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Preliminary Communication

Accepted: Sep. 26, 2011

Approved: May 22, 2012

ANALYTIC DETERMINATION OF REFERENCE PASSENGER CAR SIZE FOR PARKING SPACE DIMENSIONING IN CROATIA

ABSTRACT

Dimensions of parking spaces have been subject to standardization in recent decades in the world. Different state institutions and standardization committees regulated parking space sizes based on typical passenger car size and ergonomic conditions. Most of these regulations are not following the notable growth in size of passenger cars that has been the case in the past 30 years. In that period in Croatia, a significant increase was also observed in the number of passenger cars in mid-sized and large passenger car classes thus emphasising the problem of outdated and inadequate parking space dimension standard. In this paper an analytic procedure is presented that takes into account the number and types of passenger cars registered in Croatia that leads to the determination of reference passenger car size. This reference values, as well as other relevant ergonomic standards are used to calculate the recommended parking space dimensions in Croatia. The purpose of this analysis is to produce new recommendations and suggest new design standards for parking spaces in Croatia as well as to provide analytic procedures to conduct similar researches in other areas.

KEY WORDS

parking space, reference passenger car, parking space dimensioning, parking space on-street and off-street standards

1. INTRODUCTION

The transport phenomena and consequently the phenomenon of parking is subject of research of numerous experts in various fields of science around the world. This statement is becoming more pervasive because of increasing trend of presence of motor vehicles in urban areas in the world followed by continuous process of migration to the cities, as well as increase in the number of registered motor vehicles in the world (continued growth of 2% per year starting in 2000 [1]).

The need to park the vehicle is called the demand for parking [2]. Demand in a particular area increases with the transit, which produces the need for more parking space (estimates show that one car uses approximately four parking spaces during the day [3]). It is perfectly obvious that with the increase of motor vehicles, the demand for parking is increasing. Estimates [4] show that 95% of the time during the day a vehicle is in idle mode, which implies a distinct demand for parking. The study of the parking problems and the design of parking surfaces should be viewed starting from the base unit for parking, a single parking space. The fundamental problem of parking space size is reflected in the definition of proper dimensions to allow easy, safe and convenient parking for the majority of cars, but with the rational space usage.

The dimensions of parking spaces have been standardized in recent decades in the world. Different state institutions and committees for standardization regulate the dimensions of a standard parking space, which are based on the typical dimensions of a car, and ergonomic factors [5]. An established trend in increasing the attractiveness of passenger cars by increasing the safety and comfort in the world automotive industry has resulted in continued growth of personal vehicles of all sizes and categories. As the last of standards for dimensioning and design of parking lots on the Croatian territory was drafted and adopted in 1980 [6], the aim of this paper is to point out the need for updating the legislative framework and to offer a scientific basis to develop new normative acts.

The paper discusses the analytical procedure of calculating the average dimensions of vehicles in the Republic of Croatia as a base for calculating the dimension of a single parking space. Dimensions are then presented as new recommendations for design of parking spaces on both, on-street and off-street parking lots.

2. ANALYSIS OF PARKING AREA ELEMENTS FOR TYPICAL VEHICLE PARKING

Single parking space for a typical vehicle is a surface area needed for parking cars and driver and passengers exiting from the vehicle. Also, especially in off-street parking lots, apart from the vehicle footprint area, one should take into account the additional surfaces required for manoeuvring of vehicles and positioning on the basic parking space and the allowance required for accessing the vehicle [3].

Parking surface area consists of:

- areas required for parking of the vehicle (vehicle footprint);
- allowance area around idle vehicle;
- manoeuvring areas
- additional surfaces (green areas, unusable areas created by parking lot design, etc.).

The vehicle surface area is defined by the length and width of the vehicle or the orthogonal projection of the external borders of the vehicle (without mirrors) on the surface of the parking space [3]. This area represents the largest part of the required area for parking and is the basic element for the dimensioning of the space required for parking.

In addition to the surface of the vehicle, the parking space consists of allowance around the vehicle when it is idle. This area provides space needed for the vehicle doors to be opened and the driver and all passengers to be able to get in and out of the vehicle. This surface also serves as a surface that enables drivers to manoeuvre their vehicle when entering and exiting the parking space. In the process of designing street parking spaces which are perpendicular to the axis of the road, if there are two or more parking spaces, in general the allowance can be shared by two adjacent parking spaces.

The surface area of the vehicle is a variable value and directly dependent on the dimensions of the vehicle while the allowance is constant and, as described in [7] it is:

- on the sides of vehicles (counting both sides): 0.75 m;
- on the front and rear of the vehicle (on each side): 0.15 m.

Basic dimensions of the vehicle surface and allowance are shown in *Figure 2*:

Based on this, it has been concluded that the most important parameter for dimensioning the parking space are the dimensions of a typical vehicle. A typical vehicle should be defined as precisely as possible, so that the parking space suits most vehicles in use. It should also be noted that the typical passenger car is not universal and varies in different regions of the World (for example, a typical vehicle is not the same in the USA, Australia or Asia).

The purpose of this paper is to define a typical vehicle for the Republic of Croatia, so as to be able to create conditions for a recommendation or guideline standardization of design dimensions for at-level street parking and off-street parking spaces in the Republic of Croatia.

3. ANALYSIS OF CURRENT LEGISLATION FOR PARKING SPACE DIMENSIONS AND MARKINGS IN THE REPUBLIC OF CROATIA

In Croatian legislation, marking of parking spaces has been defined by the Regulation on traffic signs, signalisation and road equipment (Pravilnik o prometnim znakovima, signalizaciji i opremi na cestama [8]). This regulation defines only the appearance of the

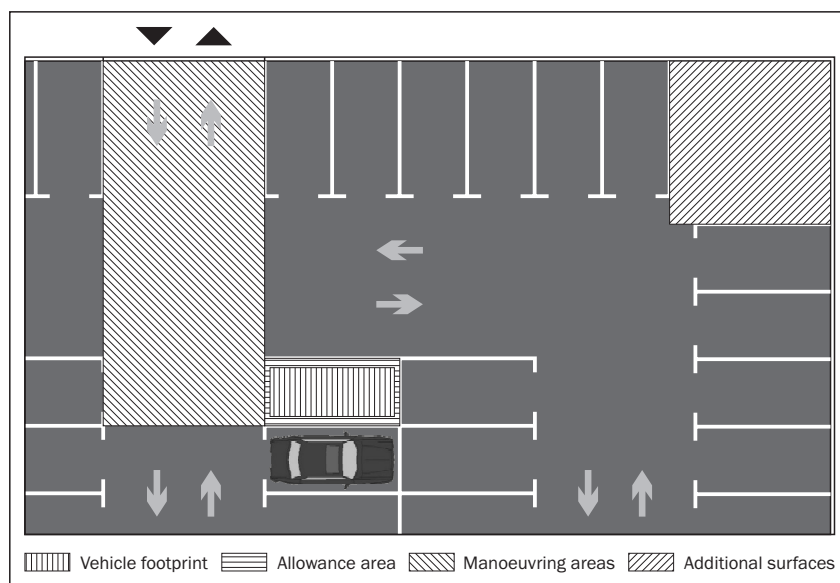


Figure 1 - Overview of basic parking surface areas

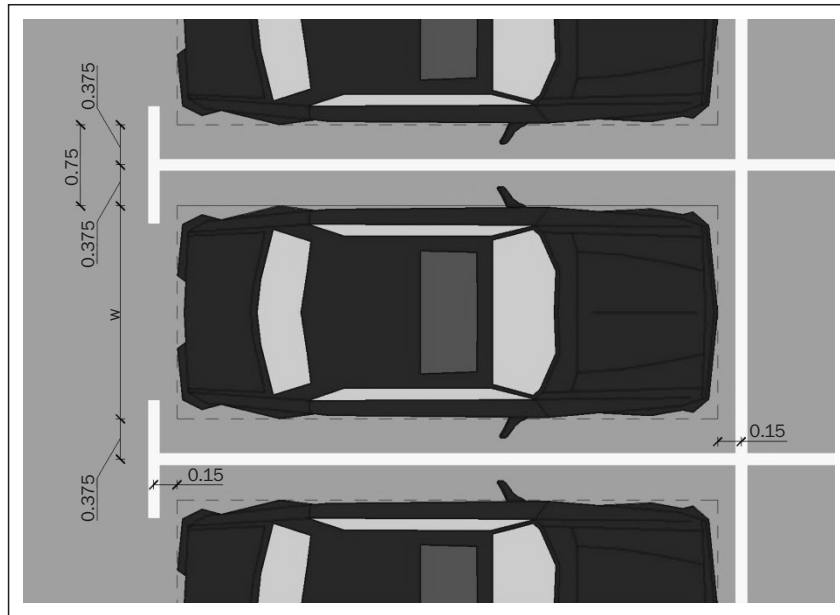


Figure 2 - Basic dimensions of the vehicle surface and allowance

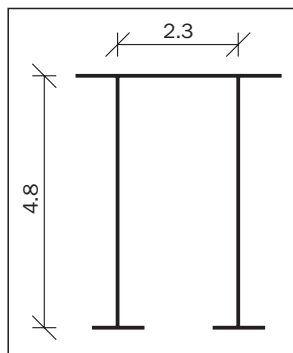


Figure 3 - Basic dimensions of perpendicular parking space according to HRN U.S4.234

road markings for highlighting parking spaces, but not its dimensions. The dimensions of parking spaces are defined by HRN U.S4.234 Standard – Marks on the pavement, other labels, markings of parking spaces (Cro.: Oznake na kolniku, ostale oznake, obilježavanje mjesta za parkiranje [6]). The specified standard has been valid since 1980. The basic dimensions of the relevant vehicle, which was typical in the time of making this standard was 4.80 x 2.30m.

In April 2008, the standard was abolished due to obsolescence and since then its application is no longer binding. It is important to point out that this norm was not replaced by other standard that would appropriately regulate the design of parking spaces on the Croatian territory. It is therefore necessary to define a reference vehicle and based on that make a calculation of required dimensions of parking spaces. It is expected that such approach to this problem will open professional discussion and create the basis for a new definition of design guidelines and new standards for designing parking spaces on the Croatian territory.

4. DETERMINATION OF TYPICAL VEHICLE DIMENSIONS

Over time, the dimensions of cars have been modified in a way that each new generation of cars became longer and more widespread, all in the context of increasing safety standards, as well as increasing the comfort standards of personal cars. The wheelbase has been also in most models of passenger cars increased. The increasing size of cars implies the reconsideration of the requirement to increase the parking space dimensions, and increase in the wheelbase of the vehicle results in the need to verify the dimensions of the allowance required for easy positioning and parking.

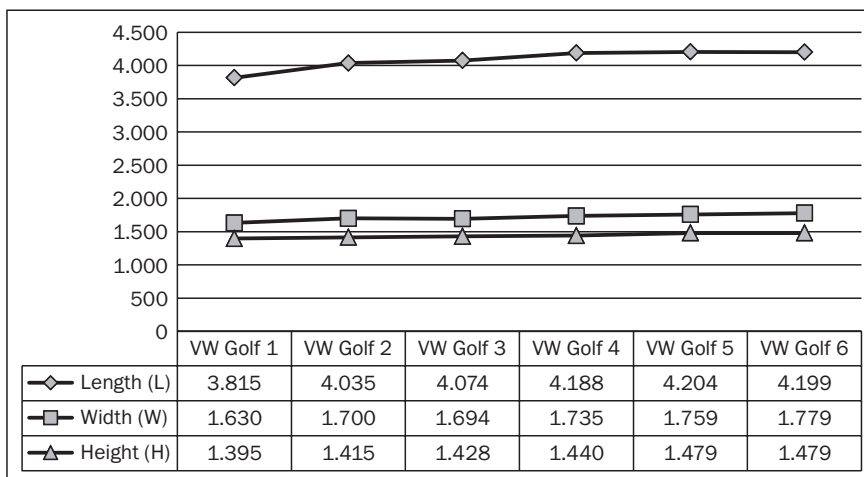
Although the necessary increase of the dimensions of the allowance for parking is partially compensated by increased wheel turning angle (which varies by model and type of vehicle), the fact is that vehicle manufacturers, because of the safety standards and because of the increase in comfort, increase the dimensions of the doors, both in terms of length (for ease of accessing the vehicle) and thickness of the vehicle door (safety aspect and placement of the equipment). This fact directly influences the increase of required allowance dimensions on the parking spaces, to provide safe and undisturbed access to the vehicle by the driver and passengers.

To present an insight into the increasing vehicle dimensions the trend analysis of vehicle size increase during the period of approximately 30 years is presented in the forthcoming text.

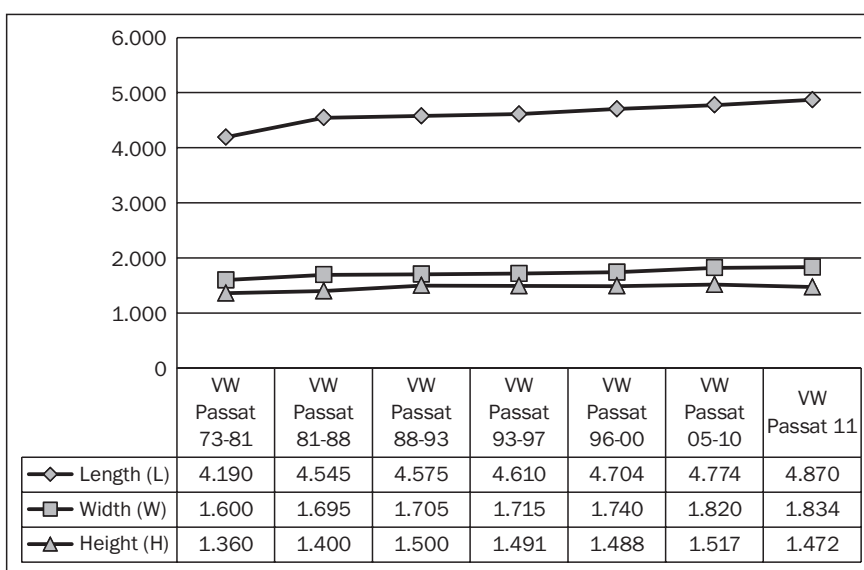
For the purpose of the analysis a classic European car from the lower middle class (VW Golf) and midsize class (VW Passat) are selected. In the analysis sum-

Table 1 - Dimension changes of characteristic vehicles in observed production period

Vehicle make, model and type	Dimensions (m)			Change in dimension starting from first production type (in %)		
	length (L)	width (W)	height (H)	length (L)	width (W)	height (H)
VW Golf 1	3.815	1.630	1.395	-	-	-
VW Golf 2	4.035	1.700	1.415	5.8%	4.3%	1.4%
VW Golf 3	4.074	1.694	1.428	6.8%	3.9%	2.4%
VW Golf 4	4.188	1.735	1.440	9.8%	6.4%	3.2%
VW Golf 5	4.204	1.759	1.479	10.2%	7.9%	6.0%
VW Golf 6	4.199	1.779	1.479	10.1%	9.1%	6.0%
<hr/>						
VW Passat 73-81	4.190	1.600	1.360	-	-	-
VW Passat 81-88	4.545	1.695	1.400	8.5%	5.9%	2.9%
VW Passat 88-93	4.575	1.705	1.500	9.2%	6.6%	10.3%
VW Passat 93-97	4.610	1.715	1.491	10.0%	7.2%	9.6%
VW Passat 96-00	4.704	1.740	1.488	12.3%	8.7%	9.4%
VW Passat 05-10	4.774	1.820	1.517	13.9%	13.8%	11.5%
VW Passat 11	4.870	1.834	1.472	16.2%	14.6%	8.2%



Graph 1 - Increasing trend in vehicle dimensions for VW Golf



Graph 2 - Increasing trend in vehicle dimensions for VW Passat

mary shown in *Table 1*, for a period of 30 years, a significant increase in dimensions of analyzed models can be observed.

This analysis leads to the conclusion that the increase in passenger car dimensions is statistically significant, in the observed period, for the vehicle form lower middle class the increase in length is 10.1%, or 9.1% in width, while the personal car from the middle class has experienced significant increase in length of 16.2% and 14.6% in width.

The observed significant increase in the size of the analyzed passenger cars confirms the argument for the necessary revision of dimensions of vehicle parking spaces.

In order to determine the typical passenger car for the Republic Croatia based on which it would be possible to define the required dimensions of parking spaces, in the following text the analysis of the structure of (newly) registered vehicles in Croatia during the period of ten years (1998 – 2008) is presented.

The analysis is limited to the period from 1998 to 2008 considering that the average age structure of the fleet of passenger cars in Croatia is 10.5 years [9]. For this reason this analysis is the reference to the fleet of passenger cars in the Republic of Croatia. Considering that the structure is dominated by the newly registered vehicles, this type of data is taken in the analysis as the year of production, i.e. the year of newly registered vehicles.

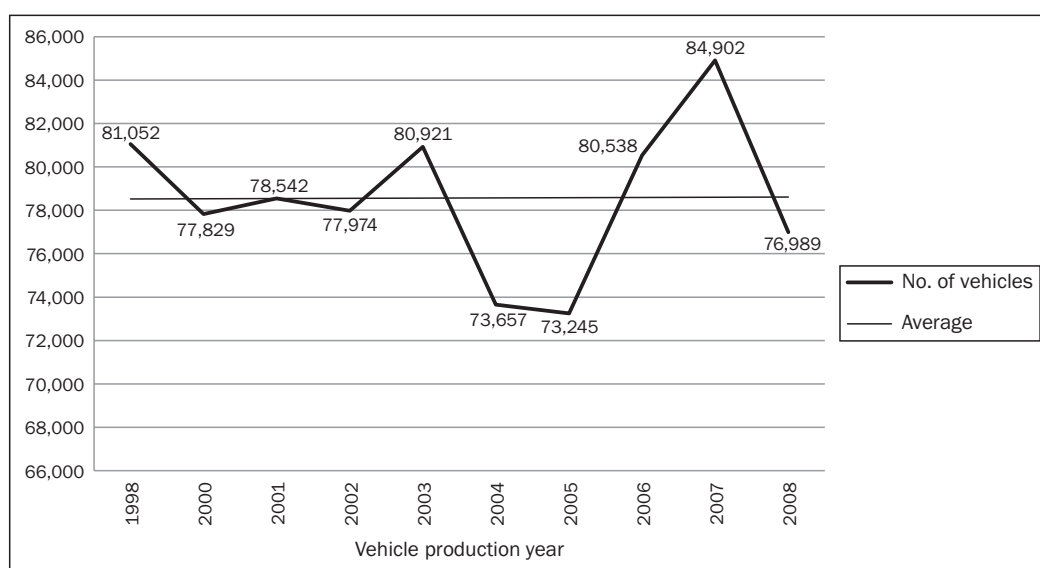
The years 2009 and 2010 have been eliminated from the sample because these years represent an anomaly in the trend of change in the number of vehicles; 2009 because the new regulations have stipulated that the first regular technical inspection of new cars is carried out after two years of exploitation, and 2010 because there was significant impact of the global economic crisis, which is why the number of

sold vehicles was considerably smaller than the average. The analysis of the number of regular technical inspections sorted by the year of production, for the period 1998 -2008 is presented in *Graph 3*.

From the analysis and the displayed chart we can conclude that the number of vehicles compared to the year of production for a period of ten years did not have a trend of constant increase or decrease. It is possible to determine the periodic increase and decrease in a period of four to five years. If we analyze the average value of the number of produced or sold vehicles in the given year, it is possible to determine that this value is on the average 78,500 vehicles. The analysis of the periodic peaks determines that the greatest number of vehicles (84,849) was produced and sold in the year 2007. Because vehicles produced in 2007 are the penultimate or the last generation of vehicles with the largest dimensions to the majority of the manufacturers, these vehicles were selected as a sample for the determination of the typical vehicle for parking spaces dimensioning. Based on this conclusion, we have selected and analyzed the dimensions of vehicles produced in 2007 which underwent regular technical inspection in 2010.

The vehicles are classified by the length, width and height. In the sample, a total of 294 different types and models of vehicles has been used for the analysis. The vehicle data were statistically analyzed and calculations were conducted for:

- the average dimension (arithmetic mean);
- median;
- maximum dimensions;
- minimum dimensions;
- 95-th percentile dimensions;
- 90-th percentile dimensions;
- 85-th percentile dimensions.



Graph 3 - Number of regular technical inspections in relation to the year of production

The analysis was performed separately for each type and model of vehicle. The results are presented in Table 2.

Table 2 - Results of car dimension analysis

	Length/m	Width/m	Height/m
Average	4.194	1.736	1.506
Median	4.469	1.787	1.514
85-th percentile	4.572	1.820	1.620
90-th percentile	4.667	1.832	1.651
95-th percentile	4.765	1.857	1.725
Minimum	2.500	1.495	1.225
Maximum	5.255	2.374	2.415

The width and length of vehicles is important for the purpose of dimensioning of parking spaces. The height can be ignored in this for this purpose. By means of conducted statistical analysis the calculated average vehicle size in Croatia is: length 4.194m and width 1.736m. The dimensions of the vehicle in the middle of the analyzed group (median) are 4.469 m (length) and 1.787 m (width). Because the average value and median have approximately equal values it can be concluded that there is a uniform distribution of vehicle dimensions within the group and that the selected sample is relevant for determining the dimensioning the reference vehicle.

The calculated dimension value corresponds to the lower middle class vehicle (according to 2010 production). It should be noted that it is not reasonable to design a parking space based on the average vehicle dimensions, considering that in this case, all vehicles that are larger than the average would have difficulties while parking. Such an approach is neither rational nor acceptable.

In the process of defining the typical vehicle for dimensioning of parking spaces it is necessary to take in consideration the fact that for the safe movement we have to adjust the elements of transport infrastructure avoiding the creation of potential critical points to all participants in traffic. Thus, transport infrastructure should be designed in a manner that allows safe and comfortable use, especially to the drivers with average driving skills.

In order to facilitate safe and comfortable use of transport infrastructure and parking spaces, the thesis was that we should meet the needs of at least 90% of participants in traffic. Therefore, the dimensions from a 90-th percentile of the sample of all the newly registered vehicles in the Republic of Croatia have been chosen to represent the dimensions of a typical vehicle.

In addition, the fact that the dimensions of vehicles with each new generation increase cannot be ignored and that it is expected that over a period of ten years this trend of growth will continue, both in individual

classes, as well as in the overall average of passenger car dimensions.

From the performed analysis of registered vehicles in the Republic of Croatia and the selected 90-th percentile dimensions for the typical vehicle are; length 4.667m and width 1.832m.

Based on these calculations a conclusion is drawn that a vehicle with a length of 4.700m and width of 1.850m should be used as a typical vehicle for designing parking space dimensions in the Republic of Croatia

5. CALCULATION OF PARKING SPACE DIMENSIONS

Calculation of parking space dimensions will be undertaken for the classical type of street parking spaces, perpendicular to the road and perpendicular off-street parking on at-grade parking lots. As at typical vehicle, on the basis of previous analysis, a vehicle with the length of 4,700mm and with width of 1,850mm has been adopted. Based on this dimensions for a typical vehicle, the parking space dimensions are determined by the following formula:

Parking space length:

$$l_{PS} = l_v + l_{ral} + l_{ral} \quad [m] \quad (1)$$

where:

l_{PS} - parking space length,

l_v - typical vehicle length,

l_{ral} - front allowance length (0.15 m),

l_{ral} - rear allowance length (0.15 m).

As for the typical vehicle, the length of the parking space should be:

$$l_{PS} = 4.7 + 0.15 + 0.15 \quad [m]$$

$$l_{PS} = 5.0 \quad [m]$$

Parking space width:

$$w_{PS} = w_v + \frac{1}{2}l_{raw} + \frac{1}{2}l_{law} \quad [m] \quad (2)$$

where:

w_{PS} - parking space width,

w_v - reference vehicle width,

l_{raw} - right allowance width (0.75 m),

l_{law} - left allowance width (0.75 m).

As for the typical vehicle the width of a parking space should be:

$$w_{PS} = 1.85 + \frac{1}{2}0.75 + \frac{1}{2}0.75 \quad [m]$$

$$w_{PS} = 1.85 + 0.375 + 0.375 \quad [m]$$

$$w_{PS} = 2.60 \quad [m]$$

Based on the analysis and mathematical calculations a conclusion can be drawn that parking space dimensions for perpendicular parking in the Republic of Croatia, should be 5.0m in length and 2.6 meters in width (Figure 4).

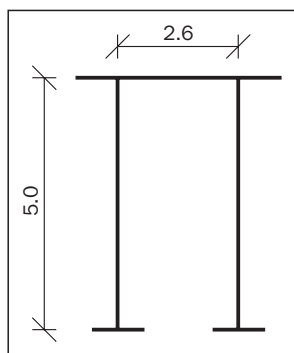


Figure 4 - Calculated dimensions of a single parking space

6. CONCLUSION

The most important element for parking lot design is the determination of proper dimensions for a parking place as the basic element of each parking lot. The parking lot design with minimum dimensions makes it difficult for the user to park or get in and out of the vehicle, while overdimensioned parking lots overuse space intended for parking. For this reason, in defining the dimensions of parking lots it is necessary to achieve the optimum relationship between the ability to easily park the vehicle and to rationally use urban space.

In the Republic of Croatia there are no guidelines, recommendations, or standards that define the dimensions of a parking space based on the actual geometric properties of the vehicles which are in use on the Croatian territory. The last standard that was used for the design of parking lots was adopted in 1980, and abandoned in 2008.

To emphasize the need for developing new standards and provide guidance for determining the dimensions of the basic element of parking lots, based on actual vehicle sizes in Croatia, the data on registered vehicles on the Croatian territory during the past 10 years have been analyzed. This analysis has determined the dimensions of a typical vehicle that is later on used for calculating the dimensions of parking spaces.

The scientific method of induction, based on statistical indicators, sales and registration data for vehicles on the Croatian territory, has been used to determine the characteristic year of manufacture and sale of vehicles on the hypothesis that it was possible to define the typical pattern of all vehicles currently in use in Croatia. As a representative sample, 294 different vehicle models have been taken into calculations by their dimensions which have direct impact on the required dimensions - length and width of the vehicle. The results from this analysis have been used to determine the dimensions of a typical vehicle, as the basis for the design of the parking space on the Croatian territory.

The dimensions of parking spaces were identified by mathematical calculation based on the typical dimensions of vehicles extended with the minimum allowance area and these resulted in the following dimensions: the length of 5.0m and 2.6m for the width of a parking lot. These dimensions should be adopted as minimum parking lot dimensions in every environment.

However, based on the identified continuous growth in vehicle dimensions described in Section 4 and the growing need for more comfortable and safer parking, we can conclude that further research is needed to calculate the size of the reference vehicle that could be used as the standard in the forthcoming ten-year period. The calculated size of a reference vehicle should take into account the appropriate trends if it ought to be the basis for dimensioning and the design of parking spaces in the future.

It can be concluded that there is need to conduct research based on a similar approach used in this article and to perform calculations that are necessary to define the dimensions of parking places for other types of parking (longitudinal and oblique) and the dimensions for parking spaces in garages as well.

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SAŽETAK

ANALITIČKO ODREĐIVANJE MJERODAVNOG OSOBNOG VOZILA ZA DIMENZIONIRANJE MJESTA ZA PARKIRANJE U REPUBLICI HRVATSKOJ

Dimenzije mjesta za parkiranje bile su tijekom zadnjih desetljeća predmet standardizacije u svjetskim zemljama. Različite državne institucije i odbori za standardizaciju određivali su dimenzije mjesta za parkiranje na temelju dimenzija tipičnog osobnog automobila i ergonomske zahtjeva. U većini slučajeva takav pristup nije uzimao u obzir porast dimenzija osobnih automobila, a koji je značovit u posljednjih 30 godina. U tom razdoblju u Hrvatskoj je zabilježen značajan porast broja osobnih automobila u kategorijama srednje i visoke klase čime se naglašava problem zastarjele i neadekvatne norme koja definira dimenzije mjesta za parkiranje. U ovom radu prikazan je analitički postupak koji uzima u obzir broj i tip vozila registriranih u Republici Hrvatskoj temeljem čega se određuju dimenzije referentnog osobnog automobila. Te referentne dimenzije, zajedno s važećim ergonomskim standardima su korištene za izračun preporučenih dimenzija mjesta za parkiranje u Hrvatskoj. Svrha ove analize je stvaranje novih smjernica i prijedloga novih standarda kod projektiranja mjesta za parkiranje koji bi vrijedili za Republiku Hrvatsku te predstavljali

janje analitičkog postupka za provođenje sličnih istraživanja u drugim područjima.

KLJUČNE RIJEČI

mjesto za parkiranje, referentno osobno vozilo, dimenzioniranje mjesta za parkiranje, norma za ulično i izvanulično mjesto za parkiranje

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