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Research Paper

Determining Classification and Standard Dimension of Vehicles for Calculating Saturation Flow for Signalized Urban Intersections

S. Pradeep Reddy [1] and Prof. P. R. Bhanu Murthy [2]
[1] (Research Scholar, Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapur (JNTUA), Ananthapuramu, Andhra Pradesh 515002, India
[2] (Professor, Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapur (JNTUA), Ananthapuramu, Andhra Pradesh 515002, India
Corresponding Author: S. Pradeep Reddy

ABSTRACT : *Saturation flow is an important aspect in intersection analysis. For heterogenous traffic conditions, the Saturation flow is usually expressed as Passenger Car Units (PCU). The PCU is derived by classifying vehicles into several modes and then counting such vehicles in the field and then applying a PCU factor to such vehicles. In modern approach, the Saturation flow is expressed directly in terms of "vehicles". For either of these cases, it is necessary to identify the classification of vehicles and their standard dimension for good quality data. Literature review has shown that the classification of vehicles and their dimensions are not standard. The process adopted for such variables in several studies is also not clear. A few aspects to be noted are that the vehicle composition in traffic varies. The probability of certain vehicles utilizing the intersection has to be examined. Further, the probability that the considered dimension of vehicle is the "average" dimension of such vehicle has to be examined. Though such aspects are reviewed, one cannot provide 100% reliable solutions, but rather conclude with a reasonable confidence that such vehicles and their composition in the traffic volume is acceptable. Traffic analysis at intersections is, therefore, more of a probability rather than an exact science. This study sets out to identify a suitable classification of vehicles and their standard dimensions for the purpose of calculating Saturation flow at signalized urban intersections with reasonable confidence. Further, the study identifies that the classification of vehicles and their dimensions are never constant, and therefore, concludes that the methodology adopted in this study can be applied to other situations and in future conditions as well.*

KEYWORDS – *Classification of Vehicles, Dimensions of Vehicles, Signalized Urban Intersections, Traffic Volume Data*

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I. INTRODUCTION

Signalized Intersections are an important part of Urban Infrastructure. By Planning, Designing and Analyzing intersections properly, one can avoid costly affairs such as intersections widening, grade separators, land acquisition, etc. However, intersection analysis is complicated. One important variable in intersection analysis is the Saturation flow. The Saturation flow is usually measured in Passenger Car Units (PCU). In this approach, all vehicles are "converted" into "car units" by applying certain conversion factors. A modern approach is measuring the Saturation flow directly in terms of Vehicles. However, the said modern approach is limited and not yet widely popular. Irrespective of using either approach, one has to be cognizant of the classification of the vehicles.

Indian traffic is heterogenous in nature and includes several types of vehicles. For illustration, just considering cars, one can observe at least 100 different sizes of cars. However, most studies refer to a "standard car" such that all cars can be classified into one category only. But car dimensions sometimes vary by more than 2 times also. Thus, defining a car requires identifying the dimensions of such cars also. A further expansion to include all modes of transportation could result in classifying into 10 or 20 or 30 types or more or less. Such classification depends on the purpose of the study.

Without entering into the core concept of the classification of the vehicles or their standard dimensions, one can realize that the situation is complex. In a practical situation, different sizes of vehicles arrive at the intersections, and such composition of vehicles could vary every minute and in every direction also. Thus, traffic analysis is based on certain "probability" by considering a "standard vehicle" and that such a "standard vehicle" is the average dimension and represents all the vehicles at the intersection.

This study sets out to examine most of the vehicles at the intersections (stating that "all" vehicles were examined would be incorrect as proving such a statement would be impossible). A total of 517 vehicles were considered in this study. Then, such vehicles were classified into different types and their standard dimensions were determined using various statistical tools. Field tests were conducted on such classification to validate the classification categories. After several iterations, the most reasonable classification of vehicles was derived, and their standard dimensions were determined. The methodology applied in this study can be utilized for future conditions and for other locations also such that highly reliable results could be achieved. It is envisaged that this study could have a profound impact on the future of traffic engineering and could be "the standard" for several years to come by completely overhauling the age-old approach and ushering this modern approach.

II. LITERATURE REVIEW

For the purpose of intersections saturation flow, the turning movement data of vehicles is required. This data comprises of the volume of vehicles, their approach direction and their departure direction. Such data can be obtained only through "visual" means because the directional movement of the vehicle needs to be tracked. Such visual data could be obtained through manual counts in the field or through video counts (which could involve manual extraction from the video or use of software for extraction of the data from the videos). It is likely that as the future technologies develop, GPS based vehicle tracking may be possible, but for the current situation such a solution is not possible.

For the purpose of visual data, vehicles have to be classified. Such classification includes categorizing vehicles into several types based on "general criteria" such as 2-wheelers, 3-wheelers, cars, buses, etc., and then further applying the dimension of such vehicles. Thus, dimension of vehicles appears to be a very effective criteria to classify vehicles. A detailed review of literature has identified that vehicles dimensions are commonly used as their classification criteria. However, most of the literature do not define any methodology for arriving at such conclusions nor do they define the standard dimensions of such vehicles.

A very popular resource in India is the Indian Roads Congress (IRC) publications. These publications define vehicles based on their dimensions but do not specify any methodology not specific dimensions. It should also be noted that most of these IRC publications are guidelines rather than standards and are also several decades old, with some dating back 40 to 50 years also. [1 to 4]. The notable publications of IRC for this purpose listed by their year of publication is noted below:

- IRC: 73-1980, Geometric Design Standards for Rural (Non-Urban) Highways [1]
- IRC: 3-1983, Dimensions and Weights of Road Design Vehicles [2]
- IRC: 106-1990, Guidelines for Capacity of Urban Roads in Plain Areas [3]
- IRC: SP: 41-1994, Guidelines for The Design of At-Grade Intersections in Rural & Urban Areas [4]

Another interesting aspect is that the classification of vehicles adopted by the IRC publications also varies, and thereby does not provide consistency. Against this background, a recent study was undertaken in India by two prestigious organizations jointly which include Council of Scientific and Industrial Research (CSIR) and Central Road Research Institute (CRRI) [5]. These organizations jointly developed an Indian Highway Capacity Manual, commonly known as the Indo HCM, which was published in the Year 2017. This manual includes various aspects related to traffic engineering. One chapter is dedicated to signalized intersections also. However, in the general classification of vehicles this manual classifies the vehicles into 14 categories, while for the signalized intersections the vehicles are classified into 9 categories only. Once again this manual limits itself to be used as a guide rather than a standard and states that engineering judgment would be required for such analysis. In the general classification, the Indo HCM provides "average dimensions" for the 14 categories of vehicles. However, the methodology adopted in arriving at the average was not stated. Also, when the vehicles were recategorized in the signalized intersections chapter, the average dimensions for such 9 categories were not provided.

To understand the methodology adopted, a detailed literature review was undertaken which included the last 20 years of studies [6 to 20]. Across such studies, the vehicles were classified from 5 to 13 categories based on the study purpose. Further, most of the studies were limited to mid-block rather than for signalized intersections. The studies related to intersections were also reviewed [21 to 22]. From these studies, it was noticed that the most notable study was by Satish Chandra et al. [7] published in the year 2003. In this study the average dimensions of vehicles in 9 categories was provided. However, the methodology related to arrive at such average dimensions was not provided. Interestingly, several similar studies were undertaken by the same author wherein vehicles were classified but such classification and the dimensions of such vehicles varied. The author does not explain the reason for utilizing different dimensions for different studies. However, this study was citied by several other studies. In such studies, some of them utilized the same dimensions without any changes, while a few other studies modified the classification and the dimensions, but once again without providing any clarification on the methodology. It was also observed that the same dimensions were utilized in the Indo HCM.

Similarly, different organizations or studies have classified vehicles into various categories based on their need [23 and 24]. The recent such effort was for the purpose of automatic toll collection using FASTag which classified the vehicles into 20 mapper classes.

Even in developed countries such as UK and US, vehicles classification does not include their standard dimensions or their methodology [25 to 28]. Interestingly, some of the studies are as old as 1978 and continue up to the recent times. In one case, the 85th percentile was used as a criteria to determine the dimension of a vehicle. It was also noted in a few studies that vehicles dimensions are varying across the years and that in the recent decades, the vehicle dimensions are increasing but the engineering design standards were not modified for such changes [29].

Thus, from the literature review, it can be concluded that there is no uniform approach to classification of vehicles or their standard dimensions. But, without utilizing uniform "input" several studies compared themselves with other studies, which begs the question of reliability of such comparisons and several studies. The classification of vehicles and their standard dimensions within acceptable statistical significance is important for these types of studies, which this study undertakes.

III. DETERMINATION OF STANDARD CLASSIFICATION AND DIMENSIONS FOR VEHICLES

3.1 The Changing Constant

Classification of vehicles is not an easy task. As stated earlier, the classification of vehicles vary based on the purpose of the study. In cases where the vehicle dimension is chosen as the criteria for such classification, such a criteria is never constant. It keeps on changing.

The vehicles dimensions (length & width) keeps changing for different manufacturer of vehicles and even for different models by the same manufacturer. Further, such dimensions change for different countries also. In addition, customized vehicles also exist which complicate the process even further. In such cases, one can only opt for probability based deductions rather than a rigid definition. These vehicle dimensions can be stated to be "static" data.

The "dynamic" situation occurs when one considers the vehicle composition at intersections. For illustration, assuming a theoretical conditions with only 10 sizes of cars, then there is no guarantee that all the 10 sizes of the cars would arrive at an intersection and that the 10 sizes of the cars would be equally proportional in the vehicular mix. Also, such variations could vary for each minute, for each direction of the intersection, for different intersections and even across different geographical location. Thus, even in a theoretical setting, the "constant" is never a constant and keeps on varying. Once again, the situation can be addressed based on probability.

Understanding and then accepting these variations in the vehicles dimensions, this study was undertaken to determine a statistically significant acceptable dimension that can be useful for the purpose of saturation flow at signalized intersections in urban conditions.

For the purpose of this study, the vehicles manufacturers brochures and websites were reviewed and numerous vehicles models & makes data was tabulated. Further, a field review indicated a few customized vehicles such as Government buses and water tankers. Hence, such vehicles dimensions were obtained through field measurements. In all, 517 unique vehicles were identified through this process.

3.2 First Iteration

In the first step, based on common sense and empirical procedures, the 517 vehicles were categorized into 17 classifications. The said classification was arrived at by visual means and a review of historical practices identified through literature review. Table 1 shows the 17 classification vehicles.

Sl. No.	Mode / Classification / Category	No. of Models
1	Motor Bikes	136
2	Mopeds & Scooters	26
3	Passenger Autos	12
4	Cargo Autos	8
5	Small Cars (length up to 4m)	66
6	Medium Cars (length 4 to 4.5m)	54
7	Large Cars (length 4.5 to 5m)	75
8	Extra Large Cars (length more than 5m)	22
9	Light Passenger Vehicles	4
10	Medium Passenger Vehicles	11
11	Heavy Passenger Vehicles	25
12	Light Cargo Vehicles	31
13	Medium Cargo Vehicles	18
14	Heavy Cargo Vehicles	7
Sub-Total		**495**
15	Trucks (> 3 axles)	13
16	Articulated Buses	2
17	Tractors	7
Total		**517**

Table 1: Classification of Vehicles in the First Iteration

On these 17 classification of vehicles, statistical analysis was conducted to determine the correlation of the vehicles in each classification. Further, the length and width of each vehicle under each classification was plotted graphically to determine outliers. The statistical analysis as 95% confidence interval indicated that the data was highly corelated and the outliers were insignificant. Thus, statistically, it was determined that the 17 classifications provided good reliability.

These 17 classifications were then subjected to field tests. Enumerators were deployed in the field and for the purpose of verifying their perception, the enumerators were split into three groups. Each of the three groups obtained the traffic volume and classification for the same direction of traffic at the same intersection. This was done to observe the variance and reliability of the enumerators. It is to be noted that the enumerators were all trained prior to the study and were well experienced in the process of traffic data collection. The data was obtained for one hour at the said location. However, the field results identified huge variations in the data. The enumerators were appraised of the situation and then retrained. Then, the field data collection was repeated again. However, the data once again proved to be unreliable and indicated highly unreliability. For the third time, the enumerators were retrained and the field data collection was repeated again. However, even for the third field trials, the obtained data exhibited high variance and was considered to be unreliable.

A closer review of the data exhibited that the variance was not significantly higher in the total numerical count of all the vehicles, but was due to the internal mis-classification of the vehicles. Hence, it was concluded that even though the first classification criteria was statistically corelated but the field data was not practically feasible for classification. Hence, this classification criteria with 17 modes was rejected.

3.3 Multiple Iterations

From the failed first iteration, several aspects were identified that contributed to such failure. One such criteria was the heavy discharge of 2-wheelers and auto rickshaw at the intersections immediately after the signal turned green. Literature review has identified that most studies have ignored the first few seconds of the data to avoid this heavy discharge. From the field data it was noted that in certain cases as many as 70 vehicles (mostly 2-wheelers and a few auto rickshaw) were discharged within 2 to 3 seconds. This translates to about 25 to 30 vehicles in 1 second which is humanly impossible to count. This initial heavy discharge is termed as "surge" which is present only in heterogenous traffic without any lane discipline. Hence, for the purpose of classification of vehicles, it was decided to ignore this "surge" as a variable. Hence, the vehicle classification field trials were conducted at fuel stations and large parking areas.

The field trials at the fuel stations and large parking areas was found to be much more comfortable for the enumerators. However, the classification of vehicles adopted in the First Iteration which included 17 modes failed once again. At this stage, it was concluded that the earlier classification of the vehicles was not suitable for traffic data collection.

Hence, multiple iterations were conducted on the classification of vehicles using trial and error method. For each such iteration, the classification was first tested statistically for correlation and only those classifications that provided statistically significant result at 95% confidence interval were adopted. Then, such classification was tested through field trials again. However, such classification and the subsequent field trials continued to fail.

At this point, it was realized that the "human factor" was an important variable in the classification of the vehicles. Humans classify vehicles into different categories based on complex relationships that are sometimes no evident even for highly capable computers or algorithms. By utilizing the human factor, the enumerators were surveyed in detail and they were asked to classify the vehicles as per their discretion. The three groups of the enumerators were observed to be converging in certain aspects. By reviewing such aspects, the enumerators were retrained and the field trials were conducted again. After several such field trials, a pattern in the classification of the vehicles was identified in the enumerators and based on such human criteria, the vehicles were classified. The said classification is shown in the next section.

3.4 Final Iteration

It was noted that the dimension of vehicle was a bad variable and was not suited for traffic classification. It was noticed that it was not possible to assess the dimension of the vehicles through visual observation. Further, the traffic data was required to be collected at intersections (where the vehicles would be moving at a reasonable speeds) rather than at fuel stations or parking garages. Hence, the human factor revealed that the type of the vehicle was a better variable. This resulted in classifying the vehicles into six modes. In the first iteration, a total of 517 vehicles were considered. However, certain vehicles were found to be insignificant in the vehicle volume, with sometimes the count being only 1 or 2 vehicles per hour. But, these vehicles were causing misclassification of certain vehicles. Hence, such vehicles, i.e., 22 types of vehicles, were ignored. The preliminary field data indicated that the ignored vehicles did not account for even 1% of the total traffic volume. Hence, the final iteration included 495 vehicles makes and models only, as shown in Table 2.

Sl. No.	Mode / Classification / Category	No. of Models
1	Two-wheelers	162
2	Three-wheelers	20
3	Cars	217
4	Light Vehicles	15
5	Medium Vehicles	56
6	Heavy Vehicles	25
Total		**495**

Table 2: Classification of Vehicles in Final Iteration

Once again, this classification of the data was subjected to statistical analysis as shown in the section below.

IV. STATISTICAL ANALYSIS

Statistical analysis was conducted on the 6 types of vehicles identified in the final iteration. Vehicle dimensions of these 6 types of vehicles were used as variables for the statistical analysis. The results identified the average dimension of such vehicle types, which was determined to be the standard dimension of those types of vehicle.

The 6 types of vehicles were also graphically analyzed. It was observed that in some cases, the dimensions of the vehicles exhibited some variations. Further, a few vehicles were identified as outliers. However, from the field trials it was noted that these vehicles contributed to an insignificant proportion of the traffic volume. But, since such data did not affect the classification of the vehicles, these vehicles were also considered in the data. Normal distribution graphs were plotted for the 6 types of data and were found to be acceptable. It was concluded with 95% confidence that the obtained average dimensions of the vehicles were significantly acceptable. Additional statistical analysis was also conducted to correlate the data. The detailed statistical analysis is shown in the tables below.

Statistics

		Length	Width	Area
N	Valid	162	162	162
	Missing	0	0	0
Mean		2.06304	.77831	1.61528
Median		2.05567[a]	.77178[a]	1.57700[a]
Mode		2.060	.790	1.522
Std. Deviation		.162251	.076043	.272514
Variance		.026	.006	.074
Minimum		1.735	.590	1.024
Maximum		2.650	1.000	2.412

a. Calculated from grouped data.

Table 3: Two-Wheelers Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.779**	.927**
	Sig. (2-tailed)		.000	.000
	N	162	162	162
Width	Pearson Correlation	.779**	1	.955**
	Sig. (2-tailed)	.000		.000
	N	162	162	162
Area	Pearson Correlation	.927**	.955**	1
	Sig. (2-tailed)	.000	.000	
	N	162	162	162

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4: Two-Wheelers Correlation Analysis

Statistics

		Length	Width	Area
N	Valid	20	20	20
	Missing	0	0	0
Mean		3.01825	1.42175	4.31095
Median		2.96500	1.46250	4.41800
Mode		2.865[a]	1.490	4.126[a]
Std. Deviation		.253327	.124364	.658376
Variance		.064	.015	.433
Minimum		2.625	.990	2.723
Maximum		3.680	1.550	5.704

a. Multiple modes exist. The smallest value is shown

Table 5: Three-Wheelers Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.651**	.920**
	Sig. (2-tailed)		.002	.000
	N	20	20	20
Width	Pearson Correlation	.651**	1	.895**
	Sig. (2-tailed)	.002		.000
	N	20	20	20
Area	Pearson Correlation	.920**	.895**	1
	Sig. (2-tailed)	.000	.000	
	N	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6: Three-Wheelers Correlation Analysis

Statistics

		Length	Width	Area
N	Valid	217	217	217
	Missing	0	0	0
Mean		4.40187	1.79659	7.97024
Median		4.44000	1.80800	7.99000
Mode		3.995	1.695	6.729[a]
Std. Deviation		.500308	.147758	1.459036
Variance		.250	.022	2.129
Minimum		2.638	1.295	3.493
Maximum		5.575	2.176	11.062

a. Multiple modes exist. The smallest value is shown

Table 7: Cars Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.841**	.970**
	Sig. (2-tailed)		.000	.000
	N	217	217	217
Width	Pearson Correlation	.841**	1	.943**
	Sig. (2-tailed)	.000		.000
	N	217	217	217
Area	Pearson Correlation	.970**	.943**	1
	Sig. (2-tailed)	.000	.000	
	N	217	217	217

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8: Cars Correlation Analysis

Statistics

		Length	Width	Area
N	Valid	15	15	15
	Missing	0	0	0
Mean		4.20593	1.73747	7.51347
Median		4.07500	1.56200	6.11300
Mode		3.800	1.500	3.511[a]
Std. Deviation		.932959	.308677	2.789011
Variance		.870	.095	7.779
Minimum		2.280	1.430	3.511
Maximum		5.458	2.260	11.470

a. Multiple modes exist. The smallest value is shown

Table 9: Light Vehicles Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.765**	.938**
	Sig. (2-tailed)		.001	.000
	N	15	15	15
Width	Pearson Correlation	.765**	1	.941**
	Sig. (2-tailed)	.001		.000
	N	15	15	15
Area	Pearson Correlation	.938**	.941**	1
	Sig. (2-tailed)	.000	.000	
	N	15	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

Table 10: Light Vehicles Correlation Analysis

Statistics

		Length	Width	Area
N	Valid	56	56	56
	Missing	0	0	0
Mean		6.84429	2.24521	15.44720
Median		6.85000	2.20000	15.22600
Mode		7.585	2.200	12.495[a]
Std. Deviation		1.085615	.222696	3.275963
Variance		1.179	.050	10.732
Minimum		4.315	1.905	8.660
Maximum		8.595	3.440	26.660

a. Multiple modes exist. The smallest value is shown

Table 11: Medium Vehicles Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.338*	.883**
	Sig. (2-tailed)		.011	.000
	N	56	56	56
Width	Pearson Correlation	.338*	1	.737**
	Sig. (2-tailed)	.011		.000
	N	56	56	56
Area	Pearson Correlation	.883**	.737**	1
	Sig. (2-tailed)	.000	.000	
	N	56	56	56

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 12: Medium Vehicles Correlation Analysis

Statistics

		Length	Width	Area
N	Valid	25	25	25
	Missing	0	0	0
Mean		10.61872	2.48776	26.50632
Median		10.30000	2.50000	24.56900
Mode		11.995	2.600	24.569[a]
Std. Deviation		1.437163	.161261	4.547909
Variance		2.065	.026	20.683
Minimum		8.887	2.160	20.021
Maximum		14.500	2.950	37.700

a. Multiple modes exist. The smallest value is shown

Table 13: Heavy Vehicles Preliminary Statistical Analysis

Correlations

		Length	Width	Area
Length	Pearson Correlation	1	.402*	.942**
	Sig. (2-tailed)		.046	.000
	N	25	25	25
Width	Pearson Correlation	.402*	1	.684**
	Sig. (2-tailed)	.046		.000
	N	25	25	25
Area	Pearson Correlation	.942**	.684**	1
	Sig. (2-tailed)	.000	.000	
	N	25	25	25

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 14: Heavy Vehicles Correlation Analysis

V. DIMENSION OF STANDARD VEHICLES

Based on the final iteration, 6 vehicle types were identified for the classification of vehicles. This Classification of the vehicles was subjected to field trials by utilizing three independent groups of enumerators. To overcome the surge situation, additional enumerators were deployed. Initially, the field trials were restricted to one intersection only and for one direction at the intersection only. The field trials provided that the three independent results were significantly similar. Hence, the field trials was expanded to include four intersections and for all directions at each of the intersections. From these field trials also, it was noticed that the traffic classification and volume data was significantly similar. Hence, the six types of the classification of the vehicles were considered to be acceptable for traffic analysis at signalized intersections. The average dimensions of such vehicles were obtained and is noted in the table below.

Sl. No.	Mode	Length (m.)	Width (m.)
1	Two-wheelers	2.063	0.778
2	Three-wheelers	3.018	1.422
3	Cars	4.402	1.797
4	Light Vehicles	4.206	1.737
5	Medium Vehicles	6.844	2.245
6	Heavy Vehicles	10.619	2.488

Table 15: Dimensions of Standard Vehicles

VI. CONCLUSIONS

Based on the numerous iterations of vehicle classifications, statistical analysis and field trials, several conclusions were reached as noted below:

- Statistical analysis alone cannot be utilized for classification of the vehicles.
- Human factors have to be considered in the classification of the vehicles.
- Dimension of the vehicle is not a good variable for classification of vehicles.
- The types of vehicles is a good variable for the classification of vehicles.
- The classification of vehicles into 6 types was found to be provide significantly acceptable results for signalized intersections.
- The average dimensions of the 6 types of the vehicles was determined and found to satisfy the statistical analysis and field trials.

It is recommended that these vehicle classifications and dimensions be utilized for traffic analysis to achieve uniform results. Further, every few years, the vehicles dimensions should be reassessed based on the manufacturers data. Preliminary field tests should be conducted to identify if any other modes of vehicles exist in such locations and if suitable additional types of vehicles could be utilized for further classification of vehicles. Further, the engineering design standards should be updated regularly to meet the changing vehicles dimensions. Finally, it should be noted that vehicles dimensions may never be constant and it is an ever-changing variable. For highly reliable results, the analysis should be flexible to react to these types of changes to the basic input data.

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