shown in Figure 1a. The 68.5% of all collisions with pedestrians belong to the frontal part of the vehicle [1]. The front right part of the vehicle has a significant share of collisions with pedestrians, 32.2%. The consequences of a vehicle hitting a pedestrian are shown by the injury curve [2], Figure 1b.

If a vehicle hits a pedestrian at a speed of 30 km/h, the probability of a fatal outcome is 10%, but if a vehicle hits a pedestrian at a speed of 50 km/h, this increases to 85%. This means that increasing the speed by only 20 km/h increases the probability of the most severe outcome more than 8 times. The largest number of traffic accidents occur at speeds of up to 40 km/h, which is taken by regulations as the reference speed for testing collisions with pedestrians.

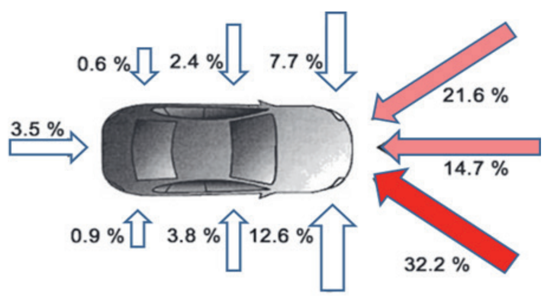

Figure 1a. Vehicle-pedestrian collision contact positions

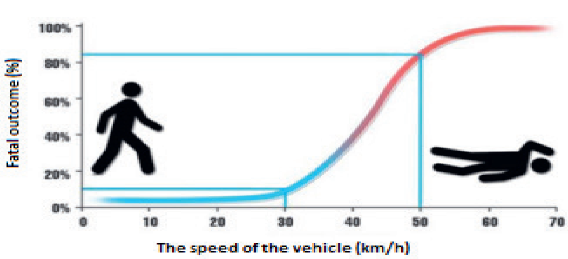

Figure 1b. Consequences of a vehicle hitting a pedestrian

Source: Crash of a vehicle into a pedestrian, 2016:12

The frequency of injuries to pedestrians in the front part of the vehicle is as follows: head injuries on the engine bonnet amount to 26.9%, and on the windshield 19.0% [1]. Thigh/pelvic injuries on the front edge of the engine bonnet are 21.2% and leg injuries are 42.6%. The higher the vehicle speed, the closer the path of the head is to the upper side of the windshield or even further towards the frame of the glass, so fatal injuries are possible. Severe injuries cause disability and treatment costs, i.e. large costs for society. Considering the population of pedestrians, the consequences of injuries differ. The elderly pedestrian population is the most vulnerable. Most traffic accidents occur when the driver brakes the vehicle, Figure 2.

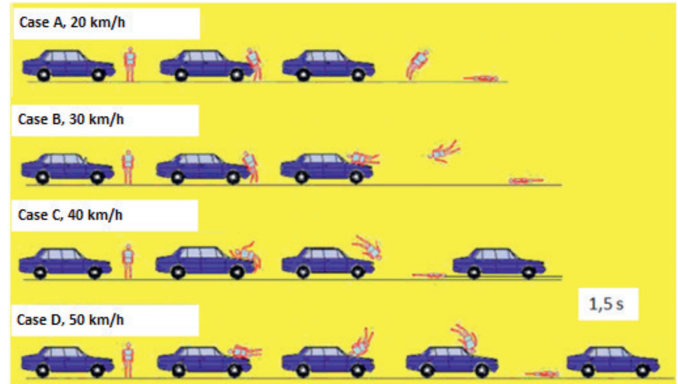

Figure 2. Trajectory of a thrown pedestrian's body as a result of a vehicle collision

Source: Multibody numerical a simulation for vehicle, 2007.

The first phase of the collision consists of the impact itself and the carrying of the pedestrian by the vehicle. In the second phase, the pedestrian's body is separated from the vehicle and the body is thrown, until the body touches the pavement. The third phase of the collision consists of the sliding of the pedestrian's body on the road until the moment when the body, due to friction on the ground, stops. The basic crash research scenario is a case where a pedestrian is moving at walking speed and sideways facing an oncoming limousine type vehicle. The trajectory obtained by a side-impacted and thrown pedestrian can be grouped into several schemes, in a time of up to 1.5 seconds [4]:

- Case A: bump at low speed, 20 km/h, vehicle brakes.
- Case B: vehicle hits a pedestrian at a speed of 30 km/h, the vehicle brakes, the pedestrian hits the bonnet and slides towards the windshield; it is thrown off and slides along the ground to a stop.
- Case C: the vehicle collides with a speed of 40 km/h, the vehicle brakes, the pedestrian is ejected.
- Case D: a vehicle hits at a speed of 50 km/h, without braking the vehicle, due to the combined effect of the speed and the shape of the vehicle, the pedestrian gets a rotation, turns over the vehicle and falls behind the vehicle.

An experienced driver will, sooner than an average driver, react to the brake faster and thus reduce the speed of the collision. The driver and the BAS (Brake Assist System) automatic brake together will react even faster to an increase in braking force, so the vehicle will stop sooner. If the driver is not concentrating on driving or the road is wet, the stopping distance of the vehicle increases.

The higher the speed of the vehicle, the shorter the time the driver needs to stop the vehicle and avoid hitting a pedestrian. Taking into account the time it takes the average driver to react and brake, a mid-range vehicle traveling at 50 km/h typically requires 36 meters of stopping distance, while a vehicle traveling at 40 km/h takes 27 meters to stop.

ANALYSIS OF TRAFFIC ACCIDENT WITH PEDESTRIANS

More than 1.25 million people worldwide die annually due to traffic accidents on the roads [3]. 25,500 people lost their lives on EU roads in 2016, and another 135,000 people were seriously injured. Almost 50% of those killed are: pedestrians, cyclists and motorcyclists. Of these, 22% of pedestrians die. The EU's goal is to reduce traffic fatalities by at least 50% by 2020.

According to the Bulletin on Road Traffic Safety 2016 [5], the characteristics of pedestrian fatalities in the Republic of Croatia are shown in Figure 3 and Table 1. Pedestrian collisions, accounting for 19.9% of fatalities, are in third place among the total number of traffic fatalities. in relation to direct collisions and vehicle landings. Therefore, the statistics of pedestrians killed in the Republic of Croatia do not differ significantly from the European data. About 61.7% of pedestrians die from collisions with personal vehicles, which is significant for this research, followed by 15.8% from motorcycles. Out of a total of 307 road users killed, 67 pedestrians - or 21.8% were killed, 419 seriously injured and 1060 lightly injured. The bulletin brings more detailed consequences with regard to a particular population. In general, the number of pedestrian casualties is extremely high for our society, but also difficult to accept economically, both due to the decline in the gross social product and the slow recovery. This is why regulations on measures to reduce pedestrian injuries are adopted and accepted.

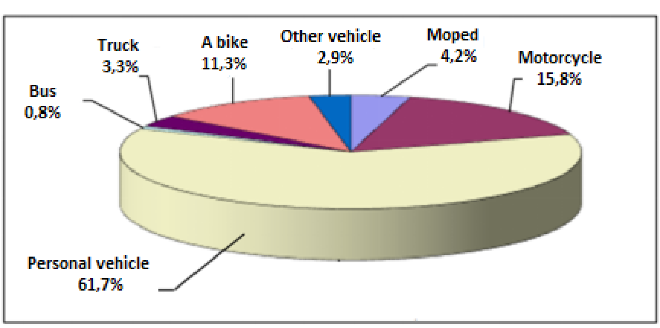

Figure 3. Persons killed by type of vehicle

Table 1. Victims of traffic accidents by type in 2016

Types of participants	Killed		Injured			
	total	%	severe	%	minor	%
Drivers	186	60,6	1.762	64,1	7.127	60,1
Passengers	54	17,6	566	20,6	3.660	30,9
Pedestrians	67	21,8	419	15,3	1.060	8,9
Other					2	0,0
TOTAL	307	100	2.747	100	11.849	100

Source: Road Traffic Safety Bulletin 2016, MUP, 2017:39, 2017:42.

On the basis of the conducted expert reports on collisions of personal vehicles with pedestrians through long-term judicial practice (>15 years), collisions of vehicles with pedestrians on city and suburban roads were analyzed in the time period from 2002 to 2017 (Table 2). Classifying traffic accidents during the performance of traffic accident expert examinations according to the type of road out of the total number of traffic accidents (90), 73 traffic accidents occurred in the settlement or city, or about 81% (Table 2). Of these, 28 traffic accidents, or about 38%, occurred on the road in the settlement (city). 45 traffic accidents, or about 62%, occurred at intersections in the settlement (city). The most common collision speed of vehicles on pedestrians in cities (settlements) is 30-40 km/h, which accounts for about 66% of the total number of collisions with pedestrians. The most common way of getting hurt is running over pedestrians. 17 traffic accidents occurred on the roads outside the cities, or about 19% (Table 2). The most common collision speed of vehicles on pedestrians is 40-50 km/h, which accounts for about 41% of the total number of collisions with pedestrians. Running over pedestrians who were lying on the road makes up about 18% of accidents.

INTEGRATED PEDESTRIAN PROTECTION

Integrated protection is a combination of the application of active and passive pedestrian protection systems (primary and secondary protection), known as CAPS (Combined Active & Passive Safety), with its functions it protects the driver, passengers and pedestrians from serious injuries. The development trend of these systems is to connect different independent systems, which develops new protection functions [12]. Such integrated systems provide more potential than the independent development of each individual system.

Vehicle manufacturers are developing an intelligent integrated system that recognizes the type and intensity of collisions and adjusts the operation of the pedestrian protection system. Based on the data of the sensor system, dangerous driving and a collision with a pedestrian are determined, when the vehicle automatically prepares for a potential collision. In the event of a safe collision with a pedestrian, a contact or non-contact passive protection system, such as the bonnet and pedestrian airbag, is activated, then information is sent to the traffic rescue service (eCall). Since 2018, this system is mandatory on new vehicle models of all manufacturers. The eCall system contacts the emergency services, and at the same time has the ability to send the exact time of the accident, location and direction of travel. This is extremely important in the event of an accident on the highway. The system can also be activated manually using the button on the front armature, when it will be called 112. This increases the protection of passengers and pedestrians.

Renowned motor vehicle manufacturers already

Table 2. Numerical indicators of traffic accidents in cities and outside cities (settlements) from 2002-2017

	Pedestrian movement mode	Pedestrian position at the time of collision	Vehicle collision speed (km/h)	Number of collisions	Pedestrian movement mode	Pedestrian position at the time of collision	Vehicle collision speed (km/h)	Number of collisions
	indicators of traffic accidents in cities				**indicators of traffic accidents outside cities**			
1.	Walking normally	Head-on impact - pedestrian facing sideways	10-30 30-40 40-50 > 50	1 14 3	Walking normally	Head-on impact - pedestrian facing sideways	10 - 30 30 - 40 40 - 50 > 50	1 1 4
2.	Walking normally	Side impact -slightly bumped laterally	10-30 30-40 40-50 > 50	1				
3.	Walking normally	Head-on impact - pedestrian facing sideways	10-30 30-40 40-50 > 50	2 8				
4.	Walking normally	Side impact -slightly bumped laterally	10-30 30-40 40-50 > 50	4 2 2				
5.	running over	Head-on impact - pedestrian facing sideways	10-30 30-40 40-50 > 50	6 12 1	running over	Head-on impact - pedestrian facing sideways	10 - 30 30 - 40 40 - 50 > 50	4
6.	running over	Side impact -slightly bumped laterally	10-30 30-40 40-50 > 50	4 12 1				
7.					accelerated pedestrian	Head-on impact - pedestrian facing sideways	10 - 30 30 - 40 40 - 50 > 50	1 3
					----------	lying on the road		3
			Total:	73			Total:	17

deliver vehicles with an active AEB (Autonomous Emergency Braking System) braking system as standard equipment. It is an autonomous emergency braking system (AEB), which detects the possibility of a collision with objects in front of the vehicle while the vehicle is moving in order to avoid or mitigate the collision, with automatic brake activation. Braking level varies up to ABS braking. Since 2015, AEBS braking systems have been introduced in new vehicles of category M2, M3, N2 and N3. The European Commission plans to mandate the mandatory installation of the AEB system in all new M1 vehicles in 2020 [8].

Studies have been carried out to assess the effectiveness of advanced active and passive pedestrian protection systems, and their combination in an integrated system [9]. The study concluded that the passive system can reduce 34% of severe head injuries (AIS 3+), and the active system 44%, Figure 4. Their combination into an integrated system is even more successful (64%), which significantly reduces serious head injuries (AIS 3+). AIS (1-6) medically determines the degree of head injuries. Research has shown that primary and secondary systems complement each other, in order to increase the protection of pedestrians, so the development of the potential of integrated systems follows. The integrated system, for example, detects a pedestrian about 0.3-1.0 seconds before the collision, which enables earlier activation of the bonnet than is normal with a contact sensor. The integrated concept opens up possibilities for countermeasures of protection in the front part of the engine bonnet, before a collision.

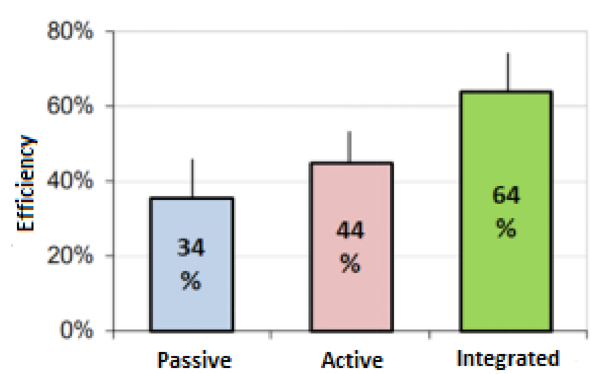

Figure 4. Efficiency of passive, active and integrated systems

Source: Priorities and Potential of Pedestrian Protection, 2011.

EUROPEAN REGULATIONS FOR PROVING PEDESTRIAN PROTECTION

The EC regulation on the homologation of motor vehicles with regard to the protection of pedestrians and other unprotected road users [6] [7], sets requirements for pedestrian protection and the test procedure. The start of application is related to the level of demand (2,3,4). The final date of application for the M1 (≤ 2.5 t) category of passenger vehicles is 24 February 2018, for M1 (> 2.5 t) 24 February 2019, for the N1 category of commercial vehicles is 24 August 2019. Leg and head models are used for testing, which are pointed or fired at the front of the vehicle, Figure 5. Testing with a full manikin is not controllable, as it is not certain where the pedestrian will hit body parts, especially the head on the vehicle. At the reference vehicle collision speed, compliance with the criteria for protection of body parts, lower leg, upper leg/thigh, child's head, adult's head is determined. Impact zones are rated as good enough, weak or bad.

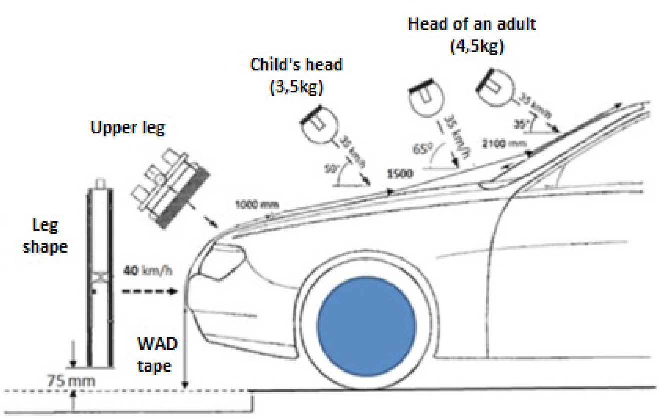

Figure 5. Elements of passive pedestrian protection test

Source: Euro NCAP, 2017.

The following vehicle tests for pedestrian protection are mandatory:

a) Leg (legform):
(1) Collision of the lower leg model with the bumper;
(2) Collision of the upper leg model with the bumper;
(3) Collision of the model of the upper part of the leg with the front edge of the front engine bonnet.

b) Head (headform):
(1) Head model collision of a child/small adult with the upper surface of the engine bonnet (speed/mass/angle : 35 km/h/3.5 kg/500);
(2) Head model collision of an adult with a bonnet (35 km/h / 4.5 kg / 650);
(3) Collision of adult head model with windshield (35 km/h / 4.5 kg / 350).

c) Testing the maximum deceleration of the vehicle (BAS braking function).

Considering the height of the bumper, the criteria for protection of the lower part of the leg (lower height of the bumper h ≤ 425 mm, and ≥ 500 mm) and protection of the upper part of the leg/thigh differ. Technical criteria for pedestrian protection homologation tests are given in Table 3. The greatest attention is paid to head protection. Brain injury is responsible for the majority of pedestrian fatalities, so the assessment of protection is based on head impact endurance criteria. In order to avoid serious injuries, the impact acceleration (de-acceleration) for the head of a child and an adult should be less than 100g (1000 m/s2) in a time of 15 ms. That value is called the HIC value (Head Injury Criterion or HPC value, Head Protection Criteria).

Table 3. Criteria for pedestrian protection homologation tests (in accordance with EC Regulation No. 78/2009, and EC No. 631/2009)

Test	Description	Condition	Parameters	Criteria
LEG	Lower leg, collision with the bumper	Impact speed 40 km/h Bumper height h ≤ 425 mm	Acceleration of the lower leg Bending angle Shear displacement	a ≤ 200g a ≤ 21^0 d ≤ 6 mm
	Upper leg, collision with the bumper	Impact speed 40 km/h Bumper height h ≤ 500 mm	Total impact force Bending moment	≤ 7,5 kN ≤ 510 Nm
------- Thigh	The upper part of the leg collides with the front edge of the bonnet	Impact speed 40 km/h Impact angle 10^0-45^0	Total force Bending moment	≤ 5 kN ≤ 300 Nm
HEAD	Child (impact on the front surface of the car bonnet)	Impact speed 35 km/h Weight of the head model 3.5 kg Angle of impact 500^0	HIC ½ of the area 2/3 of the combined area 1/3 of the area	≤ 1000 ≤ 1000 ≤ 1700
	Adult (impact on the rear surface of the car bonnet)	Impact speed 35 km/h Weight of the head model 4.5 kg Impact angle 650^0	HIC 2/3 of the area 1/3 of the area	≤ 1000 ≤ 1000 ≤ 1700
	Adult (windshield impact)	Impact speed 35 km/h Weight of the head model 4.5 kg Impact angle 350^0	HIC 5-9 points	≤ 1000

From a biomechanical point of view, the maximum level of forced deceleration of 100g must not be exceeded, which is set as the basic HIC protection criterion. A pedestrian hits the bonnet or windshield with his head. It is necessary to develop a bonnet and a windshield whose HIC values are lower than 700 [1]. Euro NACP maintains a stricter threshold for accepting a head HIC value of 650, as a zero level of protection [11], without a head fracture.

ACTIVE PEDESTRIAN PROTECTION

Each protection system has its advantages, however, a combination of active systems contributes more to the protection of pedestrians than each system on its own. In accordance with the general plan for the introduction of regulations for new models [8], starting on 01 September 2020, with two years of monitoring, and obligations for all vehicles on 01 September 2024, the introduction of the following combined active systems is foreseen, which increase pedestrian protection:

- AEB - autonomous emergency braking system (Automatic Emergency Braking System / M1, N1, for M1 and N1 vehicle categories),
- LKA - lane keeping assistance system (Lane Keep Assistance / M1, N1),
- Driver drowsiness and distraction monitoring (Driver Drowsiness and Distraction Monitoring / M, N),
- ISA - speed adaptation warning system (Intelligent Speed Adaptation / M, N).

The autonomous system provides assistance in several steps, Figure 6.

The radar system detects objects and maintains the distance between vehicles. This ACC (Adaptive Cruise Control) system is a cruise control of the selected desired speed and distance, which is already available in the vehicles of renowned manufacturers. At lower driving speeds of up to 50 km/h, it acts as an AEB emergency braking system, called the City function. If there is a risk of a collision, the driver is warned visually and audibly of the potential risk of a collision. whether the front object is at rest or driving in the same direction. After that, the driver has time (t1) to act on the brake pedal or the steering wheel to avoid a collision. If the driver does not react by braking in time (t2), the system automatically assists with pre-braking (B) and slows down the vehicle until time (t3). If the system estimates that a collision is unavoidable, the pre-crash brake (C) is activated to reduce the speed and thus the consequences of the collision.

The advanced autonomous emergency braking system AEB uses a combination of radar and camera to detect a potential collision with another vehicle or a pedestrian or cyclist [22], Figure 7. If the driver does not respond to these warnings, the system activates the brakes and slows down or stops completely vehicle. This pedestrian detection system can completely avoid running into a pedestrian at lower speeds of up to 30 km/h. At speeds up to 80 km/h, AEB reduces the collision speed of the vehicle, and thus the consequences of the collision. The system is set to avoid unwanted hard braking that can cause a rear-end collision with the following vehicle. The task of the radar is to detect objects in front of the vehicle and determine the distance from them. The camera then determines which object it is. The flashing appearance of a figure of a pedestrian on the display and an audible alarm warn of the danger of pedestrians. Thanks to the double field of vision of the radar, the difference between pedestrians and cyclists is revealed. In addition, the high-resolution camera enables the detection of movement characteristic of pedestrians and cyclists [24].

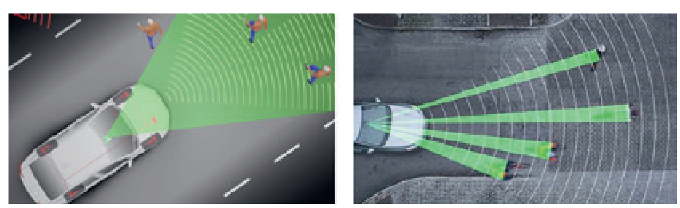

Figure 7. Radar and camera in the system for detecting the danger of collisions with pedestrians and cyclists

Source: Pedestrian and Cyclist Detection with full auto brake, 2017.

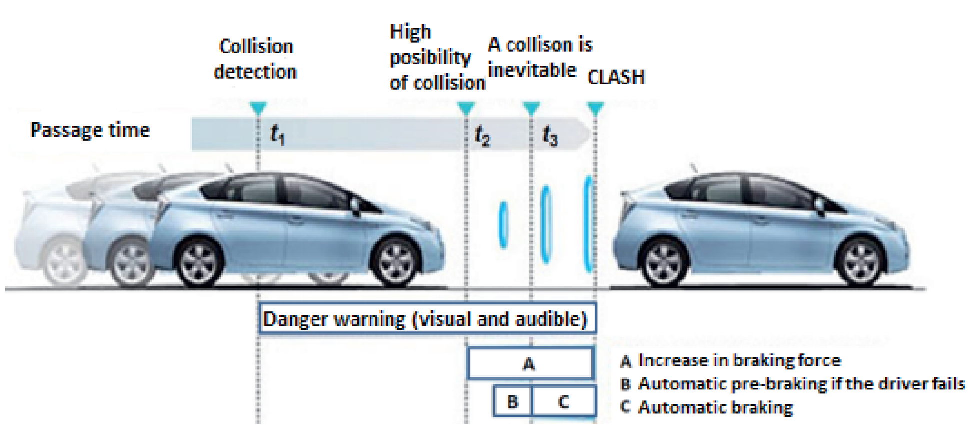

Figure 6. Scheme of the autonomous braking system using radar

Source:https://www.toyota-europe.com/world-of-toyota/safety-technology/pre-crash-safety, IV-2018.

PASSIVE PEDESTRIAN PROTECTION

The front part of the vehicle is important for the function of driving visibility, aerodynamics, design perception and engine maintenance. The principles of safety development, which contribute to the protection of drivers and passengers in the vehicle, are transferred to the principles of pedestrian protection. With a well-designed bumper and engine bonnet and windshield, serious injuries to pedestrians can be reduced.

In addition to collision speed and vehicle mass, the shape and stiffness of the front part of the vehicle have a great influence on the severity of pedestrian injuries. A heavier vehicle needs more deceleration energy. Raised crossovers and larger SUVs cause more serious injuries to pedestrians. The design of the front part of the vehicle and the stiffness properties have a dominant influence on the severity of injuries. Therefore, the risk of pedestrian injury is a function of the vehicle model.

Bumper

The bumper consists of the front lower outer parts of the vehicle structure, including the elements attached to them. In accordance with the trend of pedestrian protection and front styling, modern cars are rounded and pointed at the front, without sharp edges.

Deformation foam is installed in the bumper to soften the impact, which reduces the risk of serious leg injuries. The front part of the bumper support is deformed in a targeted manner, which prevents serious injuries to the legs. In case of a stronger impact, shock absorbers take over the damping. The height of the bumper is quite different depending on the vehicle class. According to the test criteria (Table 3), two reference bumper heights are distinguished: vehicles with a lower bumper height ≤ 425 mm and vehicles ≥ 500 mm, and a bumper height between 425 and 500 mm provides the manufacturer with one or the other choice of homologation. For the lower height of the bumper h ≤ 425 mm, at the initial speed of the vehicle of 40 km/h and the collision of the lower part of the leg with the bumper, the maximum bending angle of the knee must not exceed 21°, the maximum displacement by shearing of the knee (shear displacement) must not exceed 6.0 mm and the acceleration measured on the upper part of the shin must not exceed 200g, Figure 8a. For the height of the bumper h ≥ 500 mm, the upper part of the leg, in case of collision with the bumper, has other protection criteria: total impact force ≤ 7.5 kN and bending moment ≤ 510 Nm.

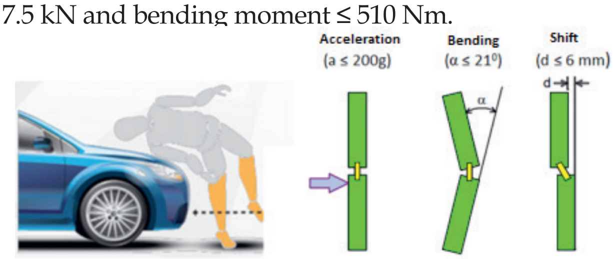

Figure 8a. Pedestrian leg model and protection criteria

Source: Current Trends in Bumper Design for Pedestrian Impact, 2004.

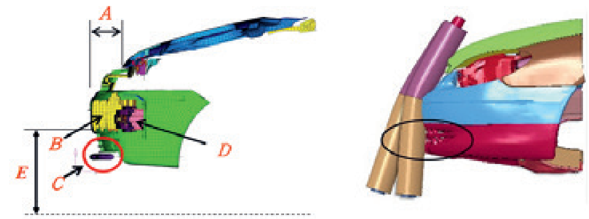

Figure 8b. The structure of the bumper and the shape of the collision between the leg and the bumper

Source: Advanced Simulation Techniques for Low Speed Vehicle Impact, 2007.

In order to achieve the best crash results for pedestrian protection, speed and protection activation time matching is performed. For example, accidental impacts to the bumper at low speeds (up to 15 km/h, when parking the vehicle) do not leave traces of deformation on the radiator, condenser of the air conditioner, etc. In the range of 20-50 km/h, pedestrian protection is activated by raising the engine bonnet, and in the event of a frontal collision, high speeds and deceleration (30-40g), shock absorbers are activated in the front deformation zone of the vehicle, in order to protect the driver and passengers in the vehicle. One can distinguish between plastic bumpers with inserted deformation foam to soften the impact and more adaptive bumpers that allow greater displacement of the elastic-dampening Crash absorber, without damaging the vital parts of the engine [14]. A bumper with a larger homogeneous reaction surface provides more protection for the legs from injuries. (D - bumper support, E - lower bumper height, B - deformation foam). Limiter C, which acts as a front spoiler, reduces the bending of the leg and the tucking of the leg under the bumper, Figure 8b.

Engine bonnet

The pedestrian hits the front edge of the engine cover with the upper part of his leg. The front edge of the bonnet should absorb the kinetic energy of the thigh impact, without fracturing the pelvis. At an impact speed of 40 km/h and an impact angle of 10-450, the protection of the pedestrian's upper leg is tested. The sum of the impact forces from the three tests must not exceed 5 kN and the bending moment of 300 Nm, while the kinetic energy of the impact should be greater than 200 J. The deformation of the front bonnet should be taken over by the protection belt - the area before the mechanism lock [15].

The most common area of impact of a child's head and the impact of an adult's head on the surface of the engine cover and windshield is determined statistically. The head protection area of a child is 1000-1500 mm, which is determined using a WAD measuring tape, and the head area of an adult is 1500-2100 mm, Figure 5. The simulation of the impact of a pedestrian of average height (175 mm) on an active bonnet is shown in Figure 9. Reference the impact speed of the head model of an adult (mass 4.5

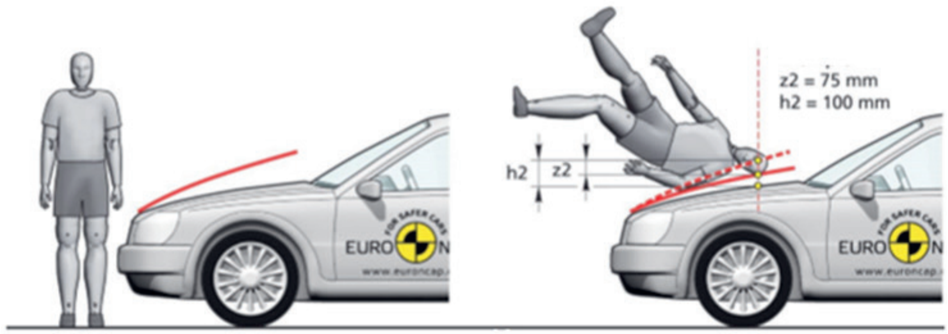

Figure 9. Simulation of a pedestrian impact on the active bonnet of the vehicle [11]

kg) on the upper surface of the bonnet is 35 km/h (9.7±0.2 m/s), at an impact angle of 650 (Table 3).

A modern bonnet is defined from the conditions of aerodynamics, design and energy absorption of head impact. The inclination of the engine bonnet towards the front is up to 100. The possibility of a vertical impact of the head on the surface of the engine bonnet is avoided, therefore the concept of a lifting or active bonnet is used. For the same head impact energy, the increased slope of the cap provides a smaller depth of deformation, i.e. less head injury.

If the bonnet is not well designed, the pedestrian can suffer serious injuries to the vital organs of the head, neck and shoulders. Vehicles have very stiff parts under the bonnet, sometimes with a gap of less than 20mm. That distance is too small and does not provide enough space to absorb the energy of a head impact. A deformation space of 75 mm of the metal cover is considered to provide sufficient protection of the head of an adult pedestrian, both from the engine and from other assemblies. In addition to the slope of the bonnet, the length of the bonnet also plays an important role in protecting the pedestrian. In the case of a shorter bonnet, the pedestrian is likely to come into contact with the A-pillar - an area of very high stiffness, resulting in an increased risk of head injury.

A lower engine and an increase in the space for deformation of the bonnet increases the protection of pedestrians. Reducing the weight of the head impact near the bumper is usually solved by changing the design of the bonnet, from the form of an inlaid bonnet to the form of a rounded bonnet (Inlaid / wraparound type) [18].

Engine bonnet design optimization for a specific vehicle model is performed based on several requirements: torsional stiffness, HIC value, depth of deformation and reduction of bonnet mass, and vibrations. The engine bonnet consists of two layers (panels): an outer sheet and an inner structure. The choice of material, profile and thickness of the layers is the most important in reducing serious head injuries. The materials used for the outer layer include sheets of steel, aluminum, plastic, and carbon fiber. The internal structure of the cap is key to achieving the cap's rigidity and absorbing impact energy and reducing head injuries. The concept of an internal structure made of sheet steel with a multi-cone profile and variable depth offers an optimal engine bonnet design concept. For example, the multi-cone design provides: cone angle range 1200 to 1600, cone depth 5 to 15 mm. Different combinations of outer and inner panel thicknesses are possible within the combined thickness of 1.6 mm (outer panel 1.1 mm, inner 0.6 mm, or equal thickness 0.8+0.8). The weight of such a limousine bonnet is about 19 kg. This ensures HIC values well below 1000, and a deformation space of 70 mm. For example, the combined thickness of the steel cover in the VW Golf and Toyota Auris is 1.5 mm, in the Mazda 6 it is 1.35 mm, and in the Ford Taurus 1.45 mm). An alternative aluminum bonnet concept of the same profile requires a combined thickness of 2.1 mm (outer panel 1.5 mm, inner 0.6 mm, or equal thickness 1.0+1.0) and a deformation space of 85 mm. The mass of such a lighter bonnet is about 9 kg. For example, the combined thickness of the aluminum bonnet in Volvo S60 and Renault Laguna vehicles is 2.3 mm, in Opel Insignia it is 2.0 mm, and in Audi A8 and Mercedes E-class 2.2 mm).

Windshield

Windshields are the cause of a large number of head injuries to pedestrians. More serious injuries on the windshield are associated with a higher initial speed of the vehicle and, accordingly, a greater impact of the head on the windshield, which can be at a smaller or larger angle of the glass (300-700). A larger slope of the glass is found in smaller passenger cars with a steeper slope of the bonnet, and a smaller slope in larger vehicles. A larger angle is the cause of a more vertical impact and greater head injuries (therefore, the installation of a pedestrian airbag is suggested).

A smaller windshield angle allows for less head penetration depth and ricocheting, resulting in less head injury, lower HIC values. Laminated glass is used to make windshields, with a thickness between 4-5 mm. Laminated glass consists of two layers of glass of different thicknesses, between which a layer of safety PVB (polyvinyl butyral) film is inserted. The thickness of the outer layer is from 1.8 -3.15, the foil is 0.76 mm, and the thickness of the second layer is 1.8-2.1 (usually 2.1+0.76+1.6) [17].

The windshield center head impact test area is shown in Figure 10. A minimum of 5 windshield impact tests shall be conducted with the head model at locations considered most likely to cause injury. The selected points must be 82.5 mm inside the edges of the windscreen. Testing with a 4.5 kg head model is performed at an angle of 350 and an impact speed of 40 km/h. The impact force of the head reaches up to 600 N, with glass breaking. The initial high acceleration is followed by a phase of glass crack propagation. Energy absorption depends on the properties of the windshield. The rigid area of the glass, around the wiper block, the area along the A-pillars and the edges of the glass, has high HIC values (> 2000), which makes these positions dangerous. The proximity of the test impact point to the A-pillar should be 110 mm away, whereby the HIC should be ≤ 1000. In order to mitigate the impact on the A-pillars, some manufacturers protect the pillars with an absorbent coating.

The force of the head hitting the windshield:
$F = m\,a_{R,}$ m – mass of the head a_r – resulting acceleration (x, y, z):
$a_r = F/m$, $HIC = f(a_r, t_1 - t_2 \leq 15\ \text{ms}) \leq 1000$

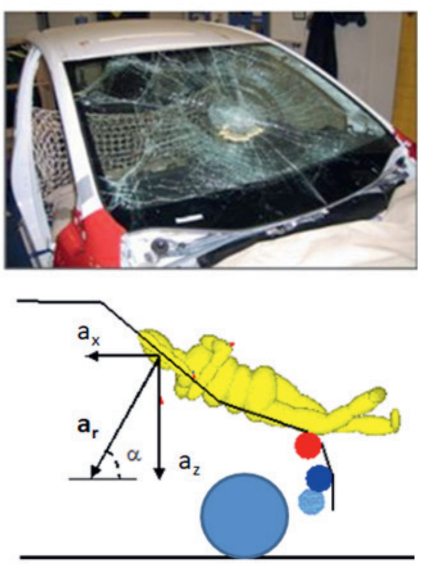

Figure 10. Parameters of the impact of the head on the windshield

Pedestrian airbag

The airbag covers the dangerous area along the A-pillars and glass edges, and 2/3 of the windshield, resulting in an impact mitigation effect, i.e. accommodating the pedestrian [10]. The installation of a pedestrian airbag cushions the impact of the head and reduces the HIC far below 1000. The airbag system is standardly installed in the Volvo V40 hatchback. Seven sensors are used for pedestrian detection [19]. When a pedestrian is detected in front of the vehicle, at speeds between 20 and 50 km/h, the airbag is activated. When activated, the rear part of the aluminum engine bonnet is released. At the same time, the air bag is filled with gas and the engine bonnet is inflated by 100 mm, Figure 11. In larger luxury vehicles and SUV-type vehicles, the head most often falls on the engine cover, so the installation of an air bag for pedestrians is not yet foreseen.

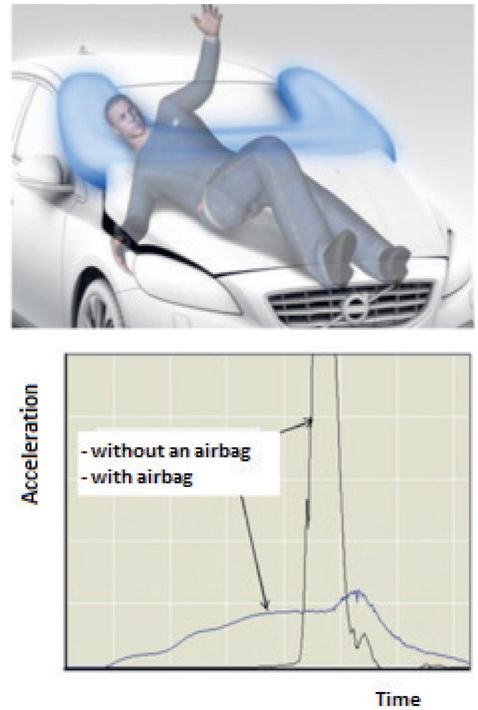

Figure 11. Acceleration of the head on the windshield, with and without an airbag

Source: Pedestrian Airbag Technology - a Production System, Volvo V40, 2015.

A comparison of the acceleration of the head at one point of impact on the airbag, with and without an airbag, is shown graphically. It can be seen that the airbag significantly reduces the deceleration and thus the HIC value. Due to the raised hood, the head impact distance from the risk position is increased, which also provides a reduction in impact compared to the bonnet position without the airbag. The airbag is made in the shape of the letter U, in order for the driver to maintain visibility while driving. The lower part of the cushion and the sides cover dangerous places for a pedestrian.

Research has shown that the airbag should be extended by 200 mm, from the current 2100 to 2300 mm, which increases protection from 60% to 90% of all injuries [9]. Based on the impact of the head on the airbag, and according to the equation of Mizuno and Kaiser, the HIC value can be calculated [23]:

$$HIC = 0.001882 \cdot V_0^{\,4} \cdot X_d^{\,-1.5}$$

V_0 – initial velocity, X_d – dynamic deformation

For example, the required dynamic cushion deformation should be greater than 94 mm in order to obtain an HIC value of less than 1000 at a speed of 40 km/h (head mass 4.5 kg, angle 350).

EURO NCAP PEDESTRIAN PROTECTION TEST

Euro NCAP (European New Car Assessment Programme) is a European program for assessing the protection of new vehicles (Brussels). The program is supported by the European Commission, seven European governments, as well as vehicle manufacturers and consumers in each EC country. Euro NCAP publishes test results and comparison of vehicles in terms of passenger and pedestrian protection. Four areas are evaluated: protection of adult passengers, protection of children, protection of pedestrians and driver assistance. It is assumed that the risk of injury to drivers, passengers and pedestrians is a function of the vehicle model or type. There are 12 positions for children, 12 positions for adults, 6 positions for the lower part of the leg and 6 positions for the upper part of the leg that are tested regularly (36 in total). To select a best-in-class vehicle, a weighted sum of points in each of the four evaluation areas is calculated. The result of pedestrian protection testing on two hatchback vehicles of the same class [11] is shown in Figure 12.

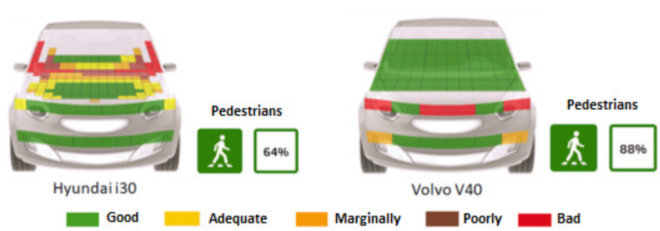

Figure 12. Assessment of pedestrian protection with and without an airbag

(Hyundai i30, Volvo V40). Source: Euro NCAP, February 2017.

The airbag technology integrated into Volvo V40 vehicles shows the best protection of the pedestrian's head. Head protection HIC values on the entire windshield are less than 650 (green, Table 4). The shortcomings are seen in the construction of the front edge of the engine bonnet which does not protect the pedestrian from serious injuries to the upper part of the leg (femur, pelvis). Total pedestrian protection is 88%, which is the highest result achieved in pedestrian protection testing so far.

Table 4. HIC pedestrian protection values (Euro NCAP, 2017)

$HIC_{15} < 650$	green
$650 \leq HIC_{15} < 1000$	yellow
$1000 \leq HIC_{15} < 1350$	orange
$1350 \leq HIC_{15} < 1700$	brown
$1700 \leq HIC_{15}$	red

CONCLUSION

The severity of injuries caused by a vehicle hitting a pedestrian depends mostly on the speed of the vehicle and the shape of the front part of the vehicle. Therefore, adequate pedestrian protection is required. The European regulation for the homologation of passive pedestrian protection systems was applied by all vehicle manufacturers (2009-2018), while the regulation of active systems is become mandatory from 2020. However, manufacturers of new vehicle models already offer complete active and passive pedestrian protection, as well as the option of semi-autonomous driving. It is considered that the regulation of vehicle protection contributes to the reduction of the number of pedestrians killed, as well as to the reduction of serious injuries at the expense of minor injuries.

The optimal engine bonnet design concept offers a profile of cones made of sheet steel (multi-cone) and variable depth. Equal HIC values can be achieved with a steel and aluminum engine bonnet. When the goal is to reduce the deformation space under the bonnet, sheet steel is the preferred choice, because the advantages of less deformation of the space are significant. If the goal is to reduce the mass of the bonnet, then aluminum sheet is the preferred choice, as it is 42% lighter than a steel cover, however, this requires more deformation space under the engine bonnet.

The airbag covers the dangerous area of the windshield, along the A-pillars and the edges of the glass, and 2/3 of the windshield, resulting in an impact mitigation effect. The pedestrian airbag cushions head impact and reduces HIC far below zero. It can be concluded that an airbag or other adequate innovative impact mitigation protection should be installed as standard in many A, B and C class M1 vehicles, which would significantly increase pedestrian protection.

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ORIGINAL SCIENTIFIC PAPER

Analysis of Traffic Accidents Caused by Overcome and Left Turn Actions in a Situation When the Vehicles Have Been Moved from the Face of the Place, and There Are no Tracks Found on the Road - A Case Study

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Abstract: The basis for a high-quality analysis of a traffic accident lies in the detailed investigation documentation, which includes precisely defined fixed positions of the vehicle and associated tracks. However, we often face the problem when the participants after the accident move the vehicles from the scene of the event for the smooth flow of traffic, before the competent authorities carry out an investigation or the European accident report is filled out. An additional difficulty arises when there are no visible traces left on the road that could be linked to the place and manner of the accident, which makes it difficult for experts to provide expertise. In such situations, experts must apply non-standard accident analysis methods. Therefore, the goal of this paper is to present, through a practical example of the technical analysis of a real traffic accident, one of the approaches to traffic accident expertise that is characterized by the described problem. The subject of the work are traffic accidents caused by overtaking and left turning, as one of the most common situations in which vehicle collisions occur. The example shows the method of determining the location of a vehicle collision in a transverse sense, the creation of a time-space analysis, and the possibility of avoiding an accident in which the drivers moved the vehicles from the accident site, and no visible traces were left on the roadway.

Keywords: Traffic accident, overtaking, left turn, absence of tracks, analysis.

INTRODUCTION

The analysis of a traffic accident implies the determination, calculation and analysis of material elements that can be obtained from the evidence collected during the investigation of a traffic accident. Such analyzes enable an objective assessment of the factual situation that existed at the time of the traffic accident or that possibly preceded the accident in a short period of time (Marković and Pešić, 2012).

The problem arises when the participants in the accident move their vehicles from the scene before the police officers carry out the investigation of the accident, without even photographing the condition, the positions of the vehicles and any traces of the accident. The reason for these procedures may be ensuring the smooth flow of traffic, filling in the European accident report or simply insufficient knowledge of the participants that such an action can destroy essential traces that are of key importance for the analysis of the accident.

Also, the provision of Article 158 of the Law on Basic Road Safety in Bosnia and Herzegovina, in which it is stated in paragraph 3 that after a traffic accident in which only minor material damage was caused, the participants are encouraged to move the vehicles from the scene. drivers are required to immediately remove vehicles from the roadway and to exchange personal data, and to fill in and sign the European Traffic Accident Report form.

According to the above, it is not a rare situation that an expert in the traffic profession, when preparing the expertise, has the task of performing a time-spatial analysis of the course of the accident, and to declare the possibility of avoiding it, based on documentation that does not contain data on the stopped positions of the vehicle after the collision, nor does it contain data about traces of the accident in the form of traces of braking, drifting or dispersion of fragments from the vehicle. Therefore, the aim of the work is to give guidelines on how to approach the expert examination of a traffic accident with a characteristic problem, in traffic accidents that occur during overtaking and left turns, and which situation represents one of the most common situations in which traffic accidents occur.

TRAFFIC ACCIDENTS IN OVERTAKING AND LEFT TURN

Overtaking is the passing of a vehicle next to another vehicle moving in the same traffic lane in the same direction (Law on Basic Road Safety in BiH, Article 9). The action of overtaking is one of the most complex actions in traffic, while the action of turning left is one of the most dangerous actions. Expertise of such traffic accidents, i.e. accidents where a collision occurs between an overtaking vehicle and a vehicle making a left turn are specific. Such accidents have some common characteristics, but each accident is also special for itself (Feher and Feher, 2016).

In the analysis of the traffic accident, the characteristic positions of the participants in the traffic accident represent the positions when the participants in the traffic accident could have been observed, when a dangerous situation arose, at what moment the driver reacted to the dangerous situation, when there was a change in the way the vehicle and other participants in the traffic accident were moving , as well as in what position the participants in the traffic accident were at the time of the collision (Vujanić and Ivanišević, 2015). The position of the participant at the time of the collision is the starting point of any time-space analysis, after which the other characteristic positions of the accident participants can be determined.

The location of the collision can be determined based on characteristic changes in the tracks of the vehicle’s movement, especially in traffic accidents with pedestrians, if the vehicle was forced to brake at the scene of the accident. At the time of the collision, the vehicles must be located immediately before the places where there are characteristic changes on the tracks of the vehicle’s movement (broken track, blackening of the track, interruption of the track, doubling of the track, shearing of the track, scratch marks, etc.). If the investigative documentation did not fix characteristic changes on the tracks of the vehicle’s movement, then the place of the collision can be determined approximately based on the position of the fallen characteristic parts or materials that fell from the vehicle (Marković et al., 2014).

In a situation in which, after the collision, the vehicles were moved from the scene of the accident, without their position having been previously fixed, and there are no traces on the roadway caused by the collision of the vehicles, there are no material elements that could be used to determine with certainty the place of primary contact vehicles in the longitudinal sense. However, in the case of overtaking and left-turning traffic accidents, based only on the analysis of visible damage to the vehicles, it is possible to determine the location of the collision of the vehicle in a transverse sense, and then perform a time-spatial analysis of the accident and an analysis of the possibility of avoiding the accident, which procedure is explained through an example in the continuation of the work.

EXAMPLE OF THE ANALYSIS OF A TRAFFIC ACCIDENT WITH A CHARACTERISTIC PROBLEM

The paper presents an example of the expertise of a traffic accident that occurred while overtaking and turning left, in which the stopping positions of the vehicle after the collision are not known, nor were any traces of the accident found on the spot.

Basic information about the accident

The traffic accident happened on 09.10.2023. year, on the regional road R1 - 2105, in the village of Donja Kola, the city of Banja Luka. The passenger car “Renault Megane” and the passenger car “Nissatn X-Trail” took part in the traffic accident.

In the Record of the investigation, in the column “description of the event”, among other things, the following was stated: “The traffic accident occurred when the driver of a passenger car of the brand “Nissan” was traveling on the regional road R1-2105, from the direction of Dobrnja in the direction of Banja Luka, and upon arrival in the immediate vicinity of the “Speed Petrol” gas station, he made a left turn, towards the area of the gas station, during which the left side of the vehicle made contact with the front right part of a “Renault” passenger car, which was moving on the same road in the same direction, and overtook a Nissan passenger car. After the traffic accident occurred, the participants moved the vehicles from the scene of the traffic accident.”

In Figure 1a. and 1b. a picture of the scene of the accident from the investigative photo documentation prepared by the PS for BS Banja Luka, as well as a sketch of the scene, was shown.

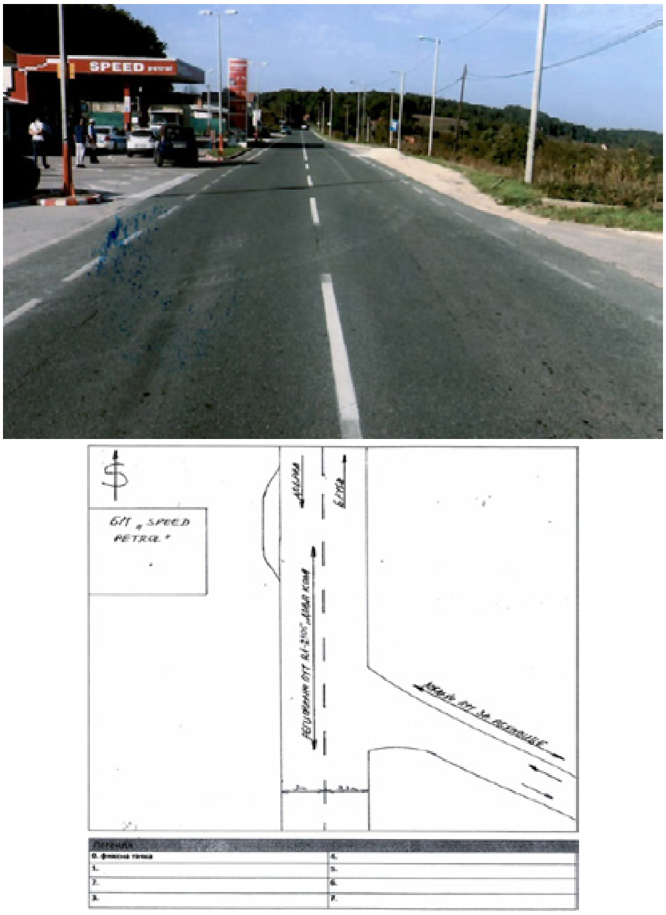

Figure 1. a) Appearance of the scene of the accident from investigative photo documentation ***b)*** sketch of the scene of the accident

The rear bumper, rear left side panel, rear left wheel, rear left door, front left door, left sill, front left fender and front bumper were damaged on the passenger car "Nissan X-Trail". The front bumper, front right headlight, front right fender, front right wheel, front right door, rear right door, rear right side panel and rear right wheel were damaged on the passenger car "Renault Megane".

Place of collision and collision position of the vehicle

Since after the accident both vehicles were moved from the scene, and there were no visible traces left on the roadway caused by the collision of the vehicles, there are no material elements on it that could determine the place of primary contact of the vehicles in a longitudinal sense.

In order to bring the vehicles into the collision position and determine the location of the collision in the transverse sense, it is necessary to first determine the collision angle between the longitudinal axes of the collided vehicles and the conflicting surfaces of both vehicles, based on the visible damage from the photo documentation.

The analysis of the damage caused to the vehicles shows that the impact force on the passenger car "Nissan X-Trail" acted diagonally, from the first half of the rear left door and the left "B" pillar to the front right headlight. On the passenger car "Renault Megane", the collision force acted along the vehicle, from the front right to the rear left corner, over the central part of the front right fender, the right wheel, the front and rear right doors.

Figure 2. a) damage to the passenger car "Nissan X-Trail" ***b)*** damage to the passenger car "Renault Megane"

A detailed and comparative analysis of the previously described damage to the vehicles and the direction of impact of the impact force, and bearing in mind their directions of movement immediately before the collision established in the Report of the investigation, it follows that the collision occurred with the front, far right part of the front bumper of the passenger car "Renault Megane" with the left by the side part of the "Nissan X-Trail" passenger car, in the middle of the rear left door and the left "B" pillar. At the time of the collision, the longitudinal axes of the vehicle overlapped each other at an angle of about 20.5°.

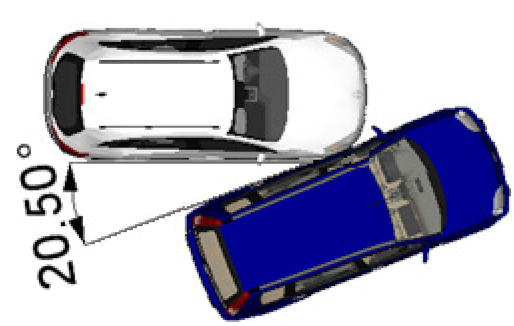

Figure 3. Collision angle between the longitudinal axes of passenger cars "Nissan X-Trail" and "Renault Megane

Table 1. Determining the turning angle of vehicles through the conflict zone (Society of Engineers and Technicians, Tables for Traffic Technical Expertise, Belgrade, 1991, page 12)

The location of the damage on the overtaking vehicle	The location of the vehicle damage in the left turn	The angle of the vehicle in the left turn [°]
Front right corner	Front left corner	5 – 15
Front right corner	Front left side half	15 – 30
Front right corner	Rear left side half	30 – 40
The front of the vehicle	Back left corner	40 – 60
Front left corner	Back right corner	60 – 65

The angle at which the vehicle turns to the left can also be adopted based on the conflict zones of the vehicle, according to Table 1. In the specific case, the front right corner of the passenger car "Renault Megane" made contact with the front left door of the passenger car "Nissan X-Trail", and which also corresponds to a deflection angle of about 20 [°].

For a precise analysis and determination of the collision site in the transverse direction, it is also important to know the radius with which the vehicle turned to the left. Since there are no physical traces that would allow determining the path of the vehicle's movement, and therefore the radius, we will use the median value of the radius that is usually achieved by vehicles when turning left, which is analyzed in the rest of the paper.

In the collection of data related to the radius of the vehicle when turning to the left, we used the results from 25 traffic accident expertises that we conducted in the past period, which occurred during turning and overtaking. Data analysis determined that the median value of the radius at which vehicles turn is 9.2 [m].

Table 2. Realized vehicle radii when turning left

NO	Realized turning radius [m]	NO	Realized turning radius [m]	NO	Realized turning radius [m]
1.	6,5	10.	9,2	19.	6,5
2.	4,3	11.	11,3	20.	15,1
3.	30,4	12.	19,0	21.	16,5
4.	3,6	13.	15,5	22.	6,9
5.	19,5	14.	8,6	23.	4,8
6.	8,2	15.	25,3	24.	32,6
7.	7,6	16.	6,8	25.	10
8.	64,5	17.	23,5	Medijan 9,2	
9.	8,7	18.	5,5		

Guided by the aforementioned data, on the sketch of the scene drawn to scale, in the simulation software for the analysis of traffic accidents PC Crash 12.1, the passenger car "Nissan X-Trail" was placed in the position in which it was at the time of the collision. This position of the vehicle refers to its transverse position in relation to the longitudinal axis of the roadway.

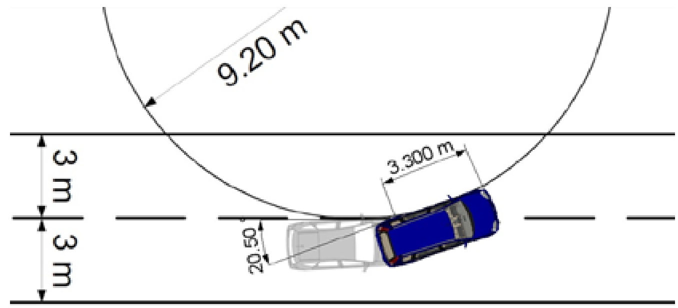

Figure 4. Collision position of passenger car "Nissan X-Trail" in relation to the longitudinal axis of the road

The drawing shows the distance traveled by the vehicle from the point of crossing over the longitudinal dividing line to the collision position, which is 3.3 [m]. As a control of the graphoanalytical method, the path that the vehicle traveled from the violation of the left traffic lane zone to the place of the collision was also obtained by calculation.

$$Sds_{Nissan} = \frac{2 \times r \times \pi}{360} \times \alpha \qquad (1)$$

$$Sds_{Nissan} = 3{,}3\ [m]$$

Where is:
Sds_{Nissan} – the path traveled by the passenger car "Nissan X-Trail" from the point of crossing over the longitudinal dividing line up to the collision position [m]
r – turning radius – 9,2 [m]
π – constant – 3,14
α – collision angle between the longitudinal axes of the vehicle 20,5 [°]

After the collision position of the «Nissan X-Trail» passenger car was determined, the «Renault Megane» passenger car was also placed on the sketch of the scene in the simulation software, in the previously defined mutual collision position of the vehicles shown in Figure 3. In this way, the location is obtained vehicle collision in the transverse sense (Figure 5). By reading from the hodogram shown in Figure 5, it follows that the vehicle collision occurred in the transverse sense on the left traffic lane, at about 2.6 [m] away from the left edge of the roadway to the right, viewed in the direction of the vehicle›s movement.

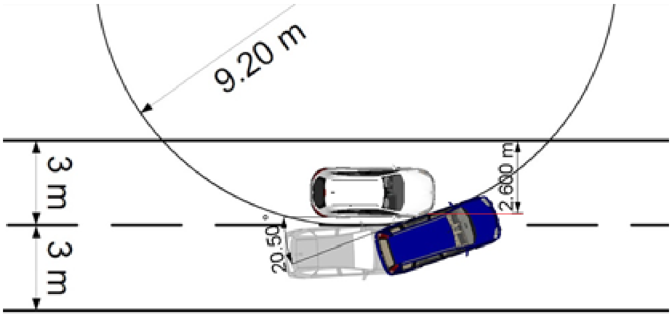

Figure 5. The location of the vehicle collision in a transverse sense

Time-space analysis

Since the location of the vehicle collision is not known longitudinally, there are no elements for calculating the speed of the vehicle at the time of the collision, as well as their speed immediately before the accident.

According to professional literature, the mean value of the speed of a vehicle in a left turn is 19.3 [km/h] with a standard deviation of 6.3 [km/h] (Bogdanović V. et al., 2010), so this speed is adopted as the speed of a Punic car "Nissan X-Trail" at the time of collision, as well as during turning.

At a speed of 19.3 [km/h], the passenger car "Nissan X-Trail" came from the place of crossing over the longitudinal dividing line to the collision position in a time of 0.6 [s].

$$t_{ds\ Nissan} = \frac{s_{ds\ Nissan}}{v_{0\ Nissan}} \tag{2}$$

$$t_{ds\ Nissan} = 0{,}6\ [s]$$

Where is:

$t_{ds\ Nissan}$ – the time elapsed from the occurrence of a dangerous situation until the collision [s]

$s_{ds\ Nissan}$ – the distance traveled by the vehicle from crossing the central dividing line to the collision position – 3,3 [m]

$V_{0\ Nissan}$ – vehicle speed during the turn – 19,3 [km/h] ili 5,3 [m/s]

The lateral movement performed by the driver of the passenger car "Renault Megane" to move from the right to the left lane in order to perform an overtaking action, on a road width of 6 [m] is about 3 [m]. It took him about 2.8 [s] for this action.

$$t_{iz} = 2{,}51 \times \sqrt{\frac{dx}{\mu_b \times g}} \tag{3}$$

$$t_{iz} = 2{,}8\ [s]$$

Where is:

t_{iz} – dodge time [s]

d_x – lateral shift – 3 [m]

μ_b – lateral adhesion at the point of greatest curvature – 0,25

g – the force of the earth›s gravity – 9,81 [m/s^2]

From the foregoing, it follows that at the moment when the passenger car «Nissan X-Trail» started crossing the longitudinal dividing line on the left half of the roadway, the passenger car «Renault Megane» was already in the left traffic lane, viewed in the direction of movement, performing an overtaking action.

According to the definition, a dangerous situation is a traffic situation that requires the reaction of at least one participant, in order to avoid an accident (III Yugoslav Conference on Traffic Technical Expertise, Zbornik radova, Belgrade 1989.). Accordingly, the dangerous situation that preceded the accident occurred at the moment when the driver of the passenger car «Nissan X-Trail» started to enter the left half of the road with the front, extreme left corner, on which the passenger car «Renault Megane» was already moving behind him. Such an action required a reaction from the driver of the passenger car «Renault Megane» in order to avoid an accident.

The analysis of the possibility of avoiding a traffic accident requires the choice of temporal or spatial «criterion» by which it will be checked whether the driver had enough time or enough space to stop the vehicle from the moment of creating a dangerous situation to the moment of the collision (Vujanić and Ivaniševic, 2015). As there are no elements for calculating the speed of the «Renault Megane» passenger car at the time of the collision, as well as immediately before the accident, there are also no elements to determine how far from the collision site it was at the time of the dangerous situation. Therefore, in this specific case, it is possible to apply the spatial criterion. Considering the known time elapsed from the occurrence of a dangerous situation to the collision, the time criterion was used for the possibility of avoiding the accident.

In our practice, the prevailing driver reaction time is 0.8 [s], which can be increased for situations of greater complexity (Vujanić et al., 2017). The response time of the system and the increase in deceleration for the passenger car are a total of 0.2 [s], so the reaction time of the human-vehicle system is 1 [s].

As the human-vehicle reaction time is 1 [s], and the time in which the passenger car «Nissan X-Trail» traveled from the violation of the left traffic lane zone to the collision position is 0.6 [s], the driver of the passenger car « «Renault Megane» under the given conditions did not have time to react to the braking system, and therefore did not have the technical means to avoid an accident.

DISCUSSION

When analyzing and determining the place of collision of vehicles in the transverse sense in the manner presented, due to the lack of material traces, it is necessary to adopt the value of the radius achieved by vehicles when turning to the left. In their Findings, experts often refer to the fact that vehicles turn left on an average radius of

10 [m]. Given that the source of the results of the aforementioned research is not known, for the purposes of the work, an analysis of the turning radius of the vehicle was performed based on the results of 25 traffic accident expertise. It was found that the median turning radius is 9.2 [m].

Using this data, the result was obtained that the "Nissan X-Trail" passenger car traveled a distance of about 3.3 [m] from the violation of the left traffic lane zone to the collision position, see formula (1). If we used the information that vehicles turn left with an average radius of 10 [m], by including this value in formula (1), the result would be that the vehicle traveled a distance of about 3 from the violation of the left traffic lane zone to the collision position, 6 [m]. This difference of 0.3 [m] would also increase the time for which the passenger car "Nissan X-Trail" went from violating the zone of the left traffic lane to the collision position from 0.6 [s] to 0.7 [s], and which further would not significantly affect the result of the time-space analysis. In other words, when determining the location of the collision in the manner presented by the example, the average turning radius of 10 [m] can be used.

The result of the time-space analysis showed that the driver of the passenger car "Renault Megane" started the overtaking action earlier, 2.8 [s], than the driver of the passenger car "Nissan X-Trail" started the left turn, 0.6 [s] . This corresponds to the previously mentioned, that the action of overtaking is far more complex than the action of turning to the left, and therefore its execution takes longer than the turn itself.

CONCLUSION

Overtaking and left-turning traffic accidents are one of the most frequent traffic accidents on the roads, and they also account for a significant share of the number of misdemeanor, criminal and civil proceedings before the courts, as well as a significant share of the number of requests for compensation for material and non-material damage caused by insurance companies. (https://www.scribd.com/document/585926322/Analiza-Tipicne-Saobracajne-Nezgode-pretnica-i-Lijevo-Skrenia-samir-Gabeljic-i-Nenad-Lukanovic, 18 March 2024). Therefore, these traffic accidents are often the subject of expert examinations, where the expert is required to perform a time-spatial analysis of the course of the accident, as well as to declare the possibility of avoiding it.

In the absence of material traces in the sense of traces of braking, drifting or dispersion of fragments from the vehicle, it can be very difficult to determine the place of collision and the collision position of the vehicle, which is the starting point of every temporal and spatial analysis of the accident. For this reason, in the paper, through the analysis of a real traffic accident, one of the solutions is given as to how to approach the expertise in this type of traffic accident with characteristic problems. The example shows the method of determining the place of a vehicle collision in a transverse sense, defining the moment of occurrence of a dangerous situation, making a time-space analysis and analyzing the possibility of avoiding an accident.

It should be borne in mind that the proposed solution has a limitation in the sense that this method of determining the location of a vehicle collision in a transverse sense can only be used in a situation where, based on the statements of the participants or witnesses of the accident, it can be reliably known that the overtaking vehicle entered the collision position the longitudinal axis is approximately parallel to the longitudinal axis of the pavement. If the overtaking vehicle, avoiding the collision, performed an additional maneuver by dodging to the left, the determined location of the collision in the transverse sense in the presented manner will not be correct.

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PROFESSIONAL PAPER

Analyses of the Parking System in Velika Gorica

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Abstract: Because there are fewer available urban spaces and more cars on the road, parking is becoming an increasingly important component of urban design. The sustainability of urban transportation and traffic flows can be greatly impacted by parking management. By using zonal parking as a parking policy measure, the city of Velika Gorica has arranged parking in its region. The parking system was examined in detail. Citizens were surveyed to find out what they thought of the parking system. Public unhappiness with the current parking system was shown by the analysis, which indicated that pricing adjustments and the provision of preferred parking permits were necessary. In areas with high demand, parking capacity must be increased. Using a collaborative approach to address parking issues can enhance traffic regulations and lead to more space for sustainable modes of transportation and pedestrian zones.

Keywords: Urban Mobility, Parking System, Parking Policy, Demand Management, Velika Gorica.

INTRODUCTION

Due to the increase in car ownership and use over the past 20 years, as well as the growing shortage of urban space, parking has become a growing priority in urban planning. For a very long period, reports and non-academic papers written by parking experts constituted the "grey" literature that dominated parking literature. Prior to the late 1990s, there weren't many scientific articles on parking (Mingardo et al., 2015). Compared to other areas of transportation, parking is still a subject of little research in traffic studies, despite its critical role in controlling the total amount of travel demand in cities.

Following World War II, when new areas were developed to make driving simpler, motor vehicle ownership and usage in and around European cities started to rise. In Europe, there has been a steady transition from loosely regulated or unregulated parking to stricter rules that began in the 1960s, particularly in urban areas. The exception was Eastern Europe, where the emergence of a market economy in the 1990s was the catalyst for a notable increase in car ownership. Outside of metropolitan centers, new urban projects frequently emulated—and frequently still do—the architectural trends that were popular at the time in the USA, Canada, and Australia. In densely populated urban areas, people began to park close to their residences, frequently obstructing traffic lanes and walkways (Kodransky and Hermann, 2011).

In major cities, cars looking for parking usually account for one-third of traffic. Parking-related disputes are among the most frequent issues that developers, operators, planners, and other parking experts deal with, and parking facilities represent a substantial financial burden on society. These issues are frequently characterized in terms of parking supply or management. Since management solutions support several strategic planning objectives, they are usually more effective than supply expansion. Policies and initiatives that lead to a more effective use of parking resources are referred to as parking management. When all factors are considered, better management is frequently the best way to address parking issues (Litman, 2021).

Parking regulations in European cities have always been a component of a larger urban transport policy that corresponds to the main concepts of the past few decades in transport policy (van Wee et al., 2011). Driving decisions can be significantly influenced by parking (Shiftan and Burd-Eden, 2001). In locations where the parking system is combined with local public transportation, economic objectives, and environmental protection aims, parking management solutions alter supply and/or demand. According to Brčić et al. (2016), parking fees can be employed as a strategy to control the impact on mode choice.

Therefore, it is essential to perform a parking policy analysis prior to making policy decisions about parking policies in a certain area. This gives a better idea of how parking regulations should be changed to increase the sustainability and functionality of local transportation as a whole.

Part of Zagreb County, Velika Gorica is a city in northwest Croatia that is the largest in terms of both population and area. Situated in the lowland region of Turopolje and on the edge of the hilly Vukomeričke Gorice, it is 16 kilometers southeast of Zagreb. The area of the city is 328.7 km²; when combined with the three recently created municipalities of Kravarsko, Pokupsko, and Orle, it makes up 552 km². Velika Gorica is the sixth-largest city in the Republic of Croatia, with 58 settlements. Settlement Velika Gorica has 30,086 inhabitants, while the city has 61,198 people, making it the sixth most populous metropolitan area as of the 2021 census.

PARKING SYSTEM

In a "Decision on the Organization, Payment, and Control of Parking in Velika Gorica," the city of Velika Gorica specifies the public spaces where parking payments will be made as well as the manner in which they will be made. Parking zones, parking zone locations, parking permit categories, parking permit usage, parking permit rates, and the rights to purchase privileged tickets and parking area supervisors were all outlined in the decision.

The business VG Komunalac d.o.o. is in charge of managing the parking operations in Velika Gorica. Authorized employees of the parking operator—controllers are in charge of managing parking. The "General Terms of Delivery of Communal Parking Services and Parking Lot Usage Agreement," published by VG Komunalac d.o.o., outlines the terms and conditions for parking service provision, as well as the rights and obligations that users and service providers share. It also details how to measure, calculate, and pay for the service.

In the city center, 1.901 public parking spaces are used for parking regulation and payment. Time-limited parking and zone parking are two of the implemented parking rules. Three zones contain 278 spaces in Zone I, 1.598 spaces in Zone II, and 25 spaces in Zone I-1h. Zone I has a 180-minute time limit; Zone II has no time limit; and Zone I-1h has a 60-minute time limit. Weekday parking hours are from 7 AM to 8 PM, and on Saturdays, they are from 7 AM to 2 PM. Holidays and Sundays have free parking. In Zone I and Zone I-1h, the hourly parking price is €0,53, while in Zone II, it is €0,40.

The following are the costs for subscription and privileged parking permits:

- Residents living in the payment zone pay €3,98 a month.

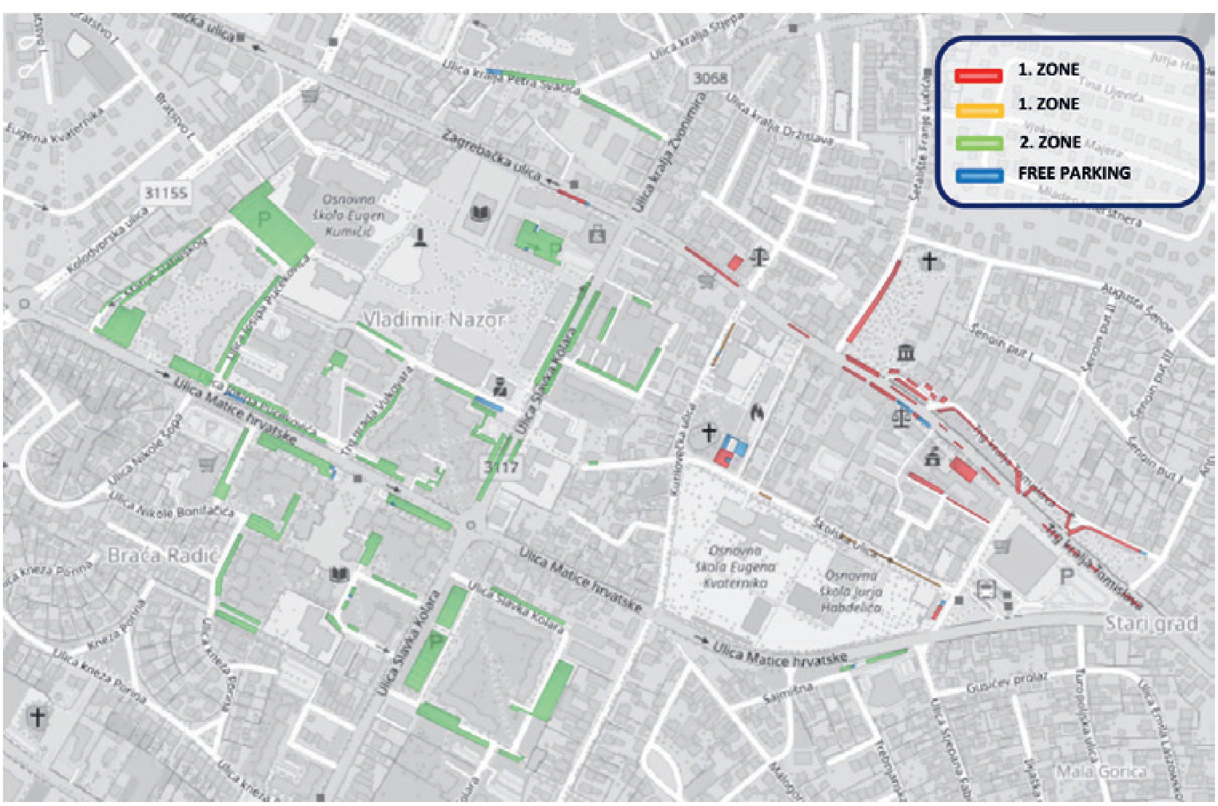

Figure 1. Display of public parking areas

- Businesses within the payment zone: €21,24 per month
- Business entity employees: €9,29 per month
- Senior citizens: €2,65 per month
- Persons with disabilities: €1,33 per month
- Owners of electric vehicles: €3,98 per month
- All public parking lot users: €39,82 per month
- Legal entities parking in all lots: €66,36 per month
- Over 40 blood donations: €1,33 per month
- Velika Gorica College students pay €9,29 a month
- Parking ticket for the day (DPK): €10,62 per 24 hours.

Parking permits are available for purchase at the VG Komunalac d.o.o. premises, via parking machines, SMS, mobile applications, and the web store. The following represents the hourly parking permit sales share by sales channel:

- Purchase of SMS: 73,15%
- Purchase of parking machines: 22,8%
- DPK purchase: 1,92%
- Purchase of kiosks: 1,26%
- Purchase of the application: 0,87%.

Ensuring that vehicles have valid parking permits is the responsibility of nine controllers who work in two shifts.

A daily parking permit (DPK) is provided in the event that a parking permit is invalid. 13.875 DPKs were issued in 2021; 38% of those were in Zone I, 3% in Zone I-1h, and 59% in Zone II.

SURVEY RESULTS

To understand public attitudes towards the parking system, a survey was conducted among citizens to gather their satisfaction ratings with the current parking offerings, including the types of parking areas used and their opinions on parking prices. This approach provides essential insights into user experiences and perceptions, which are crucial for adequately planning and improving the parking system in line with the population's needs and expectations.

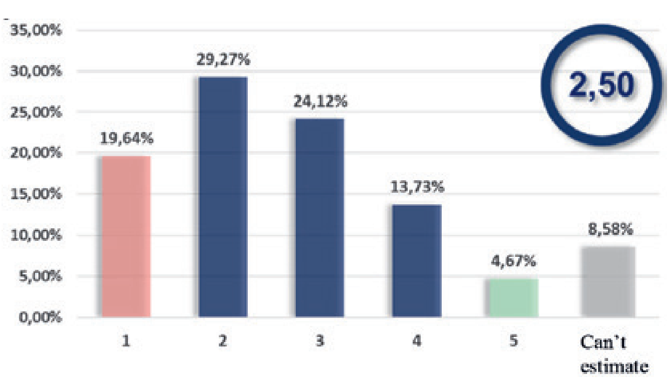

Figure 2. Satisfaction rating with the parking offer

In a survey on parking satisfaction among 1,049 respondents, the average rating was 2.50, indicating generally low satisfaction. A significant portion of respondents gave low ratings, with 19.64% rating the parking offer as 1 and 29.27% as 2, totaling nearly half of the respondents expressing dissatisfaction. Moderate satisfaction, with a rating of 3, was expressed by 24.12% of respondents, while higher ratings were less common, with 13.73% giving a rating of 4 and only 4.67% very satisfied with a rating of 5.

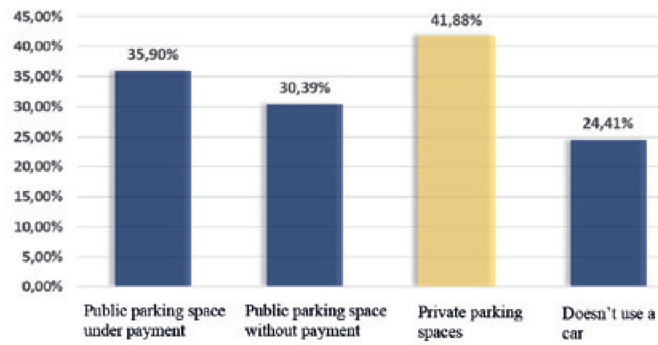

Figure 3. Types of parking spaces

In a survey on the type of parking areas used among 1,053 respondents, who could choose multiple answers, the largest share, 41.88%, used private parking spaces. This was followed by paid public parking spaces at 35.90%, and free public parking spaces were less common with 30.39% of users. These data suggest that private parking spaces are preferred among drivers, but there is also substantial use of public parking spaces, with a notable number of citizens opting for alternative transportation or not owning a personal vehicle.

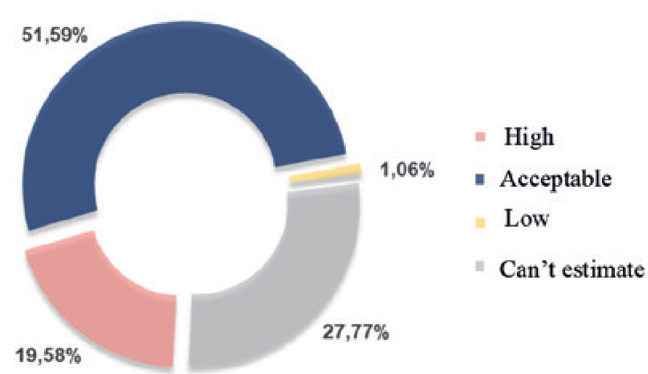

Figure 4. The respondents' opinion towards the price of the parking service- all of respondents

Among 1,037 respondents, 51.59% found the parking price acceptable. Conversely, 19.58% saw the price as high, and only 1.06% considered it low. Additionally, a significant number of respondents (27.77%) were unable to assess the parking price, possibly due to lack of use or unclear pricing.

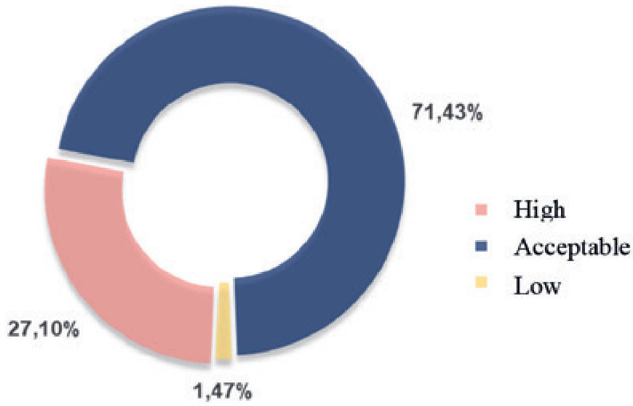

Figure 5. The respondents' attitude towards the price of the parking service- users of parking spaces

Among parking users, a smaller sample of 749 respondents, the perception of parking price differed. A larger share, 71.43%, found the price acceptable, while a higher proportion (27.10%) considered the price high compared to the general population. Only 1.47% of parking users found the price low. This contrast indicates that parking users are more likely to view the parking price as acceptable, possibly due to their regular need for parking and hence greater willingness to accept the associated costs.

CONCLUSION

A vital component of any urban area is traffic policy. When properly implemented, it could reduce traffic jams, maximize urban land use, promote environmental protection, and raise urban residents' quality of life. An essential component of traffic policy is parking policy.

The survey results reveal a general dissatisfaction with the current parking system among the citizens of Velika Gorica. With an average satisfaction rating of 2.50 out of 5, nearly half of the respondents rated the parking offer poorly. The data also indicates a preference for private parking spaces, although paid and free public parking spaces are also widely used. While a slight majority of respondents find the parking price acceptable, a notable proportion consider it high, with this perception being more pronounced among regular parking users. These findings suggest a need for revising the parking system, particularly regarding pricing and the availability of parking options, to better meet the needs and expectations of the city's residents.

Consequently, a review of the current parking system is required. This would entail improving accessibility to privileged parking licenses and changing the cost of parking. Creating more parking spaces in areas with high demand is essential. This would satisfy parking demands and enhance the region's overall traffic regulations. Additionally, road traffic safety would increase, but a more thorough examination of the total volume of traffic in the area.

Parking management should be viewed as part of the overall traffic policy. A synergistic approach to solving parking problems will also address other traffic issues in the observed urban area. This will enhance the application of traffic policy in the observed area and create surplus urban space. Such areas could then be used to expand pedestrian zones and increase the use of sustainable modes of urban transportation.

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PROFESSIONAL PAPER

Traffic Regulation Using Advanced Internet Technologies Based on Blockchain

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Abstract: Today, a large number of citizens have to use public transport as well as their own, in order to go to work, to complete business obligations in different parts of the city or to use them during vacation or recreation. The above implies an organized traffic system that implies the functioning of all entities that directly or indirectly participate in the implementation. A large number of means of public transport, private cars, motorcycles, scooters and cyclists can at a certain moment create congestion that certainly disrupts daily traffic flows. When unplanned actions take place, there is a danger that for a certain period of time there will be a stoppage and even an interruption of traffic on a certain section of the road. Such situations cause nervousness among drivers, decrease concentration and unintentionally cause traffic accidents. The main goal of this paper is to present a model of electronic business that includes remote regulation of traffic from the dispatch centre, available horizontal and vertical signalling using blockchain technology. Innovative blockchain technology is currently the best protection mechanism for digital processes that take place in wired and wireless networks. In addition to the above, the protection system includes the storage, memorization and forwarding of a large amount of information, which, through later analysis, can represent the starting point for planning future models. Traffic regulation based on advanced Internet technologies certainly increases the throughput of major intersections as well as primary roads that are important for fire engines, police and emergency services.

Keywords: Regulation of traffic flows, safety of road users, innovative models of remote control, electronic business in traffic.

INTRODUCTION

This paper deals with the regulation of traffic flows on roads with increased participation of a large number of means of transport. Given that the safety of all participants is in the first place, innovative models must be applied that improve the safety of participants as well as processes that directly affect the functioning of traffic (Subotić et al. 2021:1271). By applying available technologies, a large number of potential problems in traffic and transport can be improved in a safe and secure way (Pavlović et al. 2020:500) (Pavlović et al. 2024:564). This paper presents related research by other authors, where various models for regulating traffic are presented. In the following, factors that can affect the safe flow of traffic will be analyzed, as well as an overview of the number of traffic accidents and the number of victims. The modelling of the innovative model for traffic regulation includes the necessary infrastructure and architecture that is the basis for the functioning of the system for collecting, analyzing and forwarding messages in a secure way that is based on blockchain technology.

RELATED RESEARCH

In the available literature, one can find a large number of works that apply blockchain technology for the security of a computer system that solves a certain problem using the Internet (Pavlović et al. 2023:424) (Pavlović 2022:1). Traditional traffic light control systems rely on traffic light intervals. Because they use technology that works in accordance with a system that lacks real-time flexibility, traditional fixed traffic light controllers have limitations and are less efficient. The ability to adjust the time intervals between the green and red light signals on the traffic lights must result in fixed time intervals that are constant. Excessive and unnecessary traffic jams occur, and cars use more gasoline. This ultimately causes environmental problems as well as a number of health problems for humans. The increase in the number of private cars has a negative impact on the environment. The authors (Khare et al. 2022:235) in their paper analyze the development of a traffic system that adapts to the current traffic conditions in one lane. In most cases, the average waiting time for all lanes is set. This idea proposes to monitor the number of vehicles in the lane to reduce the average waiting time. They represent a predictive model, which will make decisions based on previous traffic patterns, mostly at normally congested crossings. Emergency vehicles will also be identified and a faster route will be established for them.

Traffic congestion is a big problem all over the world, and especially for big cities.. It can lead to reduced productivity, increased CO 2 emissions and a negative impact on the economy. One solution to this problem is to rethink the design of the traditional traffic light system using modern technologies to make it smarter. The author (Migabo 2023:1) in his paper proposes the design and implementation of a smart traffic light system. The designed smart traffic management system uses image processing techniques to detect and track vehicles on the road. By comparing the number of lanes at an intersection, a smart traffic management system is able to determine which lanes have a higher density of vehicles. Lanes with a higher density of vehicles have priority, which means they are given a longer green light to allow more vehicles to pass. Lanes with lower vehicle density have lower priority, which means they are given a shorter green light to prevent unnecessary delays. The designed system has an additional function where it detects emergency vehicles on the road. Performance evaluation and experimental evaluation of the proposed smart system demonstrate its ability to accurately and reliably detect and prioritize emergency vehicles, detect and count other vehicles, and implement lane prioritization, traffic timing, and balancing. Overall, it was found that the designed smart traffic management system is an effective tool that can help regulate traffic flow.

At present, most road traffic systems adopt a static time allocation mode, that is, whether the traffic flow is in the peak or low peak period, the time allocation period and the traffic time of signal lights are fixed and constant. This time allocation method is very easy to cause traffic jams because it cannot handle the changing traffic situation in real time. In order to solve the congestion caused by the increase in traffic flow in a short time, a method of dynamic time regulation of traffic lights is proposed for quick relief of traffic pressure. First, the appropriate value of traffic flow and green light time is obtained. The dynamic optimization of the signal timing is performed with reference to the length of the queue of vehicles, so that the time of the green light of the traffic intersection becomes a variable parameter. In the process of adjusting the traffic flow, the traditional mechanism is improved by adding the idea of a variable target value. The actual output value of the vehicle adjusted to each cycle at the previous intersection is taken as the target value of the next intersection adjustment, which can dynamically change the timing scheme with the change of traffic flow, thus reducing the invalid intersection green light time to obtain the optimal timing regulation scheme. In this way, the traffic flow of each intersection can be reasonably adjusted and finally the target value can be achieved. The experimental results show that when the traffic flow increases in a short time, the traffic congestion will be caused by the static time distribution method in a short time. The method of time distribution and flow regulation in this work by the author (Huang et al. 2021:1152) can dynamically adjust the flow of traffic and effectively relieve traffic pressure.

In the present scenario, each traffic signal is switched on and off according to the time set for it. This causes unnecessary delay in the process of clearing the traffic jam. This is because roads with no vehicles get a green signal and sides with very heavy traffic get a red signal. This causes unnecessary congestion at intersections. This can be minimized by converting traffic signals from time-based systems to traffic density-based systems. When a traffic signal is based on density rather than time, the signals are switched on and off according to the amount of traffic on the roads. This system is used to reduce congestion on the roads. Here, a camera system is used for traffic control. In order to adjust traffic signals and advise alternative routes in case of traffic jams, they collect information at their individual locations and work together with other cameras in the system. The data obtained from the cameras are processed and the density of each corresponding side is determined, and according to the data, the traffic light is turned on (Prakash et al. 2023:1).

In their work, the authors (Elchaama et al. 2017:1350) propose a road regulation system that enables the expansion of the functional coverage of city traffic regulation centres. The proposed system helps in detecting the average speed in the system, reducing the number of accidents, smoothing the flow of traffic, reducing congestion and thus making travel easier. The proposed approach is based on a system where cooperative-vehicles participate in the election of a local leader by generating, analyzing and processing complex events. The rules in this network of complex event processing are semantically defined to ensure reactivity and adaptability to any situation. The proposed approach will help reduce congestion by making traffic more fluid with a traffic regulation system that does not depend on network infrastructure and is characterized by its reactivity, self-adaptation and autonomy.

TRAFFIC SAFETY LEVEL INDICATORS

Basic factors affecting traffic safety

In everyday traffic, various situations occur in which participants can be potential culprits. Their behaviour while driving, their attitude towards themselves and other participants is not at an enviable level. In this paper, some indicators have been selected as well as a proposal of measures that an individual should take before and during driving in accordance with traffic regulations. The most prevalent factors can be presented as follows:

- **Fatigue and exhaustion:** Fatigue prevails as a cause of traffic accidents with the most serious consequences. Tired drivers make mistakes that are not the result of ignorance but poor concentration and sleepiness. To avoid a bad driving outcome, we recommend not getting behind the wheel when you are tired and sleep deprived. During driving, especially on long destinations, you should take breaks as often as possible. In every car there should be at least one bottle of drinking water and some candy, which in moments of fatigue raises the driver's concentration.
- **Non-observance of traffic rules:** The most important item when it comes to driving safety is high-quality driver training, where traffic rules are mastered in detail. High-quality driver training at a driving school must include theoretical classes prescribed by law, where material related to driving rules is adopted. This is followed by comprehensive driving training in the field, during which the drivers apply the previously learned rules. It is good for drivers from time to time to refresh the material that they may have forgotten if they do not drive for a long period of time.
- **Stress and anxiety:** The driver's psychophysical condition significantly affects traffic safety due to reduced ability to perceive and speed of reaction due to stress. If the driver is under stress due to private events, the best solution is to take a break or stop driving.
- **Technical malfunction of the vehicle:** It is not uncommon for drivers not to check the vehicle's condition in detail before setting out on the road. Validation is a very important habit that should be adopted immediately after obtaining a driver's license. Failure of the brake system, lights and other parts can cause collisions with fatal consequences.
- **Bad weather conditions:** Fog and reduced visibility on the road are among the biggest causes of traffic accidents. Winter conditions, snow, rain and ice require additional equipment, but also great caution, because then driving a motor vehicle requires considerable experience. There are sections on our roads that are very inconvenient for driving in fog or snow due to poor signalling and should be avoided.
- **Traffic jam:** Increased intensity of vehicles in certain directions is a characteristic of the summer period and annual vacations. Taking into account other factors such as fatigue and heat, the probability of a crash on the open road is much higher. If you are forced to drive on sections of the road where there is a lot of traffic, plan more frequent breaks. Check the condition of the tires and the technical condition of the vehicle before setting off on the road.
- **Driving too fast:** Incorrect driving speed can be very fatal in the event of a traffic accident, because then the consequences are more drastic. In addition to the prescribed speed, you should also keep in mind the conditions on the road, such as works, landslides and narrowing.
- **Driving under the influence of alcohol:** Drunk driving is a very common cause of traffic accidents in urban areas, especially on weekends and during major holidays. Driving under the influence of alcohol must be absolutely avoided. If you plan to travel to the celebration, plan in advance who will bring you home. A little better organization can save more lives.
- **Awkward two-wheelers:** In the summer months, there are a large number of motorcycles and bicycles on the streets, which are often a real challenge in traffic. The reason for this is that cyclists and motorcyclists do not always follow traffic rules and do not wear adequate equipment. A particular problem is that they are not sufficiently visible to other road users.
- **Use of mobile phones:** Although the use of mobile phones while driving is prohibited, it is a habit that is difficult to change. The law stipulates a fine of 10,000 dinars for drivers who use the phone, but the number of traffic accidents does not decrease. A connection between the use of a mobile phone while driving and an increased number of accidents was established. Advice to turn off phones before driving so that calls and messages do not distract drivers.

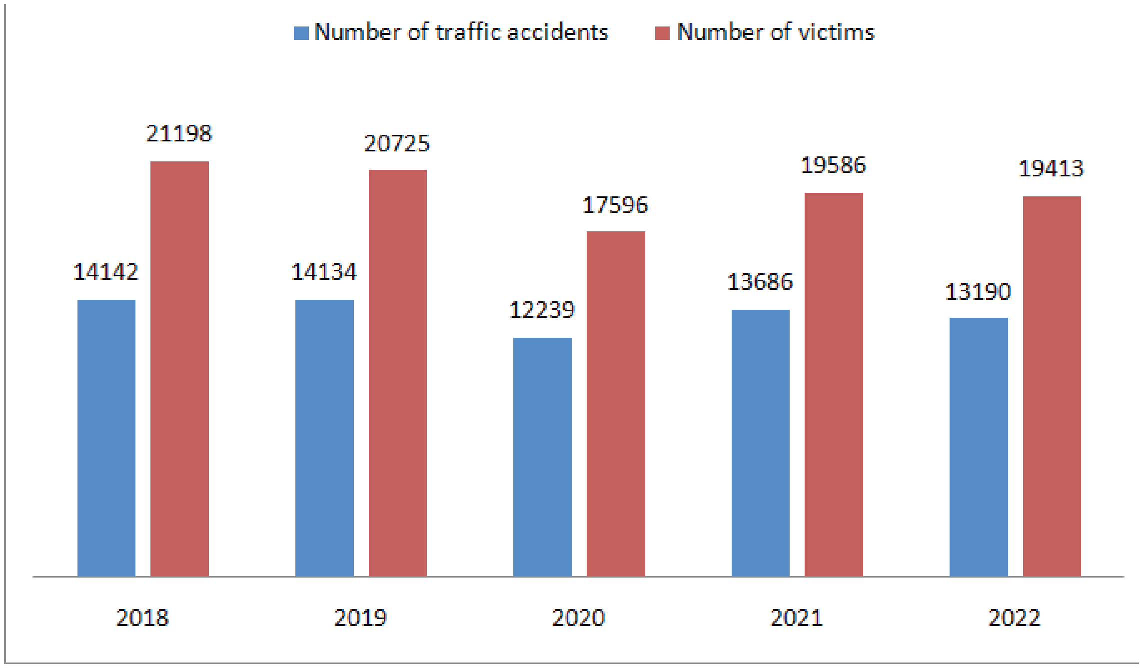

Figure 1. Indicators of the number of traffic accidents and casualties

The influence of basic factors on traffic safety

The constant increase in the number of road users, especially at intersections, leads to traffic jams that can also cause traffic accidents. The Republic Statistical Office (RSO, 2024) analyzes the number of traffic accidents every year, where the number of people who were killed is also analyzed (figure 1).

INFRASTRUCTURE AND ARCHITECTURE PROPOSAL FOR TRAFFIC REGULATION

Available technology that is applied in traffic creates intelligent transport systems that include the automation of traffic horizontal and vertical signalling. Today, when the exploitation of road infrastructure is increasing, it is also necessary to carry out reconstruction and regular maintenance in addition to the applied technologies. The application of intelligent transport systems based on advanced Internet technologies can increase road capacity and traffic safety. The protection of intelligent traffic systems is based on the application of blockchain technology, which today has become the strongest mechanism for storing, memorizing and transmitting all messages that arise in digital processes.

Traffic congestion is increasing all over the world, in large urban areas due to the increase in the number of cars, population growth, urbanization and new changes in population density. Basic factors that include the efficiency of the traffic infrastructure, increased travel time, fuel consumption, air pollution due to the burning of petroleum products can be improved with the application of advanced internet technologies in the segment of traffic regulation. Special attention should be paid to advanced applications that, with the basic goal of providing traffic participants with various services that can also be related to traffic regulation. Application of advanced technologies in traffic can be a solution to the problem of regulating and increasing safety through digital communication as well as control of the intelligent system and all traffic participants.

Infrastructure components

The model in this work should include infrastructure consisting of hardware and software in the traffic control centre, sensors embedded in horizontal and vertical signalling, video surveillance cameras and equipment for wired and wireless connectivity. The proposed model for road traffic regulation includes the following components:

K1. Physical infrastructure architecture:
- Passive equipment;
- Servers;
- Routers;

K2. Software infrastructure:
- Blockchain technology;
- Wireless transmission technologies;
- Wireless transmission standards;

K3. Infrastructure management for:
- Analysis of technical performance;
- Supervision of the infrastructure;
- User interface;

K4. E-business services:
- Content creation;
- Management of notifications;
- Data analytics;

K5. Infrastructure of quantitative components:
- Security;
- Availability;
- Efficiency.

Components of the architecture of the innovative model

The architecture of the model must provide a safe and secure way of collecting and forwarding messages detected by sensors on horizontal and vertical signalling. Messages are protected by an innovative mechanism called blockchain. The innovative architecture model contains the following components:

K1. System architecture for the storage of Regulations, Instructions, Legal Provisions:
- Database;
- Management of data on registered means of transport;
- Data archiving;
- Security and data protection.

K2. The architecture of the system for storing the generated digital messages:
- Database;
- Management of collected data;
- Data archiving;
- Security and data protection.

K3. Blockchain Technology Architecture:
- Blockchain platform;
- Closed network and right of access;
- Identification of the nodal network;
- Implementation of consensus protocols

K4. Integration of blockchain technology, computing devices, sensors with a data storage system:
- Interface for connecting to an innovative database;
- Communication protocols;
- Security and data protection.

K5. Application integration with authorized traffic regulation services:
- Interface for communication with blockchain technology;
- Services for the exchange of messages between locations on roads and the control centre;
- Security and data protection.

The main purpose of the model in this paper is to protect the data exchanged between devices and computers in the traffic regulation system. Data protection is performed using blockchain technology, which today is the most suitable data protection in a reliable and verifiable way. Blockchain represents a series of chronologically sorted records that are organized into blocks and linked, recorded in a ledger (a large database) and protected by cryptography. Each block contains a cryptographic hash code, a timestamp, and information about the transaction itself. A hash code is actually the result of a mathematical function of transforming an input of arbitrary length into an encrypted output of a fixed length and is the basic tool of modern cryptography. Each new block that is created must have a hash of the previous block, where data integrity is guaranteed because if a malicious person tries to make certain changes, he must also make changes to all previous blocks. In practice so far this has not been achievable and that is why blockchain technology is the most reliable protection mechanism. The basic functioning of blockchain technology, which has been applied to develop a model for regulating traffic and increasing security, is shown in the figure 2.

The applied blockchain technology as well as the functioning of the innovative model is shown in the picture. The sensors installed on the horizontal and vertical signalling collect data, forward it via applications to the database located in the cloud, after the flow, the collected messages are analyzed by the applications in the control centre for traffic regulation and from the centre there is feedback that determines new time intervals on the vertical signalling as and the duration of the green light. All the mentioned transactions in the computer system are protected by blockchain technology. The architecture of the model is shown in Figure 3.

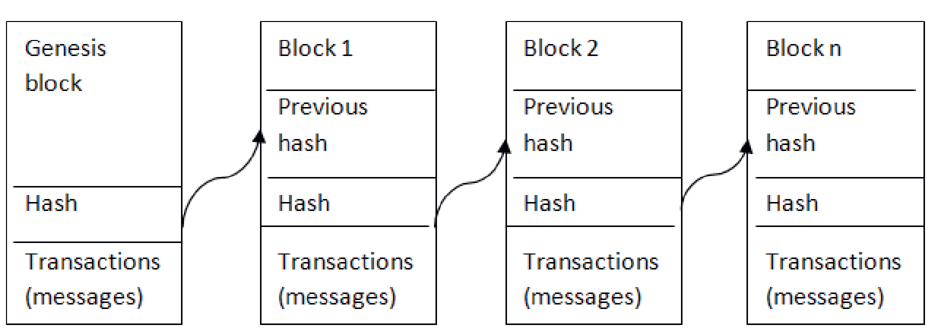

Figure 2. Functioning of blockchain technology

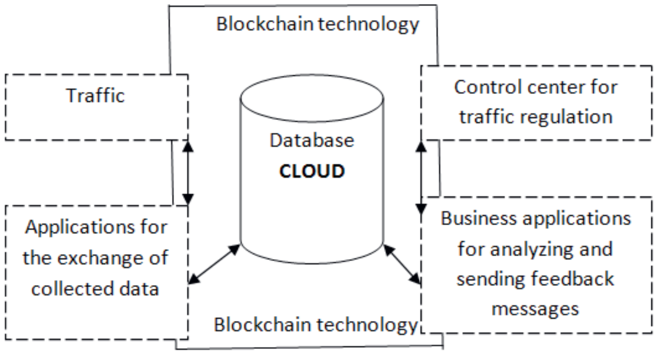

Figure 3. The architecture of the blockchain-based model

The presented architecture and infrastructure is an integral part of the traffic regulation system based on electronic business. The benefits of applying digital models multiply speed up and improve business activities when it comes to the time needed for data collection (counting means of transport at potential places where congestion may occur), a large number of people who perform the work (for counting means of transport, for processing of collected data, for calculating time intervals when changing the green light on the traffic light or prolonged retention of the red light on the traffic light) and a large number of roads on which analysis must be performed and the like. Given that it is a question of transforming previous activities involving a large number of people, this model has been reduced to a minimum. Also available computer equipment can be upgraded with certain software add-ons with minimal financial investments.

The protection of such innovative electronic business systems is carried out by advanced internet technologies with a blockchain mechanism. Blockchain provides the protection of the entire system because it includes all processes from the detection of means of transport to the feedback to the vertical signaling, the traffic light, which at that moment works on the basis of new instructions. In particular, it should be noted that after removing the potential congestion and on the basis of new information about the reduced flow of vehicles, new information is automatically created in the traffic regulation system, which is forwarded to the vertical signaling to start the regular mode of operation.

CONCLUSION

This paper presents the infrastructure and architecture of the traffic regulation model where communication and message exchange are protected by blockchain technology. Traffic regulation activities in digital transformation include a model where the human factor can be completely eliminated in current situations that can be a potential threat.

The main purpose of the model is that it automatically forwards to the control centre based on the real state of the roads detected by sensors and based on that information, feedback messages are sent that are also an order to adjust the vertical signalling. Adjusting the vertical signalling implies that the green light on the traffic light extends the time interval in order to speed up the flow of vehicles from the busy direction, while on the other side where the traffic intensity is lower, the interval of the red light prohibiting movement from that direction is extended.

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PROFESSIONAL PAPER

ISO 26262 Functional Safety Systems for Road Vehicles

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Abstrakt: The dynamics in the global automotive industry are constantly evolving, opening pathways to new markets and technological paradigms. Advancements such as H2 and e-vehicles present clear opportunities but also entail challenges of uncontrolled development, particularly with the growing influence of China in the EU.

Traffic accidents involving vehicles with electric propulsion pose specific challenges for investigators and analysts. Analyses reveal increased complexity and harmfulness of these accidents, emphasizing the need for new methods of investigation and damage assessment, as well as for tightening regulations.

The production of e-vehicles faces financial challenges and technological demands. Production efficiency, including the use of one-piece chassis panels, is crucial for competitiveness in the market. The future of the automotive industry in the EU requires complex strategies focused on the development of e-vehicles for urban needs, H2 technology for freight trucks, and alternative fuels to ensure energy independence. Traffic safety is gaining importance, recognizing energy as a key factor in global security. Attitudes of countries like the Netherlands towards e-vehicles vary, with the issue of electric energy availability highlighted as significant. In this complex landscape of the automotive industry, contemplating the future requires a balance between technological innovation, safety, and sustainability.

Keywords: e-traffic, technological curve, energy, renewable sources, independence

JEL: Q2, Q3, Q4 and Q5 - stručni članak.

ISO 26262

ISO 26262 is an international standard titled "Road vehicles – Functional safety," representing a norm for the functional safety of electrical and/or electronic systems implemented in road vehicles. This standard was adopted by the International Organization for Standardization (ISO) in 2011 and revised in 2018. Functional safety characteristics are integral to every phase of vehicle development, from specification to design, implementation, integration, verification, validation, and production release. ISO 26262 defines functional safety for vehicle equipment applicable throughout the lifecycle of electronic and electrical safety systems. The primary goal of the standard is to address potential hazards caused by faulty behaviors of electronic and electrical systems as a whole, their components, or mechanical subsystems. This is a risk-based safety standard, involving continuous qualitative risk assessment of failure occurrence and determination of safety measures to avoid and control systematic failures, as well as to treat random hardware failures or ultimately mitigate the harmful consequences of failures.

The standard regulates the safety lifecycle of automobiles in phases of management, development, production, operation, service, and decommissioning. It standardizes the development process from requirement specifications, design solutions, implementation, integration, verification, validation, and configuration. In line with the specificities of the automotive industry, it standardizes the determination of risk classes (Automotive Safety Integrity Level - ASIL). The analysis of the automotive safety integrity level indirectly determines the necessary safety requirements, ensuring the acceptability of residual risk. It ensures an adequate level of safety by creating conditions for the required validation and confirmation measures.

The content of ISO 26262:2018 is structured into 12 chapters as follows: Vocabulary, Functional Safety Management, Concept Phase, Product Development at the System Level, Product Development at the Hardware Level, Product Development at the Software Level, Production, Operation, Service, and Decommissioning, Supporting Processes, Automotive Safety Integrity Level (ASIL) Oriented and Safety Oriented Analysis, Guidelines for ISO 26262, Guidelines for the Application of ISO 26262 to Semiconductors, and Adaptation of ISO 26262 for Motorcycles.

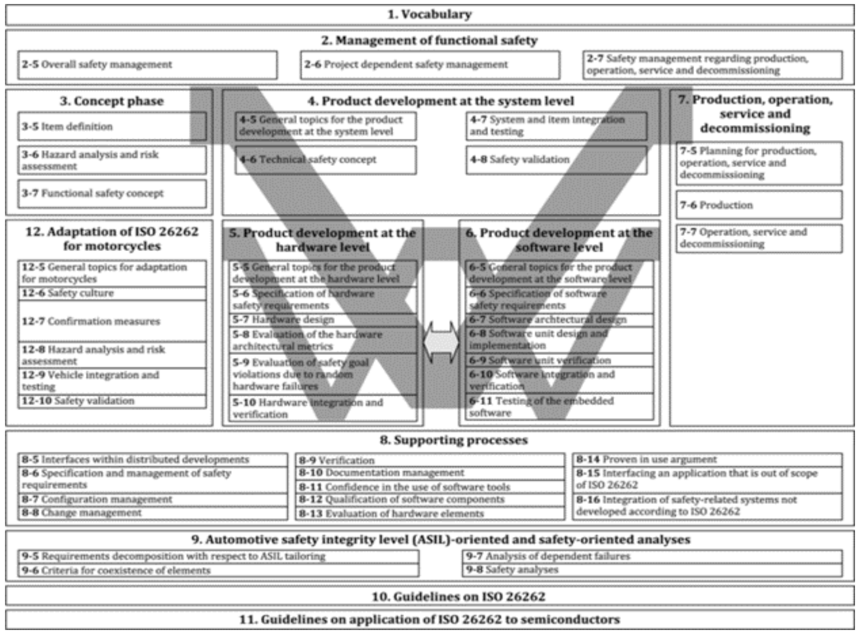


Figure 1. Overview of the ISO 26262 Structure (Source: ISO online platform)

Glossary - ISO 26262 provides a project glossary of terms, definitions, and abbreviations such as:

- item - an individual part or detail referred to by the term,
- element or system - a part or assembly with one or more hardware/software units,
- fault - identified condition that deviates and may cause a failure,
- error - deviation from the calculated or measured correct value or state,
- failure - cessation of proper behavior of an element due to an error,
- fault tolerance - capability to perform despite the presence of error(s),
- malfunction - is a failure,
- hazard - defines a state of real possibility of harm occurrence,
- functional safety - identifies the absence of unreasonable risk due to hazards caused by malfunctioning of electrical and electronic systems.

Functional safety management for vehicle applications is defined as organizational safety management, and standards for safety lifecycle in vehicle development and production.

The safety lifecycle according to ISO 26262 identifies and assesses hazards (safety risks), establishes safety requirements to reduce risks to an acceptable level, and manages and monitors safety requirements, ensuring their fulfillment in the product. These processes are treated as integrated or parallel to the quality management system, and they include:

- Identification of item (specific automotive system product),
- Definition of top-level system functional requirements for each item/position,
- Identification of a broad set of hazardous events for each item/position,
- Determination of the appropriate ASIL for each hazardous event,
- Establishment of safety goal and ASIL for each hazardous event,
- Functional safety defines the system architecture to achieve safety goals,
- Filtering of safety goals and renaming into lower-level safety requirements,
- Each safety requirement inherits the ASIL of the higher requirement/goal, but reduction is possible,
- Assignment of safety requirements to subsys-

Table 1: Safety lifecycle according to ISO 26262

Concept	Meaning
Unsafe event	The hazard at the vehicle level and the vehicle's operational situation that may lead to an accident if not timely controlled by the driver.
Safety goal	Highest safety requirement - reduces the risk of hazardous events to an acceptable level
Automotive safety integrity level (ASIL)	The classification of safety goals, as well as validation and confirmation measures in accordance with the standard, ensuring the achievement of that safety goal
Safety requirements	All safety goals from the highest to the lowest, including the levels of functional and technical safety requirements assigned to hardware and software components

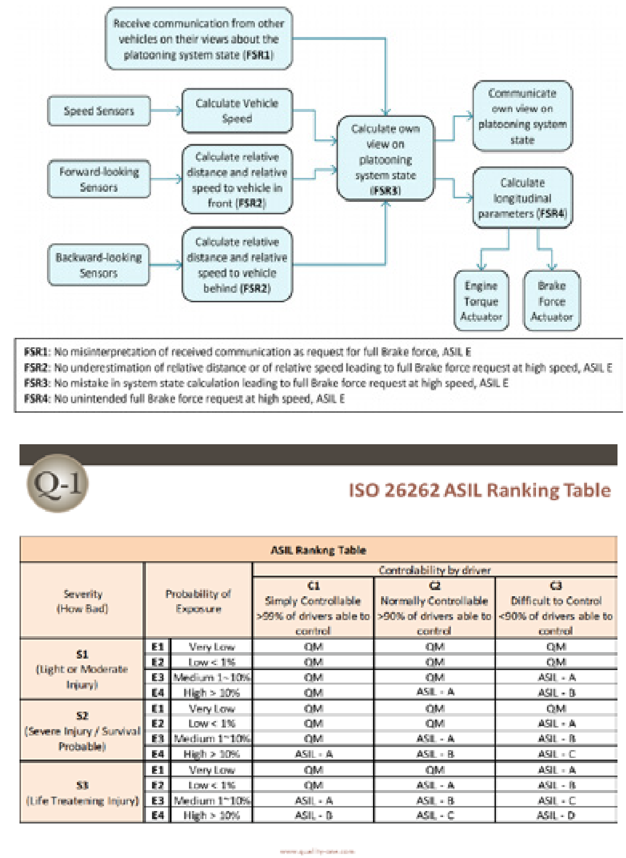
(Source: Author)

tems, hardware, and software components in accordance with standards and processes for the highest ASIL, and
- All components of the developed architecture are developed in accordance with assigned safety (and functional) requirements.

Support processes are established to provide support for the safety lifecycle processes. They are active in all phases and include:
- Control and collective analysis aimed at achieving goals, requirements (dispersed development and production),
- Precise specification of safety requirements and their management,
- Product control, their repeatability in series with the possibility of identifying changes,
- Change management including impact on safety requirements,
- Planning, control, reporting, analysis, and testing,
- Planned identification and management of all documentation,
- Software reliability and software tool suitability,
- Qualification of developed software and hardware components for integration into the developed ASIL item/position, and
- Service history analysis aimed at proving quality.

The Automotive Safety Integrity Level (ASIL) analysis is an assessment of risk reduction to the level necessary to prevent hazardous events or hazards. In the automotive industry, a set of risk reduction assessments has been developed, classified into a safety risk classification in the automotive system or its elements, ranging in size from the smallest (D) to the highest (A). By assigning an appropriate goal for addressing a specific hazard to each risk, a safety requirement arises.

Quality management is achieved when all assessed risks are tolerable. For example, in the case of a requirement for a vehicle to start, no safety processes are needed, only a standard quality management procedure, etc



ASIL Rankng Table

Severity (How Bad)	Probability of Exposure		Controlability by driver C1 Simply Controllable >99% of drivers able to control	C2 Normally Controllable >90% of drivers able to control	C3 Difficult to Control <90% of drivers able to control
S1 (Light or Moderate Injury)	E1	Very Low	QM	QM	QM
	E2	Low < 1%	QM	QM	QM
	E3	Medium 1~10%	QM	QM	ASIL - A
	E4	High > 10%	QM	ASIL - A	ASIL - B
S2 (Severe Injury / Survival Probable)	E1	Very Low	QM	QM	QM
	E2	Low < 1%	QM	QM	ASIL - A
	E3	Medium 1~10%	QM	ASIL - A	ASIL - B
	E4	High > 10%	ASIL - A	ASIL - B	ASIL - C
S3 (Life Treatening Injury)	E1	Very Low	QM	QM	ASIL - A
	E2	Low < 1%	QM	ASIL - A	ASIL - B
	E3	Medium 1~10%	ASIL - A	ASIL - B	ASIL - C
	E4	High > 10%	ASIL - B	ASIL - C	ASIL - D

Figure 2: ASIL Functioning Scheme (Source: ISO online platform) / Overview of ASIL Ranking and Guidelines (Source: Q-1 Portal, January 20, 2024)

Table 2: Overview of assessments for determination ADSL

Severity of hazard (S)	Exposure (E)	Controllability (C)
S0 – no injury	E0 –minimal probability	C0 –general control
S1 –minor and moderate injuries	E1 - very low probability	C1 - easily controlled
S2 –with severe and life-threatening injuries	E2 - low probability	C2 –normally controlled
S3 –life-threatening to fatal injurie	E3 - medium probability	C3 –difficult to control/not contr.
	E4 - high probability	

Table 3: Hazard Classification

CLASS	EXPLANATION	NOTE
D	Lowest level of life-threatening risk	Loss of braking on all wheels
C	Level of life-threatening risk	Loss of braking on rear wheels and the like
B	Difference between C and B with the largest step and possible injuries	Loss of lights, brake signals …
A	Lowest risk of injury/hazard	Example: malfunction of brake lights

(Source: Author)

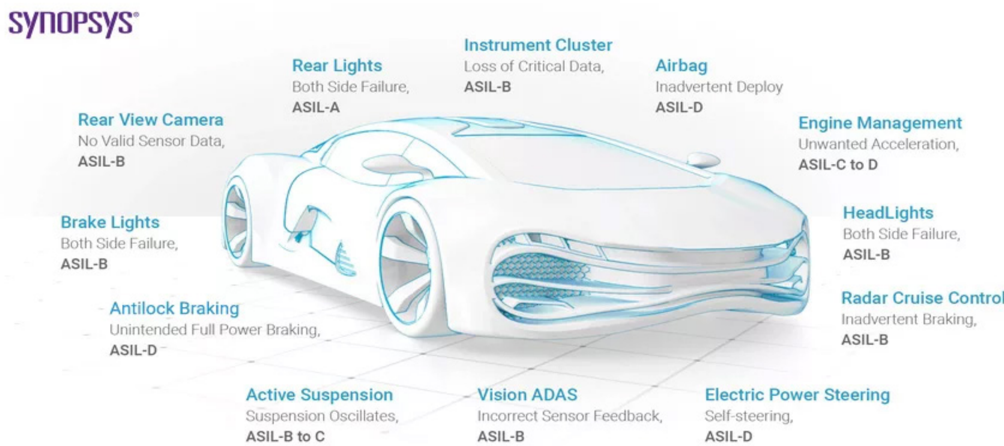


Figure 3: ASIL/Sensor Scheme (Source: Synopsys website, October 10, 2023)

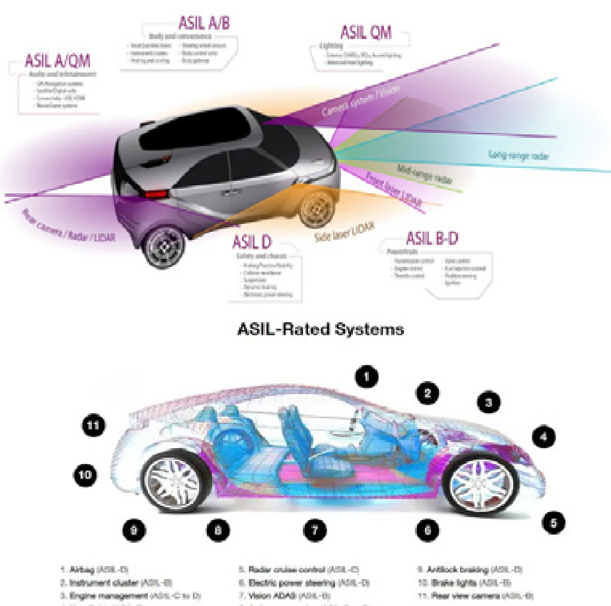


Figure 4: ASIL/Sensor Scheme (Source: Gary Hilson, EET Asia, 'ford', October 10, 2023)

For electric vehicles, ASIL is implemented after the highest safety criticality is assigned to the electric motor drive and battery management system. Alongside the drive train, airbags, anti-lock brakes, and power steering require an ASIL-D rating. This represents the highest level of stringency applied to safety because the risks associated with their failure are the greatest. Conversely, components such as rear lights require an ASIL-A rating. Headlights and brake lights would generally be ASIL-B, while cruise control would typically be ASIL-C.

It's significant that ASIL differs between electric and conventional vehicles, and it raises the question of the magnitude of hazards present in different types of vehicles. It's important to understand which vehicle and which subsystem in the vehicle pose or, under certain circumstances, cause greater destruction, damage, and endangerment. ASIL is a younger standard, so there is ongoing debate about its qualities or significance compared to other standards that have been in use for a longer period. It should be concluded that all standards must be applied, and there are always situations where

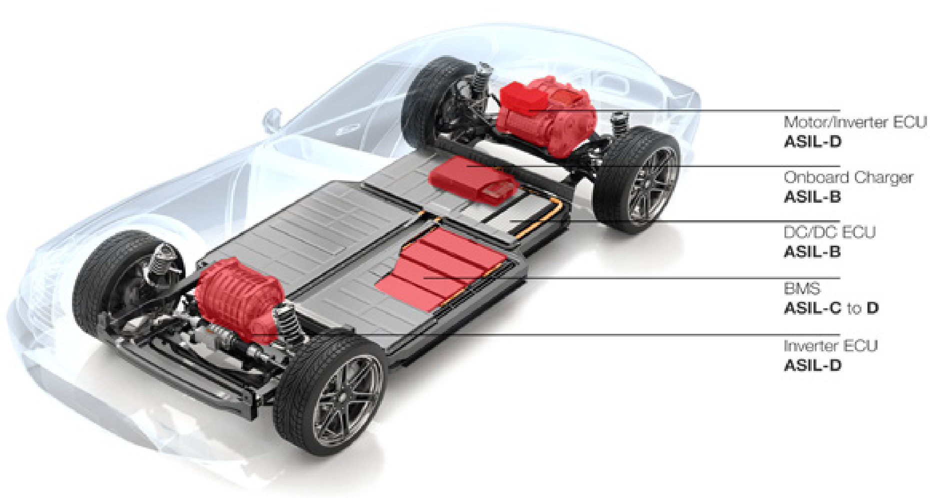


Figure 5: Schematic Overview of ASIL Ratings for Electric Vehicles (Source: https://info.typhoon-hil.com, February 20, 2024)

Table 4: Comparative Standard Overview

Approximate Mapping of ASIL Across Domains					
Domain	**Safety Levels Specific to the Domain**				
Cars (ISO 26262) (ASIL)	QM	A	B C	D	-
General (IEC 61508)	-	SIL-1	SIL-2	SIL-3	SIL-4
Railway CENELEC 50126/128/129)	-	SIL-1	SIL-2	SIL-3	SIL-4
Space (ECSS-Q-ST-80)	Kasa E	Klasa D	Klasa C	Klasa B	Klasa A
Aviation: air (ED-12/ DO-178 / DO-254)	DAL-E	DAL-D	DAL-C	DAL-B	DAL-A
Aviation: land (ED-109/DO-278)	AL6	AL5	AL4 AL3	AL2	AL1
Medicine (IEC 62304)	Klasa A	Klasa B		Klasa C	-
Household (IEC 60730)	Klasa A	Klasa B		Klasa C	-
Machines (ISO 13849)	PL a	PL b PL c	PL d	PL e	-

(Source: https://en.wikipedia.org/wiki-ASIL, 20.10.2023.)

the response to certain risks is at least controlled or tested in relation to one of the earlier established norms.

ISO 26262 is an international standard that pertains to functional safety in the automotive industry. It plays a crucial role in enhancing traffic safety in Europe by providing a framework and guidelines for the development of secure electronic systems in automobiles.

ANALYSIS OF FACTORS INFLUENCING TRAFFIC SAFETY SYSTEM

Although there is an apparent correlation between the implementation of standards such as ISO 26262 and the state of traffic safety, precisely quantifying the impact of these standards on the number of traffic accidents in Europe can be challenging. This is because the factors influencing traffic safety are diverse, including infrastructure, regulations, driver behavior, and others. However, there are several ways to analyze the impact of implementing standards like ISO 26262 on traffic safety:

- Vehicle performance analysis: A detailed analysis of the performance of vehicles developed in accordance with standards like ISO 26262 can be conducted. This would involve investigating accident cases involving vehicles that were or were not compliant with the standard.
- Statistical data analysis: Trends in reducing the number of traffic accidents after standards such as ISO 26262 are introduced or applied on a broader scale can be explored.
- Comparative study with other regions: Comparing the safety performance of vehicles and the number of traffic accidents in Europe with other regions that may not be as focused on the implementation of these standards can provide some insight.
- Surveys and opinion research: Conducting surveys among drivers and other traffic participants can provide information on the perception of vehicle safety.

Intelligent safety systems in vehicles, whether equipped with new or conventional technologies, play a crucial role in improving the safety of drivers, passengers, and other traffic participants. Key intelligent safety systems in modern and conventional vehicles include:

a. Collision avoidance system - using sensors such as radar, cameras, and lidar to detect vehicles, pedestrians, or obstacles in front of the vehicle,
b. Lane departure warning system - using cameras or sensors,
c. Distance maintenance system - using radar or cameras to assess the distance between vehicles and automatically adjust speed or activate brakes to maintain a safe distance from the vehicle in front,
d. Driver fatigue recognition system - using sensors to monitor the driver's behavior, such as steering wheel position or eye movements, to detect signs of fatigue or lack of attention,
e. Blind-spot detection system - using sensors mounted on side mirrors to detect vehicles in the driver's blind spot,
f. Automatic pedestrian braking system - using sensors to recognize pedestrians in front of the vehicle and can automatically activate brakes to avoid a collision or reduce severity.

These are just some of the intelligent safety systems in modern and conventional vehicles. Their combination provides additional protection and contributes to reducing the number of traffic accidents and injuries.

CLASSIC AND NEW TECHNOLOGIES

The global strength and power of the automotive industry in Western Europe and America have been in the development and production of internal combustion engines. In this economic capacity, giants like BMW, Mercedes-Benz, Ford, Honda, etc., have emerged. Civilization and cooperation enable advanced technologies to become practically a "household activity." The possibility of exchanging information and collaborating on a free basis has laid the foundation for the development of new forces from India, China, Thailand, etc. The European Union, as a global player in environmental protection and standardization, has had clearly defined policies to cease the production and sale of vehicles emitting CO2 by the year 2035. However, in today's world, due to the aforementioned facts, it is clear that electric vehicles can be made by anyone. Production from a garage to mass production is possible. The best example is Mr. Rimac in Croatia. In such a situation, it has happened that the markets of EU and America are flooded with Chinese vehicles that are technologically advanced and cheap.

As a measure of protection, the European Parliament has approved the Commission's proposal that Chinese electric vehicles should not be considered climate neutral. In the transport business, this regulation leaves a mark because all companies in Europe must report the CO2 footprint for their services by rail, road, or air. This is a complex issue due to the obligation to calculate the actual parameters of CO2 emissions in the use of electric energy. According to these protocols, it turns out that gasoline and diesel are more favorable for use than electric energy, and this is due to the way electric energy is produced. In terms of environmental protection, there is actually a relocation of pollution sites. Namely, the greatest pollution occurs at the location of electric energy production.

Electric vehicles (EVs) are becoming increasingly popular as an alternative to vehicles with internal combustion engines (ICE) due to their potential cleanliness and efficiency. In this work, we conduct a comparative analysis between these two types of vehicles to understand their advantages and disadvantages.

Comparative analysis shows that both E-vehicles and SUS vehicles have their advantages and disadvantages. The final choice depends on individual needs, preferences and local conditions. The new e and H2 vehicle technologies represent innovative approaches that are increasingly being used to reduce emissions and improve energy efficiency in the automotive industry.

These options represent an alternative to traditional internal combustion engine vehicles and aim to reduce greenhouse gas emissions and other harmful emissions in transportation. Key requirements in the development of these technologies include efficiency, reliability, safety, and cost-effectiveness to become widely accepted and competitive in the market.

Intelligent safety systems for electric (e) and hydrogen (H2) propulsion vehicles bring a range of challenges that differ from traditional internal combustion engine vehicles. Specific safety challenges of new e and H2 technologies include:

1. High voltage and electrical safety: Electric vehicles use high-voltage systems to power electric motors. There is a risk of electric shock to passengers and personnel in the event of an accident or damage to the high-voltage system. Therefore, passenger and personnel safety is necessary through adequate insulation, safety switches, and first aid training.
2. Battery fires and explosions: Lithium-ion batteries used in electric vehicles can be susceptible to overheating and fires in the event of a malfunction or damage. This challenge requires the development of overheating detection systems, fire suppression, and procedures for safe handling of damaged vehicles.

Table 5: Analysis of Techno-Economic and Environmental Characteristics

Element	EVs	ICE Vehicles
Propulsion	Electric motor powered by battery	ICE - gasoline or diesel engine
Performance	Higher acceleration and torque at lower speeds	Longer range on a single fueling and can refuel quickly
Emission	Do not produce direct emissions at local level	Produce exhaust gases that can be harmful to the environment
Price	More expensive to purchase and lower operating costs due to cheaper charging	Usually cheaper to purchase but higher fuel and maintenance costs
Accessibility	Subsidies and incentives - facilitations	Greater availability in most markets
CO2 Emission	Depending on the method of electricity production, lower carbon footprint	Have a higher carbon footprint due to burning fossil fuels
Sustainability	With renewable energy sources for charging - more environmentally friendly	Dependence on fossil fuels makes them less sustainable in the long run

Table 6: Characteristics and Requirements of Electric and H2 Technologies

System Elements	Electric Vehicles	Hydrogen Vehicles
Propulsion	Instead of traditional ICE engines, EVs use electric motors powered by electricity from batteries	Hydrogen vehicles use hydrogen, which, in reaction with oxygen in fuel cells, produces electricity to power the vehicle
Energy/Power Source	Efficient, long-lasting batteries are key to the performance of electric vehicles	In order to provide vehicles with adequate power and performance, fuel cells must be efficient, reliable, and cost-effective
Charging Infrastructure	Development of fast chargers and expansion of charging networks that must be accessible, reliable, and efficient	Hydrogen vehicles require hydrogen refueling infrastructure (production, storage, distribution)

(Source: Author)

3. Hydrogen safety: Hydrogen is a flammable gas, so there is a risk of fire or explosion in the event of a hydrogen leak or vehicle collision. It is necessary to ensure safe hydrogen storage, transportation, and handling systems, as well as leak detection systems and procedures for rapid evacuation in case of danger.
4. Charging infrastructure: Lack of charging infrastructure can present a safety challenge as drivers may be forced to use alternative, possibly less safe, charging methods. Inadequate maintenance or poorly designed charging stations can also pose risks of electrical or chemical accidents.
5. Crash safety: Since e and H2 vehicles use different propulsion systems and construction from traditional vehicles, there is a need to adapt safety systems in the event of a crash. This includes adaptive active and passive safety systems to ensure optimal protection for passengers and vehicles in various crash scenarios.

ISO 26262 contributes to addressing the challenges of manufacturing and using vehicles through functional safety in the automotive industry, i.e., through risk analysis, detection and diagnostic system, and error resilience. It provides a framework and guidelines for identifying, analyzing, and managing functional safety risks in vehicles, which can help address some safety challenges associated with e and H2 technologies. The fundamental contributions to addressing these challenges may include:

1. Risk analysis: This ISO requires risk analysis for all electrical and electronic systems in the vehicle, which can help identify hazards related to high voltage, battery fires or explosions in electric vehicles, as well as safety risks associated with hydrogen storage and handling.
2. Detection and diagnostic system: The standard requires the implementation of fault detection and diagnostic systems in electrical and electronic systems, which can help detect problems with batteries or hydrogen systems, etc.
3. Error resilience: ISO 26262 promotes the design of systems that are resilient to errors and can safely respond to faults or failures. This can help minimize the risk of electric shocks, fires, or explosions in electric vehicles, as well as manage the risks of hydrogen leaks or vehicle collisions.

CONCLUSION

Ecology, given its importance, is definitely a factor in traffic safety with a significantly dangerous impact on a broad scale. All measures taken since 2011, with the first publication of ISO 26262 and others, have yielded results. In the EU, there is a trend of continuous decrease in the number of fatalities by around 4.5% annually. Similar statistics are observed in Bosnia and Herzegovina. The number of electric vehicles is significantly increasing at a rate of about 12%.

ISO 26262 is not specifically tailored to all aspects of safety related to e and H2 technologies, so it may be necessary to combine ISO 26262 with other standards, regulations, and best practices relevant to these technologies, which is crucial for the successful proliferation of e and H2 technologies in the automotive industry and their acceptance by consumers.

Due to the growing economy and competition, Europe must focus on new technologies that offer various forms of powertrains or propulsion concepts, towards hydrogen technologies that have unparalleled advantages. Strategies must be flexibly set by defining goals and without imposing technological guidelines, ensuring the achievement of goals with optimal technological solutions and without delving into the details of specific technologies and industries.

Attention and resources need to be directed towards the development of other e-fuels, synthetic fuels that could provide an additional alternative, especially from the perspective of the vehicle lifecycle from production to use and recycling. This approach enables stability in the automotive industry, provides an opportunity for simpler solutions in traffic safety, and allows the introduction of new standards that will provide an opportunity for a safer environment and the continued development of civilization.

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PRELIMINARY REPORT

Application of Fuel Cell and Green Hydrogen Technology in Buses for Public Urban Transport Passengers

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Abstract: The system of public urban passenger transport is one of the most important functions of any city. The bus subsystem is still the most prevalent in most cities of the world. In addition to the proven advantages in use, the main demands placed on the bus subsystem are environmental suitability and neutrality, through the increasing use of buses with zero and low emission of harmful exhaust gases. Fuel cell-powered buses using green hydrogen are currently a technology with great potential with the goal of completely decarbonizing carbon dioxide (CO_2) emissions originating from the bus subsystem. The paper will present the basic characteristics of fuel cell buses, legal frameworks for application in the countries of the European Union, and experiences in the application of this drive concept in some cities.

Keywords: Fuel cell buses, green hydrogen, public urban passenger transport.

INTRODUCTION

The public urban passenger transport system is one of any city's most important functions. Buses powered by diesel fuel and compressed natural gas (CNG) are still the most prevalent driving system in most cities of the world but with a constant trend of decreasing representation and their substitution with buses with zero emissions of harmful gases, which are electrically powered buses and buses powered by hydrogen H_2 using fuel cell technology. According to UITP data, in 2018 the share of diesel-powered buses in sales was around 80% [1], and in 2023 their share would be below 40% [2].

Seen from the aspect of environmental performance, diesel-powered buses had a constant trend of refinement and improvement, as the requirements through the EURO norms were increasing (especially pronounced in the first 20 years of the 21st century). Public city transport buses powered by compressed natural gas (CNG) have been present in many cities worldwide for many years, thus becoming a proven alternative to diesel-powered buses.

Their mass use, primarily in EU cities (Madrid, Barcelona, Rome, Turin, Nantes, Bordeaux, Porto, The Hague, Malmö, Ninberg, Seville, Florence, Ljubljana, Zagreb...) was recorded in the period from 1992 to 2015, as one of the effective solutions for reducing the emission of harmful exhaust gases from vehicles and savings in exploitation costs.

After 2015, there was a noticeable stagnation in the mass use of CNG buses in public city transport systems as a result of the appearance on the market of buses with hybrid (diesel-electric) drive, and then fully electric buses (E-bus). In the last two years, buses powered by hydrogen H2 using fuel cell technology have become increasingly common. The Buses powered by fuel cells according to EU Directive 2019/1161, which entered into force in August 2021, are categorized as vehicles with zero emission of harmful gases and, together with electric buses, represent an application strategy with the aim of substitution of diesel-powered buses, so that from 2033, zero-emission buses (E-bus, fuel cells) should have absolute primacy in use in the public urban transport system of cities.

According to the aforementioned Directive, all EU member states must, according to the prescribed quota, have a representation of buses with low and zero emissions when purchasing new buses. For the period until 31.12.2025. year, the most developed countries of the EU (Germany, the Netherlands, Sweden...) must have a total participation in the procurement of new buses with low and zero emissions 44% of which 22% must be buses with zero emissions. EU member states that are less economically developed (Bulgaria, Romania, Croatia) have a set quota for the participation of buses with low and zero emissions between 28% and 32% [3].

Tendencies of increasing use of buses with zero and low emission of harmful exhaust gases are shown through the number of newly registered buses for public city transport for EU 27 countries, including Norway, Iceland and Switzerland in 2023: 6,354 buses with electric drive, 4,022 buses with hybrid (diesel-electric drive), 2,883 CNG-powered buses and 181 hydrogen-powered (fuel cell) buses, while the number of newly registered diesel-powered buses is 6,570 [2].

It is also important to mention the EU Directive 2014/94 [4], which refers to the use of alternative fuels in the transport sector, namely: Electricity, natural gas, biomethane, biofuels, hydrogen, synthetic diesel, liquefied petroleum gas, which should reduce the use of fossil fuels (diesel, gasoline) in the transport sector, where the share of the use of hydrogen as an energy source in the so-called energy mix in the transport sector is defined for each EU country.

It is known that hydrogen as a chemical element does not exist freely in nature, but it is present in the largest number of compounds. Its presence in water gives it the character of an alternative fuel with inexhaustible reserves. Industrial production of hydrogen H_2 is possible in two ways [5].

- Through the process of electrolysis of water, $H_2O = H_2 + ½ O_2$, Anode: $2OH = ½ O_2 + 2 H_2O + 2 e-$, Cathode: $2 H_2O + 2 e- = H_2 + 2 OH$.
- Through the process of carbon-hydrogen reformation (most often natural gas-methane),
- $CH4 + H_2O = CO + 3 H_2$

In both cases, it is necessary to provide a large amount of electricity for the production process. The question arises as to how to obtain the electricity that is used in the production of hydrogen. If electricity obtained from thermal power plants where the primary energy source is coal is used, as a result, we have large amounts of carbon dioxide CO2 produced in the process of burning coal, which hurts the occurrence of the greenhouse effect and climate change.

The way electricity is produced and transmitted is of essential importance when analyzing the environmental performance impacts of electric buses on a regional or national level, i.e. analysis from «well to wheel», WTW (Well to Wheel). The analysis of WTW carbon dioxide emissions is important to understand and compare the emission levels emitted by buses with different propulsion systems, including fuel cell buses.

The aspect of carbon dioxide emission that occurs during the electricity production phase is particularly important, given that electricity is obtained from different sources, which can be represented by the value of the standard factor of the total carbon dioxide emission expressed in gCO2eq/kWh. The values of the gCO2eq/kWh factor for European countries in 2019 are shown in Figure 1 [6].

Countries with a greater share of renewable sources such as hydro power plants, wind parks, and solar power plants have a significantly lower value of CO_2 emissions (Iceland, Sweden, Norway...) than countries where electricity production is primarily from coal (Poland, Greece, Serbia), BiH...). Only the use of electricity obtained from completely renewable sources (hydropower plants, wind parks, solar power plants) for the production of hydrogen by the electrolysis process, which will be used for vehicles with fuel cells, is a sustainable solution to decarbonize transport. The hydrogen obtained in this way represents "green hydrogen". Figure 2 shows the production, storage, and distribution of green hydrogen.

The green hydrogen produced in this way has the full effects of application in the transport sector: It is completely ecologically suitable due to zero CO_2 emissions, the dependence on the use of fossil fuels is reduced, and it promotes the development and implementation of innovative technologies. A typical plant (electrolyzer) for the production of green hydrogen where electricity is obtained from photovoltaic panels with an installed capacity of 2 MW has a production of 18 kg H2/h and storage tanks of 1,013 kg, which is enough to serve a fleet of 10 fuel-cells buses.

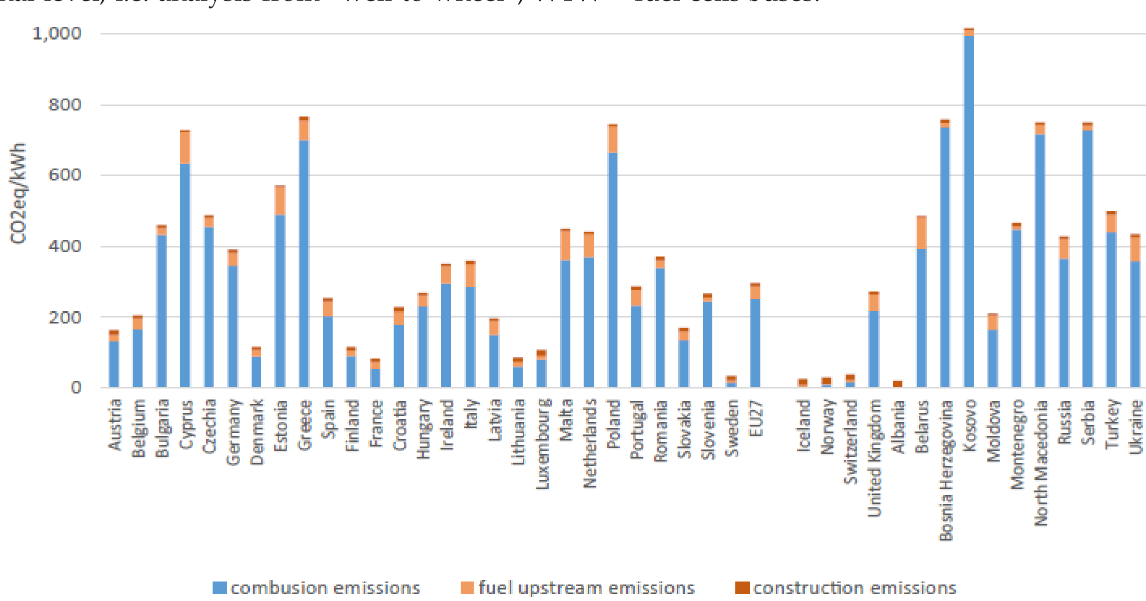

Figure 1. Total CO_2 emission (gCO2eq/kWh) in the process of electricity production in European countries

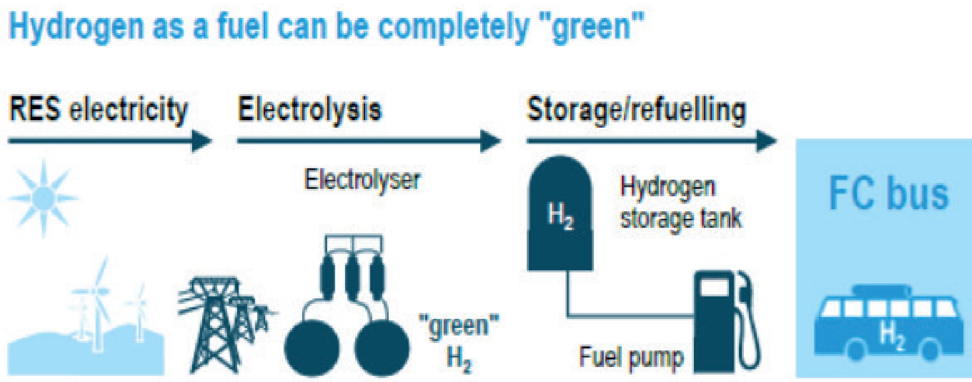

Figure 2. The way of producing, storing and distributing green hydrogen

Such a facility with a complete charging infrastructure costs around 10.7 million Euros [7]. Figures 3 and 4 show a hydrogen production facility (electrolyzer) and a hydrogen bus filling station in South Tyrol (Italy) [8].

Figure 3. Hydrogen production plant (electrolyzer)

Figure 4. Basic components of a fuel cell bus

FUEL CELL ELECTRIC BUSES

Buses powered by fuel cells, FCEB (Fuel Cell Electric Bus) use hydrogen (H_2) stored in tanks and oxygen (O2) from the atmosphere to generate electricity that is generated through an electrochemical process and which is accumulated in batteries. This type of vehicle drive is a possible solution to the global energy problem because it uses hydrogen (H_2), which is found in nature primarily in water in unlimited quantities.

The main advantage of using this type of drive is that there are no emissions of harmful substances in the process of obtaining electricity, so this bus concept has zero impact on the environment. The presentation of the basic components of a bus powered by fuel cells is shown in Figure 5, and Figure 6 shows the principle of operation of a fuel cell [9].

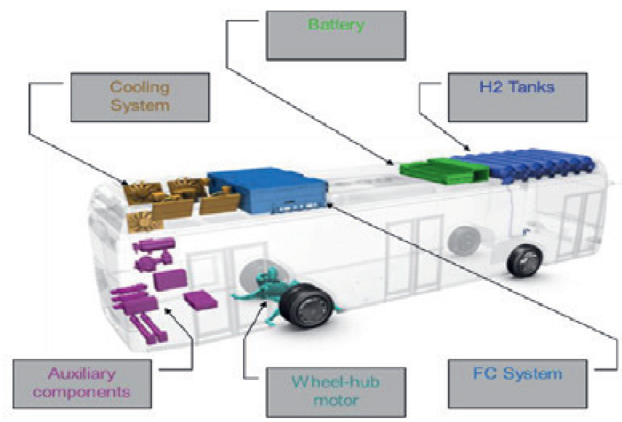

Figure 5. Basic components of a fuel cell bus

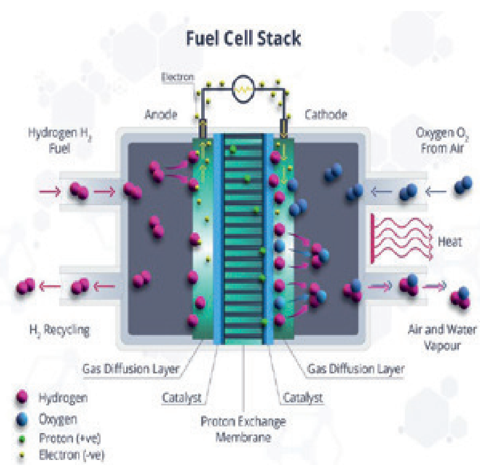

Figure 6. The principle of operation of the fuel cell

Hydrogen is stored in special tanks under a pressure of 350 bar, which are located on the roof of the vehicle. After reducing the pressure to an operating pressure of 8 bar, the hydrogen is delivered to the fuel cell module. The two modules consist of several fuel units (cells) that are interconnected. Each cell separately represents one current source. In the fuel cell module, oxygen

Figure 7. Caetano H2 City gold

Table 1. Technical characteristics of the Caetano H2

Type: Caetano H2 City Gold
Tank capacity H_2: 37,5 kg
Pressure in tanks: 350 bar
Toyota Fuel cell system: 70 kW
Capacity of Li-battery: 44-80 kWh
Charging time: max 10 min
Drive system: Siemens, PM, 180 kW
Consumption H_2 : 7-9 kg/100km
Autonomy of movement: 400-500 km
Price H_2: 6 €/kg
Pass.capacity: 87 passengers
Availability: > 95 %

(O_2) is taken from the air and also injected into the module. Each fuel cell has an anode and a cathode, as well as a catalytic membrane. By bringing hydrogen (H2) and oxygen (O_2) molecules into the cell, electrons between the anode and cathode establish a circuit, while free protons passing through the catalytic membrane bind to oxygen molecules to which a part of the electron from the cathode is added, thus making water (H_2O) and heat as a byproduct of the reaction. Cooling of the module and ensuring the working temperature of 70÷80 is done through the cooling system.

The current produced in the cells is collected in high-capacity lithium batteries, after which it is inverted into alternating three-phase current, with a voltage of 500÷900 V and a frequency of 400 Hz. The current obtained in this way starts the drive electric motor whose torque is transmitted to the automatic transmission and further to the drive wheels [9]. Figure 7 shows a bus powered by fuel cells manufactured by Caetano-Toyota, where 8 buses are in regular operation in Barcelona. Table 1 shows the techno-exploitation indicators [10].

Buses powered by fuel cells have an increasing tendency to be used in EU and UK cities. Table 2 shows the number of buses in use by year [11, 12].

Table 2. Number of fuel cell buses in European Union and United Kingdom cities

Year	Number of FC buses in EU and UK cities
2017	50
2020	115
2023	370
2025	1200

According to the UITP the share of buses powered by fuel cells in the sale of new buses on the EU market will have a constant upward trend. Thus, in 2025, it will amount to about 7.4%, while in 2030, the share will increase to 12.5%, which can be seen in Figure 8 [13].

Buses powered by fuel cells are produced and marketed by almost all leading manufacturers of city transport buses: Solaris bus, Mercedes, VDL, Skoda, Van Hool, Caetano bus, Rampini, Safra, Wright bus, Alex-

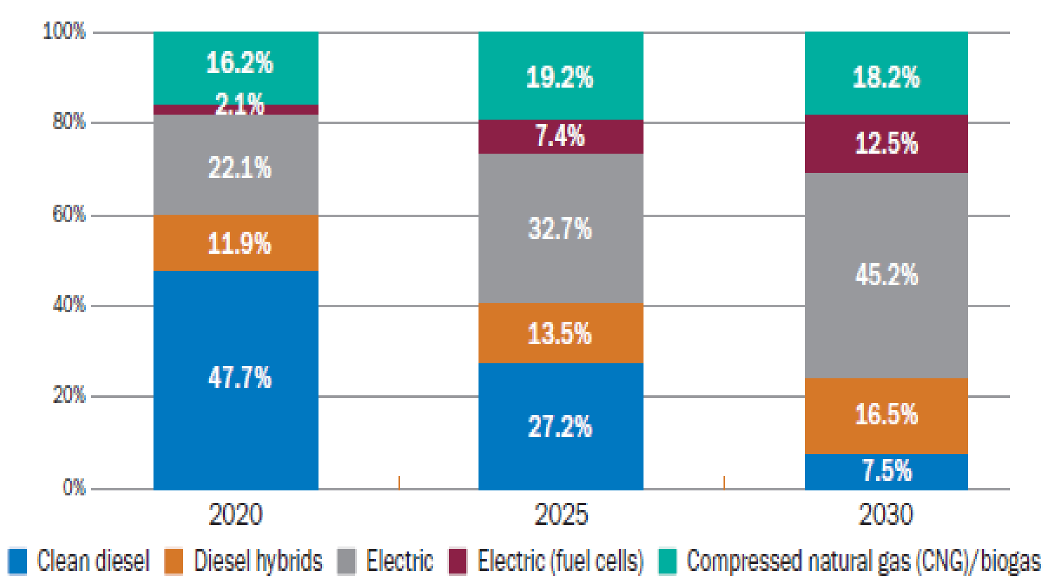

Figure 8. Representation of buses for city transport by drive systems on sale in EU

ander Denis. One of the measures to encourage larger purchases is the limited maximum price of buses with a standard length of 12 meters in the European Union, which is around 625,000-650,000 € [11,14].

DEMO PROJECTS WITH FUEL CELL BUSES

The potential of using this type of drive as completely environmentally friendly was recognized earlier, and the first demonstration projects were realized at the beginning of the 21st century. The CUTE (Clean Urban Transport for Europe) project was particularly significant and resulted from the initiative of the EU Commission for Energy and Transport in cooperation with Daimler Chrysler - Evobus [15]. The main goal of the project was to review the technical, technological, ecological, and economic aspects of using fuel cell technology in public transport vehicles. The project lasted in the period 2001-2006. year and included over 40 participants (vehicle manufacturers, hydrogen companies, refueling companies, public transport operators, scientific institutes, universities, etc.).

Based on the criteria related to the experimental use of buses (climate, geometric characteristics of the routes, lines passing through the central city area), hydrogen production, and distribution systems, 9 EU cities were selected (Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm, Stuttgart). Subsequently, Reykjavik (Iceland) and Perth (Australia) were included in the STEP (Sustainable Transport Energy for Perth) project. Since July 2006, Beijing (China) has also joined this project.

Projects where the possibilities of using buses powered by fuel cells in public city transport systems were considered, so far had several phases, depending on the number of cities that took part and the defined periods in which the techno-economic analyses were considered. The most important projects are:

- CUTE / Clean Urban Transport for Europe, 2001-2006. year
- ECTOS / Ecological City Transport System, 2001-2006. year
- STEP / Sustainable Transport Energy for Perth, 2004-2007. year
- Hy Fleet-CUTE / Hydrogen fleet for Clean Urban Transport for Europe, 2006-2009. year
- CHIC / Clean Hydrogen in European Cities Project, 2010-2017. year

Projects JIVE/JIVE2 (Joint Initiative for hydrogen Vehicles across Europe)

The JIVE/JIVE2 project is the most important project of the European Union to introduce fuel cell buses and infrastructure for the production of green hydrogen in EU cities as much as possible. The project started in 2017 and brought together 19 cities from the EU and the United Kingdom to start the permanent and mass use of fuel-cell buses.

The JIVE/JIVE2 project provides financial support to participating cities for the purchase of vehicles and the construction of infrastructure. All the biggest manufacturers of this type of bus (Solaris bus, VDL, Van Hool, Caetano bus,...) and equipment Siemens energy, Ballard, Shell..., are included. Table 3 shows the cities included in the JIVE/JIVE2 project [16].

Table 3. Cities participating in the JIVE/JIVE2 project

Projects JIVE/JIVE2 City, Region	Number of FC buses
Aberdeen, UK	21
Auxerre, France	5
Barcelona, Spain	8
Birmingham, UK	20
Brighton, UK	22
Charleroi, Belgium	10
Cologne, Germany	50
Dundee, UK	12
Emmen, The Netherlands	10
Gelderland, The Netherlands	10
Groningen, The Netherlands	20
London, UK	20
Pau, France	5
Rhein Main, Germany	10
South Holland, The Netherlands	20
South Tyrol, Italy	12
Toulouse, France	5
Velenje, Slovenia	6
Wuppertal, Germany	20

From the table it can be seen that in the mentioned cities the most common number of vehicles in the fleet is between 10 and 20, the exception being Cologne (Germany) where 50 buses with fuel cells are in operation, which represents the largest fleet in Europe.

CONCLUSION

The introduction of hydrogen-powered buses using fuel cell technology is one of the most effective strategies that should contribute to the reduction of harmful gas and carbon dioxide emissions from public urban transport vehicles in cities. The use of green hydrogen as completely carbon neutral is an additional quality of this drive concept compared to electric buses that take electricity for charging from the public distribution network whose production method comes from fossil fuels.

The introduction of buses powered by fuel cells in the cities of the European Union has a constant trend of growth and for now, it is present only in the most developed cities/regions. It is expected that in the coming period, the number of buses powered by fuel cells will be even higher. The limiting factors for more mass use, above all in countries with less economic power, are the high investment costs of building hydrogen production facilities, the still significantly higher price of buses compared to conventionally driven buses, high safety standards, specific maintenance, training, etc.

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PRELIMINARY REPORT

EU Recommendations for Sustainable Development of Cities

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Abstract: The paper presents EU recommendations in the concept of plans for the sustainable development of transport in cities, which was created as a result of extensive dialogue between stakeholders and planning experts from all over the EU, supported by the initiatives of the European Commission through the development of a number of projects. The European Commission has been actively promoting the concept of sustainable urban mobility planning for several years. Through the funding of a series of projects related to this topic, stakeholders and experts were brought together to analyze existing approaches, discuss problem areas and identify best practices. Public urban and suburban passenger transport systems (JGTP), according to the principles of the European Commission, play a key role in achieving the goal of sustainable development and sustainable transport in cities. In this way, plans can help cities in the efficient use of existing transport infrastructure and services, and ensure economical implementation proposed measures.

Key words: sustainable development, urban mobility, public city transport.

INTRODUCTION

Strategies for sustainable development of transport in cities is a balanced development of economic, ecological and sociological goals. Negative transport impacts are numerous and diverse and require continuous monitoring (Gladović et al. 2023). The current strategic document for the development of traffic in the EU entered into force in 2011. The white paper from 2011 entitled "Guidelines towards a single European transport area - Towards a competitive and energy-efficient transport system" [1] represents the global aspect of development in the transport sector, presents future challenges and difficulties of development and provides guidelines for the creation of transport policy until 2050. The key challenges of future traffic development are:

- reduction of dependence on the use of fossil fuels;
- construction of modern infrastructure and greater multimodality of the system by applying the methods of „smart management" and information systems.

The strategic document was adopted together with other documents directly related to the reduction of energy dependence until 2050 [2] and forms an integral part of the European Commission's policy aimed at reducing dependence on the use of non-renewable energy sources.

The importance of the transport policy for the overall energy efficiency of the EU is underlined once again in the announcement of the latest date, which is based on the goals until 2030 regarding the reduction of energy dependence [1]. It was established that results are being achieved in accordance with the set goal of reducing fossil fuel consumption by 20% by 2020, and a new goal was set - reducing consumption by 30% by 2030.

Public urban and suburban passenger transport systems (JGTP), according to the principles of the European Commission, play a key role in achieving the goal of sustainable development and sustainable transport in cities.

Generally, it can be concluded that in accordance with the large number of demands of the environment, the quality and sustainability of the urban traffic system must be evaluated from the aspect of all modes of transportation and the demands of all users of the system. The full effectiveness of the system could be achieved through:

1. 1. Integration of different modes of transportation;
2. 2. By redistributing modes of travel from cars to public transport by applying traffic demand management measures (mobility plans, parking policy, tariff policy in public transport, increasing the quality of public transport services);
3. 3. Technological innovations in the sector of motor vehicles and
4. 4. More effective management of traffic flows through intelligent transport systems.

SUSTAINABLE URBAN MOBILITY PLANS (POUM)

Transport demand management strategies aim to optimally use the available transport infrastructure of the urban environment and to rationalize and reduce the number of trips by private car when the use of a private vehicle is not necessarily required. Therefore, the transport demand management approach translated into Sustainable Urban Mobility Plans (POUM) is a response to the growing transport problems of cities. By combining strategies aimed at reducing the use of private cars and strategies aimed at increasing the attractiveness of using other modes of travel (public urban passenger transport and non-motorized traffic), the improvement of the transport system as a whole is achieved.

Sustainable urban mobility can be achieved by applying an integrated approach to planning that takes into account all types of traffic in cities and their surrounding areas. Such an approach is enabled by Sustainable Urban Mobility Plans (POUMs), which form a set of interrelated measures that gradually lead to meeting the mobility needs of citizens and businesses. At the same time, POUM aims to improve the quality of life in cities and strive to balance the quality of the environment, economic development and social justice. In order to accelerate the implementation of this approach in Europe, the European Commission adopted the Action Plan on Urban Mobility [3]. This document assists local authorities in the development of POUM by providing them with guidelines for action, promoting the exchange of best practices, identifying reference points, and supporting educational activities for experts in the field of urban mobility.

POUM is a strategic plan that builds on the existing practice in traffic planning and is based on the principle of integration, participation and evaluation in order to satisfy the existing and future mobility needs of city residents, thus ensuring a higher quality of life in cities and their surroundings. A sustainable traffic system in cities, as the main goal of POUM, is achieved by increasing the accessibility of administrative and commercial content while simultaneously reducing the negative external effects of traffic development such as traffic accidents, noise, air pollution, climate change and energy dependence.

The main characteristics of POUM are as follows:

- Participatory approach that includes citizens and actors from the beginning to the end of the planning process.
- Commitment to sustainability that will balance economic development, social justice and environmental quality.
- An integral approach that takes into account the practices and policies of different sectors, levels of administration and neighboring institutions.
- A clear vision, purpose and focus on the achievement of measurable goals are embedded in a comprehensive sustainable development strategy.
- Review of transport costs and benefits, taking into account wider social costs and benefits.

The development and implementation of the POUM is a continuous process consisting of eleven main steps (Figure 1). In practice, these activities may be performed partially parallel or may contain feedback links. A detailed description of all steps and activities can be found in the guidelines «Development and implementation of the Sustainable Urban Mobility Plan»[4] .

Previous experiences have shown that the implementation of POUM can provide a number of advantages for cities and their residents. Namely, the implementation of the plans affects the improvement of the image of the city because the city involved in the planning of sustainable urban mobility can leave the impression of an innovative city facing the future. People-oriented urban mobility planning ultimately results in improved citizen mobility and better access to urban areas and their services. One of the basic starting assumptions in the development of plans is that the plan is made for people, not for cars and traffic, and work on improving air quality, reducing noise and mitigating climate change leads to positive effects on health and significant savings in healthcare. Planning for people means planning with people. With the help of citizens and other actors, decisions regarding urban mobility measures can achieve a significant level of «public legitimacy». All prepared plans should be harmonized with various European directives that are adopted at the global level, so that sustainable urban mobility planning provides an efficient way of fulfilling the legal obligations prescribed by the EU.

In cities across Europe, there are different approaches to planning of sustainable urban mobility. Namely, while some countries such as France and Great Britain are considered forerunners in this area, in other European countries POUM is still a new or unknown planning tool. Examples of good practice and instruments that illustrate the development and implementation of POUM form a database that provides valuable material for cities

Figure 1. Planning of sustainable urban mobility

across Europe, and at the same time the database provides inspiration for work on any new POUM.

One of the first projects to support a sustainable urban transport system in our country is a UNDP (United Nations Development Program Serbia) project which goal is to reduce metropolitan emissions in Belgrade by improving the public transport system, promoting the participation of cyclists in traffic and providing a political framework for the development of sustainable traffic. The four-year project ends in 2014 and the final result is the creation of a POUS that will ensure the harmonization of Belgrade's traffic systems with economic, social and environmental protection needs, while minimizing unwanted consequences on the economy, society and the environment.

MOBILITY MANAGEMENT AND TRAVEL PLANS

Mobility management is a concept that promotes sustainable transport and manages the demand for passenger car use by changing the attitudes and behavior of users. Mobility management is based on the so-called «soft» measures, such as informing passengers, communication, organizing different types of services and coordinating the activities of different users. «Soft» measures most often increase the efficiency of «hard» measures within the framework of urban transport (e.g. new tram lines, new roads and new bicycle paths), they do not necessarily require large financial investments, and the relationship between invested funds and benefits can be significant.

The main goal to be achieved with the concept of mobility management is to achieve a greater degree of sustainable mobility, with the following objectives:

- to encourage a change in users' attitudes and behavior towards greater use of environmentally friendly modes of transport (EMFT),
- to improve access to all people and organizations by strengthening the conditions for sustainable development,
- integrated and more efficient comprehensive land use and traffic planning,
- reduction of traffic growth by limiting the number of vehicles, driving length and the need to use passenger cars,
- integration of different modes of transportation i
- increasing the economic efficiency of the entire transport system.

Mobility management consists of a large number of measures, as shown in Table 1.

Table 1. Classification of mobility management measures

CATEGORY	EXAMPLE
Information	Information obtained before and during the travel, information centers, websites, applications
Promotion	Promotional campaigns, travel tips, measures aimed at specific user groups (employees, elderly, students, pupils, residents), individual marketing, discount campaigns
Organization and coordination	Car sharing, car pooling, bike & ride system, park & ride system, tickets for all types of transport
Education and training	Eco driving, employee training, cycling courses
Measures targeting certain locations	Mobility management in companies, schools, shopping centers, hospitals, government agencies, at various events, in residential areas
Time and space flexibility	Work from home, reducing hospital visits, avoiding rush hour driving, flexible working hours
Support measures	Parking management, installation of new parking lots for bicycles, financial measures, charging for driving

In many countries, mobility management is mostly related to places where trips are made, such as companies, schools, administrations, etc. In these cases, mobility management means managing the way users travel to a specific location and a large number of measures fall into this category. One of possible measures is a travel plan that aims to manage and change the habits and behavior of users in the transport system who travel from and to a specific location (e.g. employees of companies, students and teachers in schools, customers in shopping centers, etc.). The travel plan usually combines measures that promote walking, cycling, public transport and car sharing, as well as measures that reduce the need to travel.

Travel plans can be extremely useful for large companies that have a large number of trips per day, for the reason that employees have to travel to and from work every day, and this type of travel usually takes place during peak load periods, i.e. in the morning and in the afternoon. The management of these trips, which would lead to their reduction, redistribution to other modes of transportation or redistribution in terms of the time during the working day when the trips take place, can have great benefits in terms of environmental protection, but also economic and economic benefits for the company.

The purpose of travel plans is to streamline travel within the company. It is a comprehensive planning policy, which can be voluntary or binding, but always agreed. All initiatives within travel plans are aimed at limiting the use of passenger cars by developing alternative solutions: walking, use of bicycles, public passenger transport, car sharing, group ride services, etc. Travel plans include a number of different measures that lead to:

- reducing the number of trips by passenger car to and from the workplace,
- increasing the number of people who share a car for commuting,
- reducing the need for travel, especially during peak load periods, and
- enabling employees to use alternative modes of transportation.

In line with circumstances, each company sets goals that are specific to its business. However, the main goal of all the measures applied within travel plans must be aimed at reducing the use of passenger cars in favor of other modes of transport. The impact of the applied measures can be measured in various ways, such as the distribution of traffic on modes of transport, the average occupancy of vehicles, the number of trips by passenger car during the peak hour, etc.

There are a number of examples of good practice that show the positive effects of implementing travel plans [5] [6] [7]. At the Institut Gustave Roussy (Vilgeif, France), which has around 2,200 employees, after the introduction of measures such as group driving services by car and the introduction of a bus line that connects the Institute with the public urban passenger transport network (JGTP), the number of passenger car users decreased by 17%. The software company Oracle Corporation (Berkshire, Great Britain) recorded a 13% reduction in car users, which also affected the reduction of parking requirements, and monthly savings amounted to approximately 13,000 liters of fuel. The high participation of private vehicles (72%) in work trips was a problem of Coimbra Hospital (Coimbra, Portugal). The key results of the implemented measures were a reduction in the number of car trips in favor of JGTP by over 10%, as well as a reduction in fuel consumption by 15%. In the area of Brussels (Belgium), travel plans are implemented in about 280 institutions with over 240,000 employees. Measures aimed at promoting alternative modes of transport reduced the use of cars for business trips by 5%, while the use of JGTP increased by around 4%. A similar experience was had by 120 companies in the area of the city of Toulouse (France), where there was also a decline in the use of cars to go to work in favor of trips made by public transport, bicycles or car sharing.

CHALLENGES AND OBSTACLES IN DEVELOPMENT OF URBAN MOBILITY IN THE CITIES OF SOUTH EAST EUROPE (SEE)

The Green Paper on Urban Mobility - Towards a New Culture for Urban Mobility identified five challenges that cities face and must overcome in order to move towards “free-flowing cities and municipalities”, namely:

- congestion
- dependence on fossil fuels
- increasing the flow of cargo and passengers

- accessibility of the urban mobility system
- security.

Congestion creates negative economic, health, environmental and social impacts, and affects mobility not only at the city level, but also on intercity transport routes that pass through urban areas. Possible solutions include a multimodal approach, encouraging cycling and walking, appropriate parking policies, online work and online trade, car-pulling/car-sharing), etc. Dependence on fossil fuels which cause emissions of CO2 and other pollutants, as well as noise pollution, significantly contribute to climate change and worsen air quality and human health. Possible ways to overcome this challenge include: developing cleaner combustion engines and setting minimum standards for vehicle performance; research and introduction of alternative fuels and support for the development of infrastructure for supplying them in urban areas; and ultimately restricting or banning transportation in certain urban areas. The increase in the flow of cargo and passengers need to be viewed in combination with limited possibilities of expanding the traffic infrastructure, i.e. from the point of view of limited space, inadequate finances and from the position of advocating sustainable development. Possible ways to overcome this challenge include improving the efficiency of intelligent transport systems (ITS), integrating the JGTP tariff structure of all types of JGTP and a quality information system to achieve better fleet management, accessibility of the urban mobility system.

The existing systems, which include public passenger transport system (JGTP), pedestrian and bicycle paths, roads, etc., should be of good quality, which means that, depending on the case, they should be efficient, fast, frequent, comfortable, reliable, safe, flexible, affordable and accessible to vulnerable groups (elderly people, children, citizens with disabilities, pregnant women, etc.). In addition, the phenomenon of uncontrolled urban sprawl makes this challenge more complex. Possible ways to overcome this challenge include providing collective transportation options for citizens' needs, establishing an appropriate legal framework (e.g. by establishing appropriate public procurement standards), developing fast and frequent JGTP solutions, such as "Bus rapid transport systems - BUS rapid transport" and, as a comprehensive measure, the development and implementation of plans for sustainable urban mobility. Safety is a key aspect of a high-quality urban mobility system that includes the safety of infrastructure and vehicle fleet, as well as the safety of citizens accessing the system (e.g. walking from home to the bus stop). An unsafe system can discourage the use of JGTP and result in isolation of citizens and greater use of private vehicles. Possible ways to overcome this challenge include investing in safer infrastructure (e.g. installing lighting on pedestrian and bicycle paths), introducing a vehicle fleet accessible to citizens with reduced mobility and implementing education and information campaigns. In this sense, it is also important to mention the macro and micro economic challenges that need to be faced in order to improve the sustainability of the JGTP system and improve the sustainability of the cities served by those systems. Macroeconomic challenges relate primarily to declining urban productivity growth rates and differential productivity outcomes between different parts of cities, where it is important to identify the links between urban productivity growth and investment in transportation and other community infrastructure.

CONCLUSION

The design and implementation of timely, effective and sustainable transport solutions in many cities, including in the cities of Southeast Europe (SEE) are often hampered by institutional and administrative deficiencies. Although institutional reform does not necessarily lead to a single institution that will manage multiple aspects and functions of sustainable urban transport, interdepartmental coordination or interdepartmental integration is necessary for comprehensive addressing of the issue of sustainable urban transport. Actions to overcome these obstacles should be adapted to different stakeholders and should include, accordingly, a series of measures jointly implemented by all stakeholders (city/municipal authorities and administrations, associations of cities and municipalities, national authorities, companies dealing with public city passenger transport, companies dealing with communal services, investors, development institutions, scientific institutions, etc.) [8].

Solutions for improving sustainable urban mobility are available and proven but the lack of necessary capacities at all levels of government - from national to municipal - slows down their successful implementation. One of important preconditions for the development of sustainable urban mobility in SEE countries is strengthening of capacities at two different levels: at the state level and at the local level (city/municipality).

We can say that development of sustainable urban mobility (OUM) requires a strong, city/municipal administration oriented towards environmental issues based on the efficient organizational structure which includes multidisciplinary experts. The main objectives of the unit for sustainable urban mobility should be the following:

- Significant increase in road safety in the city/municipality
- Development of the city/municipality based on the principles of sustainable urban mobility
- Economic development of the city/municipality through general improvement, increased investment and new green jobs in the transport sector

- Significant reduction of fuel consumption and related CO2 emissions from the transport sector
- Successful transformation of the city/municipality into an environmentally sustainable city/municipality.

In the long term, it is necessary to establish integrated urban planning, with a special focus on traffic demand indicators, the establishment of an efficient process of public urban passenger transportation and sustainable urban mobility of citizens so that the development of cities is sustainable and the quality of life continuous and achievable (Drašković et al. 2023).

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PRELIMINARY REPORT

Urban Road Safety in the Republic of Serbia

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Abstract: Advantages of traffic have been known since the first day of traffic development. However, as society evolved so did the traffic and road safety consequently developed. In this way, the negative effects that traffic has on the society, where traffic accidents and their consequences have a leading negative effect, has started to be notices. This is also shown by the fact that an average of 1.35 million people is killed in traffic accidents a year worldwide. However, the development of the society introduces us to the new traffic consequences, such as: air and environment pollution, increased levels of ambient sounds, physical inactivity and the development of numerous diseases (cardio-vascular, respiratory, diabetes) and the onset of mental illness. Namely, it has been estimated that more than two hundred thousand people prematurely died since the beginning of this century because of air pollution and environmental hazards – traffic is largely contributing to CO2 emissions. In this regard, the issues of urban road safety is being given increasing importance today, namely the reduce use of privet passenger cars and the increasing efforts to create space for vulnerable road users. The subject of this paper is the analysis of urban road traffic safety on the territory of 20 selected local governments of the Republic of Serbia. In addition to the basic demographic characteristics of the selected local governments, the paper will present the results of a questionnaire conducted on citizens' attitudes about urban traffic safety. Although the majority of residents choose walking as the main transport mode, they believe that it is necessary to improve the infrastructure offer for active transport modes, which would significantly contribute to the development of pedestrian and bicycle traffic. A significant number of respondents exceed the speed while driving a motor vehicle, although they show that they are aware of the risks that speeding leads to, especially with regard to vulnerable road users.

Keywords: Urban road safety; Road traffic safety; Public health; Road traffic pollution.

INTRODUCTION

Living in the 21st century has become unimaginable without road traffic and all its benefits. However, as road traffic developed more and more, the negative effects and consequences that road traffic has on the social, health, ecological and economic aspects of human life also appeared. Some of the most significant negative effects are: road traffic accidents (material damage, number of injured people and fatalities), depletion of natural resources, pollution of the environment with exhaust gases and waste materials, noise, stress caused by participation in road traffic, social pollution (pollution of interpersonal relations) and similarly. As a consequence of the development of road traffic, cities around the world face problems related to unequal mobility and accessibility, pollution, road traffic accidents and the like (Mohan et al, 2017). This problem has been recognized as the "Road Traffic Safety Epidemic" (Feng Wei and Lovegrove, 2012), due to the fact that the built environment directly affects the dependence on the automobile, but also the socio-economic status of the individual. It is precisely this dependence on automobiles that represents a major public health problem (Douglas et al, 2011), i.e. a social issue, the solution of which is the basis for creating sustainable cities (Živković, 2021).

Referring to the definition of a road traffic accident, where it is an event that occurred on the road, in which a person is killed or injured or property is damaged, Máslaková (2017) states that a road traffic fatality is the most serious consequence of the same. However, road traffic accidents also affect the mental state of the individual. These consequences often remain long-lasting, or at least in the following period after physical recovery (Máslaková, 2017). In addition, Douglas et al. (2011) state that road traffic accidents are not the only consequence of road traffic development, they recognized that automobiles have an impact on air pollution, but also on increased ambient noise. Every year, more than a million people die prematurely due to air pollution, which causes cardiovascular diseases and the development of cancer cells, especially among vulnerable groups of road users (Douglas et al., 2011). Douglas et al. in their work state that the noise emitted by road traffic affects the development of sleep disorders, hypertension and an increase in blood pressure in people who are exposed to increased influence. Air pollution is positively associated with poorer mental health, while road traffic noise is only associated with medical prescription of anxiolytics (Klompmaker et al., 2019). Air pollution and an increased level of ambient noise, as a result of traffic, contribute to an increased level of cholesterol (Sørensen et al., 2015), but also to an increased risk of heart attack, as the second cause of death in the world (Haddad et al., 2023). In addition, if the lack of green spaces in urban areas is taken into account as a contributing factor to public health, a high risk of type 2 diabetes (Sørensen et al., 2022) and a significant mental health disorder can be added to this list, especially in adolescents (Bloemsma et al., 2022).

The development of active transport modes is recognized as a good alternative to the use of private automobiles, which has a positive impact on the public health of residents and the environment (Živković and Todorović, 2020). Following the definition by Cook et al. (2022), in which they state that active transport modes include all „travels in which the sustained physical exertion of the traveller directly contributes to their motion", they state that in addition to walking and cycling, active modes of transport also include walking, the use of wheelchairs, riding scooters and skateboards and the like (Cook et al., 2022).

Cycling is an environmentally friendly urban transport mode (Nawrath et al., 2019), which, together with walking, has positive effects in terms of physical activity and obesity (Pucher et al., 2010a; Wanner et al., 2012), cardiovascular system, type 2 diabetes and inflammatory markers (Andersen et al., 2000; Celis-Morales et al. 2017; Dinu et al., 2019; Matthews et al., 2007, Saunders et al, 2013; Shaw et al., 2020; Smith et al., 2019). By changing the transport mode and by increasing the use of active transport modes, there is an increase in the general state of health (Barajas and Braun, 2021). Nawaz and Ali (2020) state that the use of active transport modes is influenced by certain parameters, such as: social parameters (recognition of responsibility towards health and the environment), behavioural parameters (economic aspirations) and cultural parameters (laws and policies) (Nawaz and Ali, 2020).

However, active transport modes, and above all the use of bicycles, are considered as much as ten times more dangerous than driving a motor vehicle, but the results show that cities with a high share of bicycle traffic are safer, not only for cyclists, but also for all road users (Marshall et al., 2019). It is important to note that the choice of active transport modes is significantly influenced by the sense of convenience, danger, crime rate and traffic fatalities (Fernández-Heredia et al., 2014), especially in urban areas.

With the aim of solving the problem of road traffic in today's conditions, urban road traffic safety is part of road traffic safety as a scientific discipline (Živković, 2021), it helps to establish the foundations of a new way of thinking about traffic safety. Namely, society did not always have the same problems regarding road traffic safety, so road traffic safety developed accordingly (Lipovac et al., 2014). Society has gone through five different phases of traffic safety in five different time periods: phase 1 – road traffic accidents are rare and isolated cases (until 1925/30); phase 2 – road traffic insecurity is a social problem (from 1925/30 to 1965/70); phase 3 – the first attempts to curb the growth of road traffic accidents (from 1965/70 to 1975/85); phase 4 – continuous reduction in the number and consequences of road traffic accidents (from 1975/85 to 1998); phase 5 - global road traffic safety management (since 1998). The world (including the Republic of Serbia) is still in the fifth stage of road traffic safety development, where road traffic accidents are recognized as a significant cause of death and injury to millions of people around the world. However, the further development of society, and above all the increase in the number of passenger automobiles, increasing air pollution, increasing noise resulting from road traffic, the space occupied by motor vehicles and road traffic congestion, decreasing mobility and the worsening health condition of citizens, pave the way for to the new period of road traffic safety development - towards urban road traffic safety (phase 6) (Živković, 2021).

This paper will present the results of a questionnaire conducted on the territory of 20 local self-governments in the Republic of Serbia, all with the aim of identifying problems in the field of urban road traffic safety and defining the measures that need to be implemented in order to overcome them.

URBAN ROAD TRAFFIC SAFETY

As society continues to develop, and so does road traffic, which leads to new problems, i.e. the negative effects of road traffic and leads to the development of the so-called of urban traffic safety. Namely, the accelerated urbanization of developing countries presents challenges for the road traffic systems of cities, especially if their goal is to meet the mobility and accessibility needs of citizens, while on the other hand providing them with a sustainable, safe and healthy environment (GIZ, 2017). The development of the state also leads to an increase in the number of inhabitants, which necessarily leads to an increase in the road network, but also endangers the safety of (vulnerable) road traffic users. The result of this is an unnecessary increase in the number of dead and injured in road traffic accidents, which consequently entails socio-economic and health consequences for both individuals and the state. The increased number of victims in road traffic accidents mainly refers to vulnerable road users, such as pedestrians, cyclists, motorcyclists, etc., who account for more than half of those killed in traffic accidents (this is the eighth cause of death in the world; WHO, 2018).

In order to improve road traffic safety in built-up environments, an urban safety management approach has been developed (GIZ, 2017). In order to be able to manage urban safety, it is necessary to:

- there is a formal safety strategy;
- road traffic safety is integrated with other urban strategies;
- all road traffic participants are taken into account, especially vulnerable participants;
- take into account the characteristics of all roads;
- there is cooperation with other sectors;
- there is engagement of a large part of the scientific community;
- there is active involvement of all road traffic participants;
- special strategies are developed for each individual city area, especially if different structures are involved;
- there are programs for monitoring realized safety goals.

Urban road traffic safety is a part of road traffic safety as a scientific discipline, but a part that is still in the initial stage of development. In this regard, Živković (2021) presented a definition, which can be considered as the basis of the development of a new concept: "Urban road traffic safety is part of the scientific discipline of road traffic safety, which studies the impact of the negative effects of traffic on society, and which, on the other hand, develops the improvement of the environment and the psycho-physical health of people in cities that are socially and economically suitable for life."

This definition covers the efforts of the scientific community to combat road traffic accidents and their consequences (fatalities and injuries), as the most common adverse impact, and exposure to traffic, i.e. environmental pollution (air pollution, noise), land use, development of mental and physical diseases etc. The goal is to create a city for residents, with enough space for vulnerable road users, with a reduced number of motor vehicles, a good public transport system, clean air, and with social and economic sustainability. It can be concluded that urban road traffic safety is a very broad concept, which, in addition to road traffic safety itself also includes urbanism, architecture, medicine and psychology, sociology and ergonomics.

RESEARCH METHODOLOGY

This paper will present the results of an on-line questionnaire conducted on the territory of 20 local self-governments in the Republic of Serbia, all with the aim of identifying problems in the field of urban road traffic safety and defining the measures that need to be implemented in order to overcome them. We have tried to collect data from several local self-governments, which are different in size and structure, using questionnaires.

The questionnaire was made in the form of an on-line questionnaire with 30 questions, which, in addition to the basic demographic questions, also included questions from the domain of road traffic safety, mobility and urban road traffic safety. The questionnaire was available to respondents in the period from March to May 2023, and the questionnaire was filled out by 1,134 respondents.

RESULTS

Demographic characteristics of the sample

Out of the entire sample of respondents who filled out the questionnaire, 43% of the respondents are male, and 57% of the respondents are female. Looking at chart 1, it can be seen that most respondents belong to the age group of 31-40 years of age (33%), which is expected, since this group is the most mobile active. While, on the other hand, the questionnaire was filled out by the least number of persons older than 65 years, only 0.4%, which can be connected with the method of distribution of the questionnaire - the on-line form of the questionnaire.

From chart 2, it can be seen that most respondents belong to the group of employed people (70%), while the fewest respondents belong to the group of retired people (only 1%), which is expected if we look at chart 1 with the percentage distribution of respondents by age.

From the point of view of road traffic safety, 7% of respondents experienced a road traffic accident in the last year. Of the total number of respondents who had a road traffic accident in the last year, the percentage of drivers and passengers in passenger cars (5 each), pedestrians (3%), bicycle drivers (2%) and motorcycle drivers (1%) stand out the most.

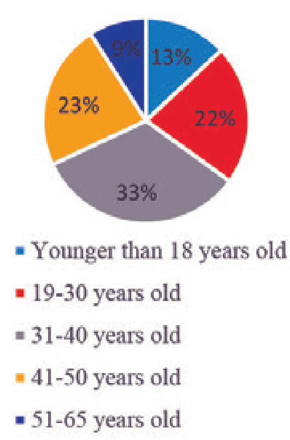


Chart 1. Percentage distribution of respondents by age

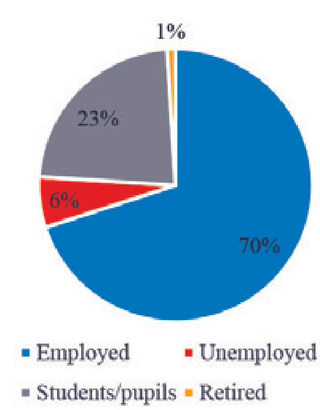


Chart 2. Percentage distribution of respondents by work status

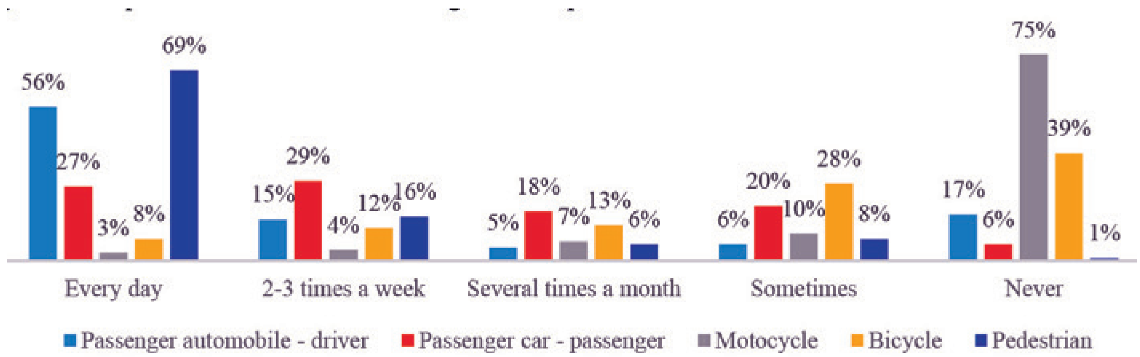


Chart 3. Percentage distribution of respondents by the type of transportation they use most often

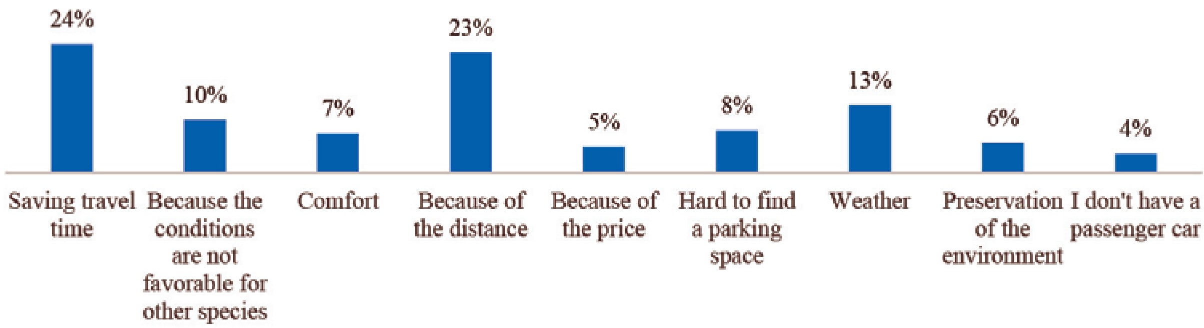
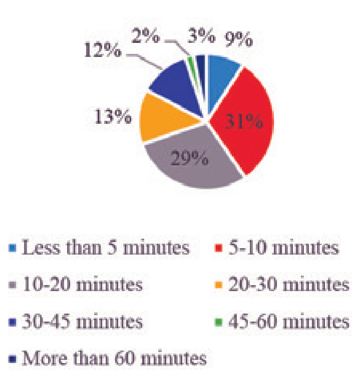


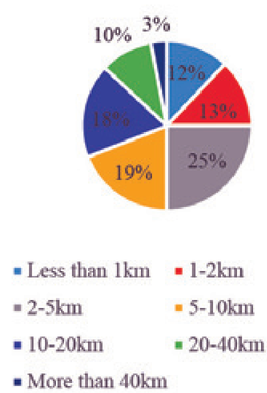
Chart 4. Percentage distribution of respondents by reasons for using the most common transport mode

Use of different transportation modes

From chart 3, it can be seen that the highest percentage of respondents use walking as a everyday transportation mode (69%), followed by the use of a passenger car as a driver (56%). On the other hand, 75% of respondents stated that they never use a motorcycle as a transport mode. In addition, it was observed that only 1% of respondents never choose walking as a transport mode.



Graph 5. Percentage distribution of respondents by the time period of the average trip by the most common transport mode



Graph 6. Percentage distribution of respondents by the length of the journey by using the most common transport mode

On chart 4, it can be seen that most respondents choose their most common transport mode in order to save travel time (24%), followed by the distance they travel (23%).

During the use of the most common transport mode, most respondents spend between 5 and 10 minutes per day (31% - chart 5), while most of them travel between 2 and 5 km per day (25% - chart 6).

Road traffic safety

From the part where the demographic data of the respondents are described, it can be seen that 7% of the respondents had a road traffic accident in the last year, where road traffic accidents involving passenger automobiles stand out. In this regard, respondents were asked to recognize how dangerous certain transport modes are in the places where they live (chart 7). Percentage-wise, respondents recognize all the offered transport modes

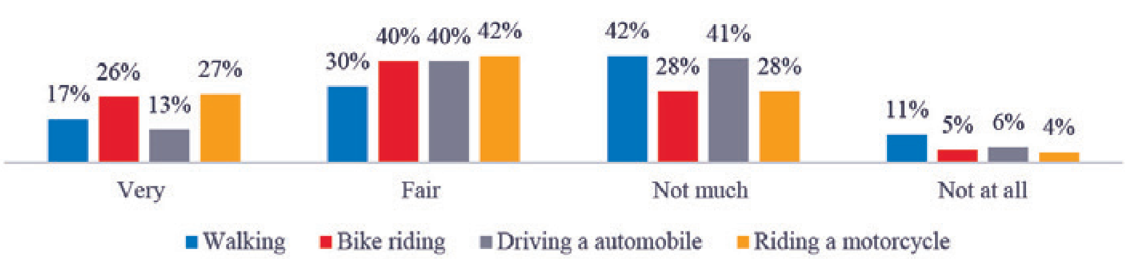


Chart 7. Percentage distribution of respondents by the opinion of how dangerous certain modes of transport are recognized

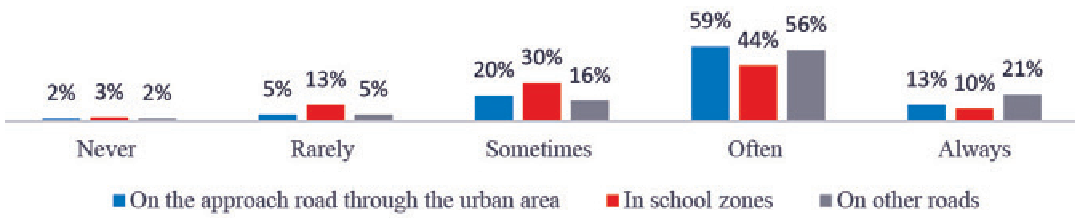


Chart 8. Percentage distribution of respondents by the opinion of how often other road users exceed the speed limit

(walking, cycling, driving a car and motorcycle) as dangerous transport modes.

Bearing these results in mind, the respondents stated their attitude as to how often other road users exceed the speed limit in certain areas (road passage through the urban area (speed limit is 50 km/h), school zone (speed limit is 30 km/h in urban areas), other roads - chart 8). From graph 8, it can be seen that the highest percentage believes that other road users exceed the speed limit in all offered areas, where the passage of the road through the urban area stands out. However, the data on speeding in the area of the school zone is particularly worrying, where it is known that children, due to their weaker psycho-physical characteristics, are less able to estimate the speed of vehicles.

Following the view that all transport modes are recognized as having a significant level of danger, the respondents stated their opinion on how safe the road traffic infrastructure is in terms of road traffic flow (chart 9). It can be seen that the largest percentage of respondents believe that the road traffic infrastructure does not provide a sufficient level required for safe road traffic (not safe at all - 17%, insufficiently safe - 43%).

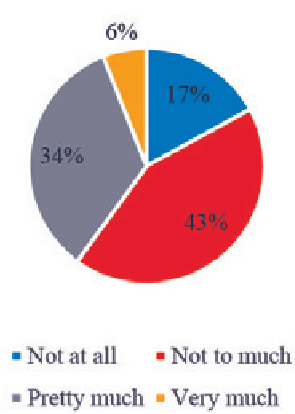


Chart 9. Percentage distribution of respondents according to their opinion on how safe the road traffic infrastructure is

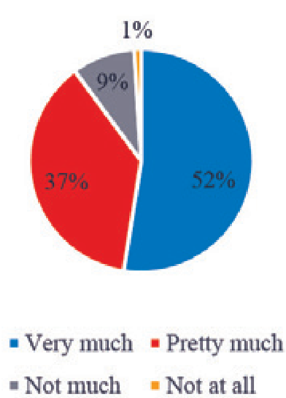


Chart 10. Percentage distribution of respondents by concern regarding road traffic accidents, as one of the problems of urban road traffic safety

Following the previously mentioned results, one could expect a very high percentage of respondents' concern about road traffic accidents, which may be the result of all of the respondents' previous attitudes (very worried - 52%, fairly worried - 37% - chart 10).

Following this attitude of respondents from the previous chart, chart 11 shows that the largest percentage of respondents consider that road traffic accidents are a very important problem of urban road traffic safety that should be solved as a priority (very important problem - 75%).

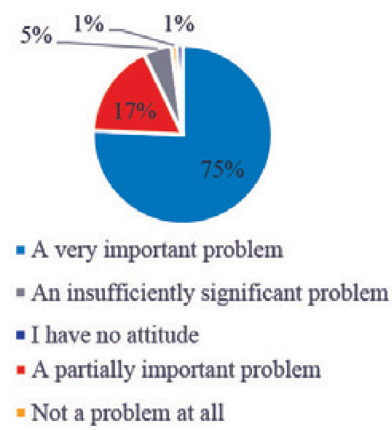


Chart 11. Percentage distribution of respondents by the recognition of road traffic accidents as an important problem of urban road traffic safety that needs to be solved as a priority

Urban road traffic safety

Urban road traffic safety, in addition to road traffic safety in a general sense, also includes citizens' attitudes about mobility, which can result in a change in the transport mode, but also in the quality of the environment. In this regard, the respondents indicated how satisfied they were with the infrastructural offer (road surface, pedestrian surface, bicycle surface). Chart 12 shows that the respondents are not satisfied with the infrastructural offer of all the offered infrastructural surfaces, which can affect the use of different modes of transport and the feeling of road traffic safety.

The quality of the infrastructure directly affects the choice of transport mode, where the attitude of the respondents regarding accessibility to everyday centres of attraction (workplace, school, store, etc.) should also be observed. Chart 13 shows that a high percentage of the respondents are satisfied with the accessibility for all the offered transport modes (in the offered transport modes, walking was deliberately omitted, bearing in mind that the other infrastructural areas are insufficiently developed).

However, the respondents recognize that it is necessary to make investments in pedestrian and bicycle in-

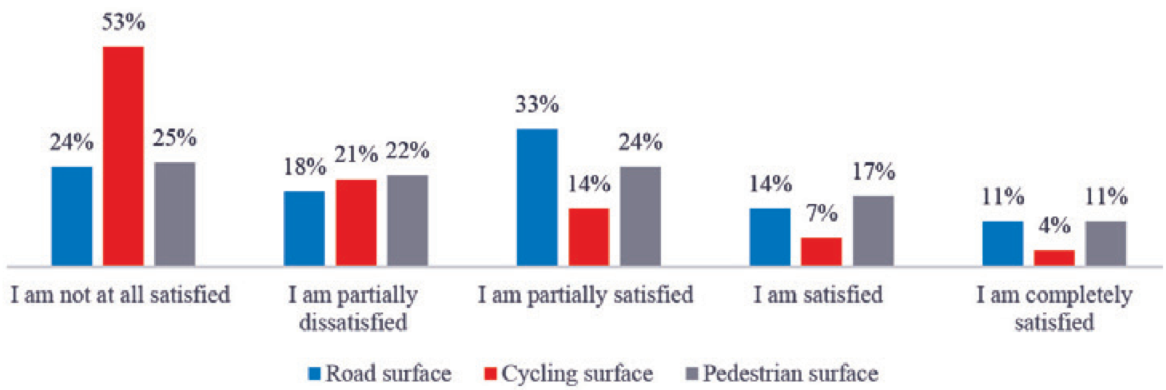


Chart 12. Percentage distribution of respondents by satisfaction with the infrastructure offer

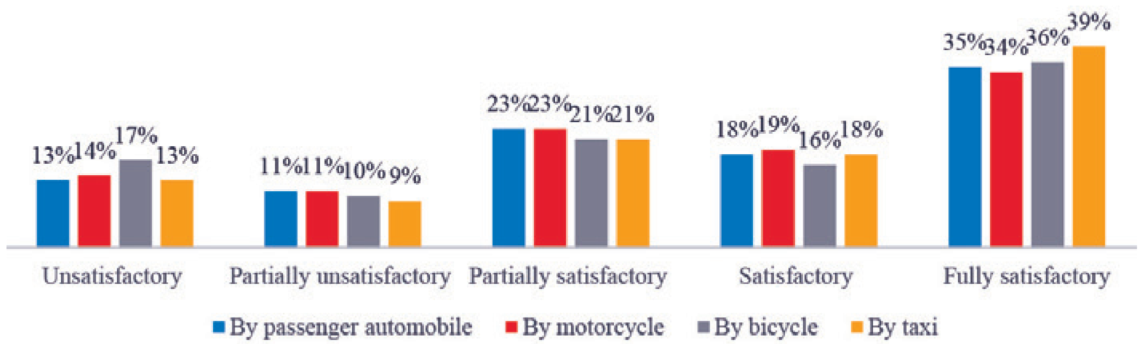


Chart 13. Percentage distribution of respondents by satisfaction in terms of accessibility

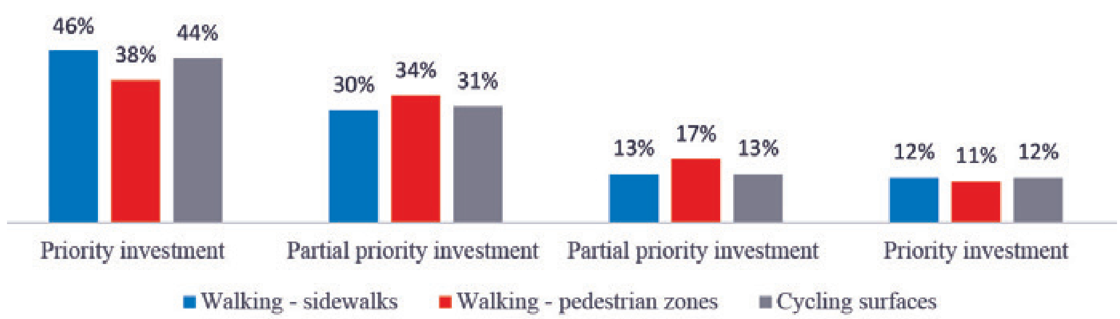


Chart 14. Percentage distribution of respondents by the attitude regarding priority investment in infrastructure area for active transport modes

frastructure (chart 14), which may result in a change in the mode of transportation and a greater use of active transport modes.

As one of the goals of urban road traffic safety is the reduction of air pollution, which is a consequence of road traffic, the respondents indicated how satisfied they were with the air quality in their places. Chart 15 shows a particularly high level of dissatisfaction with air quality (approximately 80%), where respondents recognize road traffic as the main source of air pollution (45% - chart 16), in addition to industry and households.

From the point of view of urban road traffic safety, respondents are particularly concerned about the number and consequences of road traffic accidents (52%), but they also recognize environmental pollution (49%) and road traffic congestion (40%) as factors of their concern for life in the city environments (chart 17). Although re-

Chart 15. Percentage distribution of respondents by their attitude regarding satisfaction with air quality

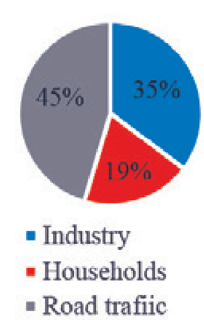


Chart 16. Percentage distribution of respondents by the opinion of which factors contribute the most to air pollution

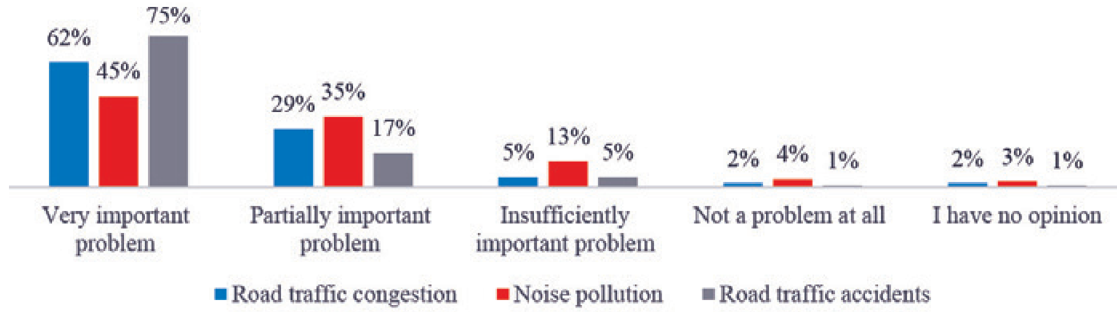


Chart 17. Percentage distribution of respondents by concern regarding the problem of urban road traffic safety

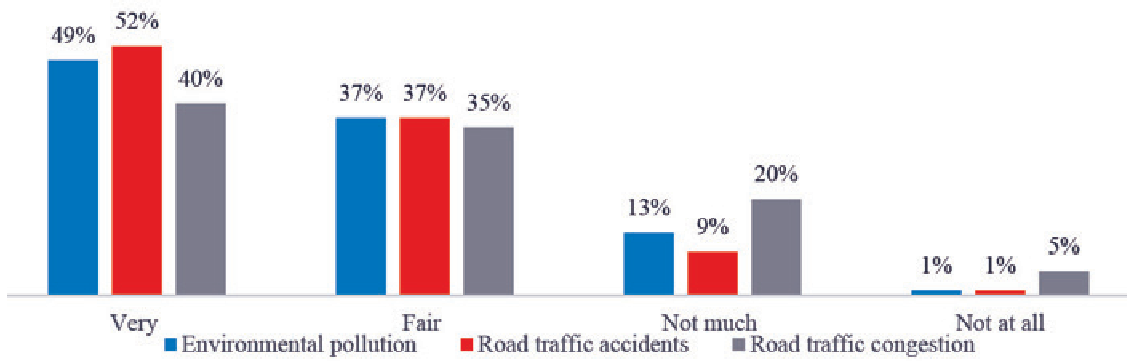


Chart 18. Percentage distribution of respondents by recognition of urban road traffic safety problems that need to be solved as a priority

spondents recognize road traffic accidents (75%) as the leading problem that needs to be solved as a priority, one can see their readiness to solve the problem of road traffic congestion (62%), but also to solve the problem of environmental noise pollution (45%) (chart 18).

Measures to improve urban road traffic safety

From the point of view of improving urban road traffic safety, respondents believe that it is necessary to improve pedestrian (27%) and cycling (25%) areas, which are actually the measures most supported by re-

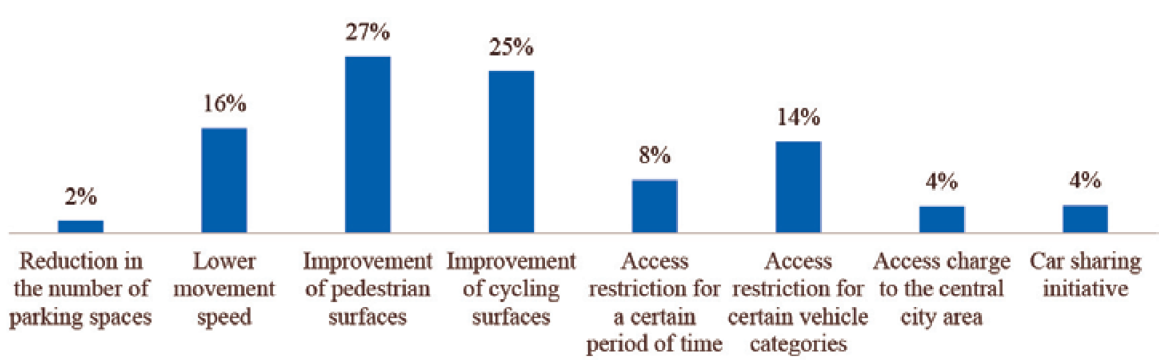


Chart 19. Percentage distribution of respondents by the measures they would support in order to improve urban road traffic safety

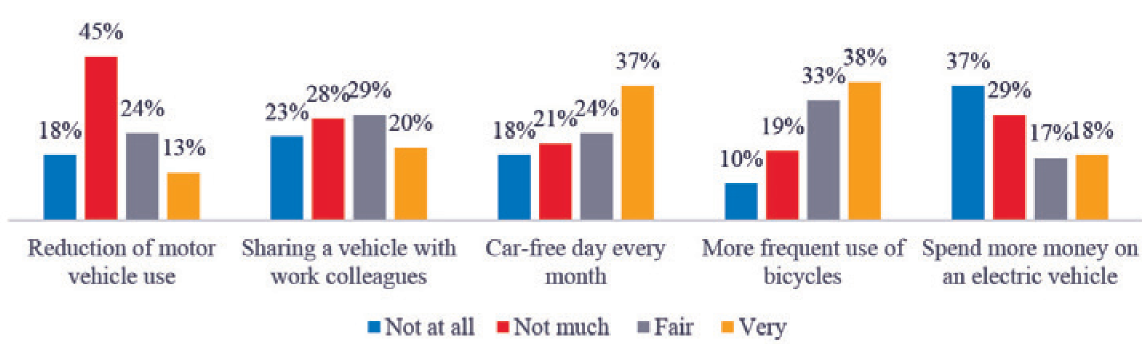


Chart 20. Percentage distribution of respondents by the recommendations they would personally accept in order to improve urban road traffic safety

spondents (chart 19). On the other hand, the measures least supported by the respondents are charging for access to the central city area and initiatives for the use of shared cars (4% each), as well as reducing the number of parking spaces (2%).

Taking into account the personal attitude of the respondents, most of them are ready to increase the use of bicycles and reduce the use of private passenger automobiles in order to improve urban road traffic safety, while allocating more money for the purchase of electric vehicles is a measure that the majority of respondents, from a personal point of view, would not support (chart 20).

DISCUSSION

In addition to benefits, the development of road traffic has also led to the appearance of negative effects, such as: road traffic accidents, pollution of the environment with exhaust gases and noise, damage to human health, occupation of public space and the like. However, unequal mobility in cities around the world and other negative effects of road traffic have led to the emergence of a "road traffic safety epidemic", which needs to be addressed in a systematic way. Road traffic has a major consequence of damaging human health, which is due to physical inactivity and the appearance of obesity, on the one hand, and the appearance of various cardio-vascular and respiratory diseases that are a consequence of air pollution, on the other hand. However, road traffic noise can also lead to the development of various mental illnesses and increased prescription of anxiolytics.

The use of active transport modes (first of all, walking and cycling) can lead to the improvement of human health and the reduction of all negative effects of road traffic, which significantly contributes to the creation of sustainable cities suitable for life. Precisely for this reason, the term "urban road traffic safety" introduces the world to a new phase of development of the thought about road traffic safety, where the goal is no longer only to reduce the number and consequences of road traffic accidents, but to reduce the impact of all the negative effects of traffic on life in urban areas.

This paper presents the results of research carried out on the territory of 20 local self-governments in the Republic of Serbia, where 1,134 respondents expressed their views on the current state of urban road traffic safety through an online questionnaire. Percentage-wise, all transport modes are represented in the total sample, where walking (69%) and the use of passenger cars by drivers (56%) stand out. In this regard, the respondents state that the main influence on the choice of their daily transport mode is the saving of travel time (24% - most respondents spend 5-10 minutes on their journey) and the distance they travel (23% - most respondents during their journey travel 2- 5 km).

The largest percentage of the total sample of respondents believes that other road users often exceed the speed limit when they are on the road passing through the urban area (with a speed limit of 50 km/h) and in school zones (with a speed limit of 30 km/h). This is precisely what leads to the feeling that all transport modes are recognized as quite dangerous by the respondents who filled out the survey questionnaire.

From the point of view of urban road traffic safety, mobility and satisfaction with the infrastructure offer are closely related to the goal of changing the mode of transportation among residents. However, the results of the conducted questionnaire show that a large percentage of respondents are not satisfied with the infrastructural offer available to them, but on the other hand, they have a high level of satisfaction with regard to the accessibility of the attraction centers towards which they gravitate every day. This is precisely what leads to the recognition of the great need for investment in infrastructure that is primarily intended for vulnerable road users, i.e. active modes of transport, such as walking and cycling. These investments and the change in the transport mode can result in a change in the respondents' attitude that road traffic is the biggest source of environmental pollution, and lead to an increase in satisfaction with air quality.

In order to contribute to the improvement of urban road traffic safety, and bearing in mind the respondents' view that it is necessary to invest in pedestrian and bicycle infrastructure, the recommendation for further work is the implementation of projects for the development of active transport modes, both at the level of the entire Republic of Serbia and at the level of each local individual self-governments. Managed in this way, there will be a change in the transport mode from private passenger automobiles to active transport modes, which further results in a healthier environment and better human health. The program for the development of active transport modes must contain an analysis of the existing and a proposal for future infrastructure, as well as promotional and preventive activities that will demonstrate the very importance of urban road traffic safety.

CONCLUSION

Urban road traffic safety is slowly introducing the world to a new phase of development of traffic safety thinking, where the goal is no longer just to reduce the number of traffic accidents, but to minimize all the negative effects of traffic functioning. In this regard, it is necessary to continue working on the development of different forms of micro-mobility, which can result in the improvement of human health, by reducing air pollution with exhaust gases and noise, and which overall can lead to the development of sustainable cities and towns that are suitable for life.

This paper presents the results of research carried out on the territory of 20 local self-governments in the Republic of Serbia, where 1,134 respondents expressed their views on the current state of urban road traffic safety through an online questionnaire. Percentage-wise, all transport modes are represented in the total sample, where walking (69%) and the use of passenger cars by drivers (56%) stand out. In this regard, the respondents state that the main influence on the choice of their daily transport mode is the saving of travel time (24% - most respondents spend 5-10 minutes on their journey) and the distance they travel (23% - most respondents during their journey travel 2- 5 km).

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