Comprehensive Analysis of Minibuses Gravity Center: A Post-Production Review for Car Body Industry

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Highlights:

- The center of gravity (CoG) on the minibus on various loads was reported in this study

- The case study was conducted on a minibus with a capacity of 30 passengers to be used in a mining area

- The test results are expressed in a coordinate system (x, y, z) which represents the longitudinal, lateral, and vertical distances to the center of the front wheel axle

- These test results contribute to the domestic car body industry

Abstract

The center of gravity (CoG) on the minibus is one of the fundamental parameters that affect the operation of the vehicle to maintain traffic safety. CoG greatly affects vehicle maneuverability due to load transfer between the front and rear wheels, such as when turning, braking, and accelerating. Therefore, this research was conducted to evaluate the operational safety of minibuses produced by the domestic car body industry. The case study was conducted on a minibus with a capacity of 30 passengers to be used in a mining area. Investigations on CoG were carried out based on the minibus specification data, especially the dimensions and forces acting on the wheels. Minibuses as test objects were categorized in two conditions, namely without passengers and with 30 passengers. The test results are expressed in a coordinate system (x, y, z) which represents the longitudinal, lateral, and vertical distances to the center of the front wheel axle. CoG coordinate values without passengers are (2194.92; 7.11; 1327.97) mm and CoG coordinates with full passengers (30 people) are (2388.52; 13.04; 1251.72) mm. The test results show that the change in CoG at full load is not significant which indicates the minibus is safe when maneuvering under normal conditions.

Keywords: Center of gravity, Minibus, Vehicle body industry, Maneuver safety

1. Introduction

Recently, it is very interesting to study the industrial and technological developments of various light and heavy vehicles that are widely used on the roads. Domestically produced vehicles, especially the body or domestic assembly to meet the mobility needs of the general public, are

commonly found on Indonesian roads, especially inter-provincial, urban, rural and other highways. These vehicles consist of light vehicles, minibuses, buses, single trucks and other four or more wheeled vehicles. Currently, the body industry or the assembly of various combinations of vehicles is increasing with the advancement of the carrying capacity of automotive products. Therefore, controlling new types of vehicles on existing roads in Indonesia with the existing difficulties, requires an experienced driver who knows the operational character of the vehicle's maneuvers [1].

The likelihood of a serious accident increases, as the driver overreacts to minor disturbances that occur in the vehicle making it difficult to control the stability of the vehicle. Sometimes the construction or structure of the vehicle may easily cause stability and maneuverability problems even under normal operating conditions. The problems that arise in these vehicles are mostly caused by various conditions (eg: full load; unsuitable road conditions; conditions during braking, turning or turning maneuvers where instability easily occurs which one of the effects can be rolled over) [2]–[5].

A vehicle that rolls over, easily causes a fatal collision with another vehicle especially if this happens on a major highway where traffic is heavy. The source of the cause of this rollover condition rarely gets the attention of experts or researchers working in the field of road transportation [6], [7]. Many researchers abroad have studied many special cases where the focus of their research is the physical form of the vehicle, especially multi-articulated vehicles that are in maneuverable conditions [1].

The internationally accepted method of regulating rolling stability is through a rollover threshold (SRT) static assessment or test, to determine the maximum lateral acceleration the vehicle can withstand before rolling over. SRT is determined by physical testing, or through multibody dynamics simulation; However both of these approaches are expensive and time consuming. Analysis by Benade et al. [8] consider various simplified tools for estimating the articulated SRT of heavy vehicles, and compare the results with the SRT values determined using multibody dynamics simulation.

Road traffic accidents investigated by the transportation safety commitee or by researchers are certain general motor vehicle accidents consisting of single accidents (collision, overturning, and burning), accidents involving two road users, multiple vehicle accidents and public bus accidents by train [9]–[11]. In addition, accidents that must be investigated are certain general motorcycle accidents that have a tremendous impact on humans, road traffic facilities and infrastructure [12].

Based on Article 1 number 24 of Law Number 22 of 2009 concerning Road Traffic and Transportation, what is meant by a traffic accident is an event on the road that is unexpected and unintentional involving a vehicle with or without other road users resulting in human casualties and/or property loss. While in article 93 paragraph 1, Government Regulation no. 43 of 1993 concerning Highway and Traffic Infrastructure, a traffic accident can be defined as an unexpected and unintentional event on the highway, involving a vehicle with or without other road users, resulting in human casualties or property loss.

Vehicle dynamic stability is the main charactiristic that must be considered by vehicle body manufacturers or manufacturers because vehicle stability can reduce potential discomfort for the driver/passenger and provide a sense of security when on the road for passengers and other road users [13]–[15]. There are often long queues of traffic jams because there is a single vehicle accident, especially a container type vehicle or bus that rolls over at a corner or roundabout. One of the reasons is because the driver has an excessive reaction when maneuvering without having technical awareness of the existence of the vehicle's center of gravity position [12].

The location of the center of gravity (CoG) of the vehicle becomes important when maneuvering, especially to reduce or prevent the vehicle from rolling over at certain speeds, especially on roads that have slopes or when cornering [16], [17]. Therefore, it is appropriate that all vehicles, especially manufactured products or body parts, need data on the technical characteristics of the location of the center of gravity of the vehicle that can be used as a reference when the vehicle is operated, especially for vehicles used by the general public both for transporting goods and people.

One of the vehicle stability factors, especially to avoid rolling or rolling conditions due to differences in height on both sides of the road so that the vehicle tilts to follow the contours of the road, is the location of the center of gravity both in the vertical and horizontal directions to the fulcrum or vehicle tires calculated from the road surface. The higher the location of the center of gravity from the road surface, the easier it is to change the horizontal and vertical bearing forces

on the left and right vehicle tires. This difference in bearing force occurs especially when the vehicle is tilted so that it becomes unstable or the vehicle is easier to roll.

An important parameter in the main design considerations of vehicles/buses is the vehicle characteristics related to the center of gravity, where the position of the center of gravity of the bus design as a whole including the super structure of the body is an important parameter of design regulations [18]–[21]. Therefore, this research aims to provide an overview of the preparation of methods to obtain quantitative and qualitative values as standard values for car body products or domestic vehicles that can be used as references for the preparation of Indonesian National Standards for automotive products, especially public transportation vehicles. Therefore, the research activities carried out are:

- Conducting theoretical studies through the preparation of methods of measuring and analyzing the center of gravity of the domestic car body industry products in the form of buses.
- Creating or developing terminology related to the measurement or analysis of the vehicle's center of gravity.
- Knowing and analyzing quantitative values of vehicle geometry.
- Knowing and analyzing the distribution of vehicle loads on the axle or tires.
- Developing and analyzing standard procedures for determining the vehicle's center of gravity.

2. Literature Review

In the automotive industry, technical regulations are indispensable for several reasons, includes:

- Providing security and safety guarantee,
- Guaranteeing international cooperation in determining the minimum technical conditions of a system or part of an automotive, and
- Increasing in the number of vehicles produced due to traffic jams.

The position of the center of gravity is one of the fundamental parameters that affect the operation of the vehicle by the driver in order to maintain traffic safety [22]–[27]. This position greatly affects the maneuverability of the vehicle due to the transfer of load or payload between the wheels of the vehicle, for example when turning, braking and accelerating. The increase in the load on the wheels of the vehicle due to the transfer of gravity to the wheels of the vehicle results in a decrease in the operational capability of the vehicle for the wheels receiving an increase in load and also due to a decrease in the relative forces on the tires both longitudinally and laterally to the increase in load. This results in increased vehicle rollover sensitivity [28].

In reference to UNECE regulatory standards R66 and ADR 59/00, the total energy in the rollover test depends on the vehicle/bus center of gravity. Therefore, every vehicle body product, especially passenger buses, must determine the location of the center of gravity as accurately as possible. The method of measuring dimensions, angles and load values as well as the accuracy of the measuring instrument must be recorded carefully. The accuracy of the measuring instrument must meet the following requirements [19]–[21]:

- for length measurements 2000 mm, the accuracy value is 1 mm.
- for length measurements > 2000 mm, the accuracy value is 0.05 %
- for angle measurement, the accuracy value is 1%.
- for load/weight measurement, accuracy value is 0.2%.

The initial data to determine the location of the center of gravity is taken from the manufacturer's specifications, namely the dimensions or distance between the left and right wheels (wheelbases), as well as the front and rear wheel axles. The location of the center of gravity of the body of the vehicle is determined from three main parameters, namely:

- Longitudinal distance (l_1) is the distance from the center of gravity to the front axle.
- Lateral distance (t) is the distance from the vertical longitudinal center plane of the vehicle.
- Vertical height (h_0) to the ground with the condition of the vehicle tire specifications.

The method for determining l_1, t, h_0, is to use a measuring device or load cell on each tire to determine the weight of the vehicle based on the force value of each scale (F_1, F_2, F_3 and F_4). Another method can be to use a measuring table specially designed for weighing vehicles where the table can be tilted when the vehicle is on it and the angle of inclination can also be measured or determined.

The longitudinal (l_1) and lateral (t) coordinates of the center of gravity are determined from the results of the analysis of a horizontal flat surface as shown in Figure 1, where each wheel of the vehicle is placed on a weight measuring device (scale/load cell). The position of the steering

wheel is set straight ahead. Each measuring instrument records the magnitude of the wheel load force (F_1, F_2, F_3 and F_4) simultaneously which is then added up as the total weight of the vehicle.

The longitudinal distance of the center of gravity relative to the center of the front wheel contact point l_1 (see Figure 1) can be calculated by Equation (1).

$$l_1 = \frac{(F_3 + F_4)L}{W} \tag{1}$$

where:
F_1 : the value of the measuring instrument load force on the left front wheel,
F_2 : the value of the measuring instrument load force on the right front wheel,
F_3 : the value of the measuring instrument load force on the left rear wheel,
F_4 : the value of the measuring instrument load force on the right rear wheel,
W : $F_1 + F_2 + F_3 + F_4$ = total weight of the vehicle, and
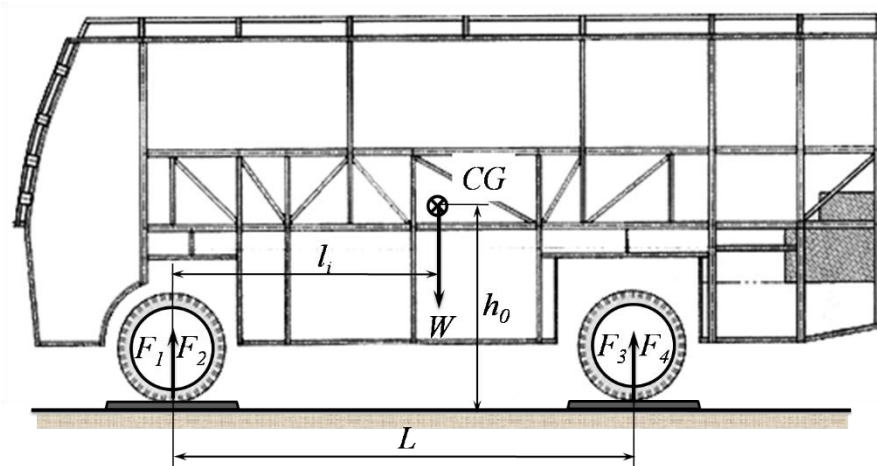l : the distance between the axle of the front and rear wheels.

Figure 1. Position of the center of gravity in the longitudinal direction

The lateral distance of the vehicle's center of gravity (t) relative to the vertical longitudinal center plane (BPLV) (see Figure 2) is calculated by Equation (2).

$$t = \frac{(F_2 - F_1)\frac{T_1}{2} + (F_4 - F_3)\frac{T_2}{2}}{W} \tag{2}$$

where:
T_1 : distance between the center of the left and right wheels on the front axle, and
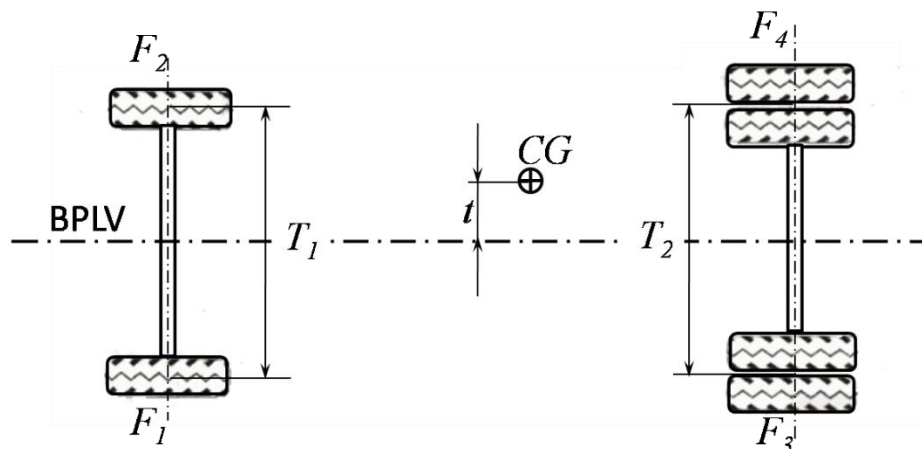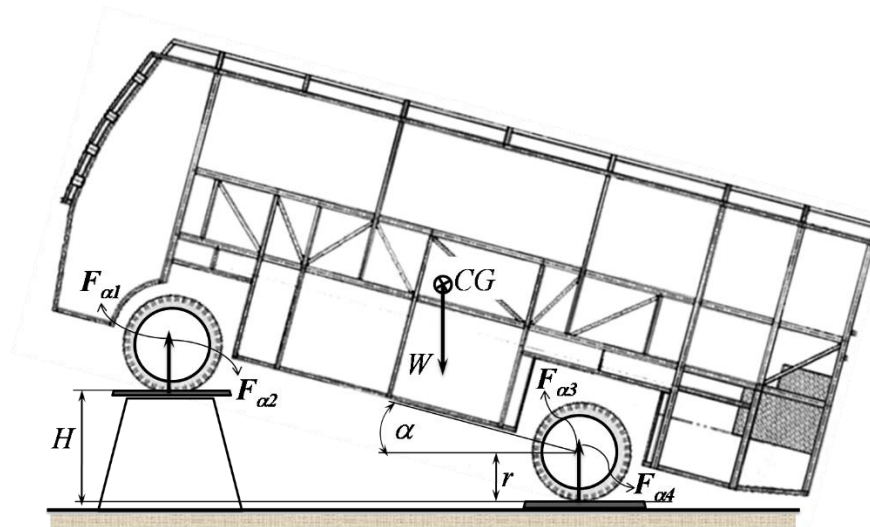T_2 : distance between the center of the left and right wheels on the rear axle.

Figure 2. Position of the center of gravity in the lateral direction

The height of the center of gravity (h_0) is calculated by tilting the vehicle in the longitudinal direction (see Figure 3), which then records the magnitude of the force on both front and rear axles.

The measurement steps that must be considered to obtain the required data include:

- Two measuring scales are placed on the horizontal surface of the two rear wheels. This position must be considered in accordance with environmental conditions so that the vehicle can be tilted longitudinally at a certain angle and the rear end of the vehicle does not touch the horizontal plane surface.
- Another pair of measuring instruments is positioned to support the two front wheels with a horizontal surface above the structure that supports the measuring instrument where the structure has a certain height, so that the angle can be determined. The determination of the height of the measuring instrument is adjusted to the conditions in the field, where the larger the angle will give better/accurate results.
- Measurement or recording of the load value of each wheel is carried out simultaneously where the direction of the steer or wheel must be straight ahead. The weight of the vehicle is obtained from the sum of the measurement results of each wheel.

The longitudinal slope angle kemiringan can be calculated using Equation (3).

$$\alpha = \mathbf{arcsin}\left(\frac{H}{L}\right) \tag{3}$$

where:

H : the height between the horizontal plane of the rear wheel and the front wheel, and
L : distance between the center/axle of the front and rear wheels.

The total weight of the vehicle when tilted horizontally is calculated using Equation (4).

$$W = F_{\alpha total} = F_{\alpha 1} + F_{\alpha 2} + F_{\alpha 3} + F_{\alpha 4} \tag{4}$$

where:

$F_{\alpha 1}$: measuring load on the left front wheel.
$F_{\alpha 2}$: measuring load on the right front wheel.
$F_{\alpha 3}$: measuring load on the left rear wheel.
$F_{\alpha 4}$: the size of the load measuring the right rear wheel.

If the application of Equation (4) results in the total weight of the vehicle being different from the weight of the vehicle measured on a flat surface, then the measurement is analyzed or repeated with the same vehicle. The difference in the value of the weight measurement on the front wheel after being raised as high as *H* is calculated by Equation (5).

$$\Delta F_{1,2} = \left(F_1 + F_2\right) - \left(F_{\alpha 1} + F_{\alpha 2}\right) \tag{5}$$

The height of the vehicle's center of gravity (h_o) can be determined using Equation (6).

$$h_o = r + \left(\frac{L}{\tan \alpha}\right)\left(\frac{\Delta F_{1,2}}{W}\right) \tag{6}$$

Where, *r* is the height of the center of the wheel axle to the surface of the measuring instrument or the radius of the wheel/tire of the vehicle.

3. Method

The application of the formulas in the literature review is carried out using data on test objects that are arranged systematically to facilitate the use of formulas, especially for calculating the height of the center of gravity. Each parameter is defined according to the symbols in the formula [29]. This research was carried out with a case study as a test object is one unit of a domestically assembled bus vehicle to be used in a mining area with a capacity of 30 passengers, as shown in Figure 4. Technical data of the test object is shown in Table 1. The equipment used for measurement in this research is shown in Table 1.

Figure 4.
Photographic view of the test objects

The implementation of the research begins with measuring the dimensions of the vehicle test object to match the technical specifications of the vehicle to be tested. For this reason, referring to Equation (1) and (2), it can be determined the value of L in Figure 1 and the values of T1 and T2 in Figure 2.

Furthermore, to determine the position of the center of gravity, the initial step is to determine the position on a flat plane according to the longitudinal direction or the x (l_1) direction and the lateral or y (t) direction. Vehicle weight measurement is done through four wheels, each of which is placed on top of a load cell. Measurements were made on two types of test objects, namely vehicles with no passengers or empty and full load/passenger vehicles which amounted to 30 people according to the number of seats available.

Table 1.
Specifications/dimensions of the test object

No	Description	Dimension (mm)
1	Distance between the axle of the front wheel to the rear wheel (L)	3850
2	Wheel/tire spokes (r)	390
3	Overall vehicle height	3160
4	Body height	2690
5	Width	2240
6	Left-right front wheelbase (T_1)	1665
7	Left-right rear wheelbase (T_2)	2240

Table 2.
List of equipment used for vehicle center of gravity measurement

No	Name of equipment	Sum	Function
1	Jig	1 unit	Jacking test object
2	Load Cell 6 ton	4 unit	Scales
3	Data logger 30 channel	1 unit	Data recorder

The first measurement was carried out on the vehicle's position in the flat/horizontal plane to obtain F_1, F_2, F_3 and F_4 data. This measurement is carried out for both types of empty and full-loaded vehicles, where measurement data is recorded through a data logger. Measurements in the horizontal plane are shown in Figure 5. Meanwhile, the measurement of the forces on the wheels is then carried out when the front wheel is raised as high as H as shown in Figure 3. The load cell position is still at the same wheel position when measuring the condition of the vehicle on a flat plane. In the longitudinal inclined condition, the wheel forces are F_1, F_2, F_3 and F_4. Measurements are made on the same test object as the measurement on a flat plane, namely an empty vehicle and a full load. The height of the vehicle's center of gravity (h0) is carried out using the Equation (3) to (6) after all parameters are obtained. Furthermore, the numerical values obtained are evaluated especially for vehicle operations, especially when maneuvering related to security and safety.

4. Results and Discussion

Through the stages in the research method, the measurement data are arranged based on the ease of application of the formula used. Measurement of weight or forces that hold the weight of the vehicle through the wheels where the condition of the vehicle is in a flat/horizontal position as shown in Figure 5. Meanwhile, in a longitudinal inclined position (the front wheel is raised) and the force recorder (data logger) is shown in Figure 6. The results of the measurement of wheel forces and vehicle weight are shown in Table 3.

Figure 6.
Measuring in an inclined
position and data logger

Table 3.
Measuring vehicle
load

Load type	H (mm)	Measurement Result (kg)				Total weight (W)
Empty/		F_1	F_2	F_3	F_4	SF
no passenger	0	1364.36	1339.89	1764.08	1822.20	
		$F_{\alpha 1}$	$F_{\alpha 2}$	$F_{\alpha 3}$	$F_{\alpha 4}$	6290.53
	400	1307.26	1236.90	1821.18	1925.19	
Full/		F_1	F_2	F_3	F_4	SF
30 passengers	0	1569.32	1592.77	2544.15	2623.69	
		$F_{\alpha 1}$	$F_{\alpha 2}$	$F_{\alpha 3}$	$F_{\alpha 4}$	8329.93
	400	1478.57	1488.76	2634.90	2727.70	

To get the position of the center of gravity in the horizontal plane, the longitudinal distance l_1 and lateral t with the coordinate center located at the center of the front wheel axis as shown in Figure 1 and Figure 2. Based on the vehicle specification data in Table 1 and the measurement results shown in Table 3, then the position of the center of gravity can be calculated using Equation (1) and (2). From the calculation results, the values of the longitudinal and lateral distances for the test vehicle type without load and full load are shown in Table 4 for the longitudinal distance and Table 5 for the lateral distance.

Table 4.
Longitudinal
distance calculation

Load Type	F_3	F_4	L	W	l_1
Empty/no passenger	1764.08	1822.20	3850	6290.53	2194.92
Full/30 passengers	2544.15	2623.69	3850	8329.93	2388.52

Table 5.
Lateral distance calculation

Load Type	F_1	F_2	F_3	F_4	W
Empty/no passenger	1364.36	1339.89	1764.08	1822.20	6290.53
Full/30 passengers	1569.32	1592.77	2544.15	2623.69	8329.93

The calculation of the height or distance of the center of gravity from the ground surface h0 is determined in several stages, namely starting with determining the angle of inclination through Equation (3). By using Equation (3), where the front wheel is raised as high as *H* = 400 mm, while the front and rear axle distances are *L* = 3850 mm, then angle = 0.104 radial = 5.964°.

The application of Equation (4) parameter values and the results of their calculations are shown in Table 3 of the results of vehicle weight measurements. As for the application of equation 5, the results are shown in Table 6. Furthermore, the calculation is carried out using equation 6 which the result of the height of the vehicle's center of gravity when the load is empty and full is shown in Table 7. In this case the parameters are the same for the two types of vehicles, namely the wheel radius. Vehicle *r* = 390 mm, front and rear axle distance *L* = 3850 mm and angle = 0.104 radial = 5.964°.

Table 6.
Implementation of Equation (5)

Load Type	F_1	F_2	$F_{\alpha 1}$	$F_{\alpha 2}$	$\Delta F_{1,2}$
Empty/no passenger	1364.36	1339.89	1307.26	1236.90	160.09
Full/30 passengers	1569.32	1592.77	1478.57	1488.76	194.76

Table 7.
Height of center of gravity

Load Type	W	$\Delta F_{1,2}$	h_0
Empty/no passenger	6290.53	160.09	1327.97
Full/30 passengers	8329.93	194.76	1251.72

The expression of the calculation of the position of the center of gravity relative to the center of the vehicle's front axle can be represented in spatial coordinates referring to the X, Y, Z axes. Where the longitudinal axis is expressed as the X axis, while the lateral axis as the Y axis and the vertical axis or Z axis. In this case, if a coordinate system is used (x, y, z), then the position of the center of gravity of the vehicle has coordinates (l_1, *t*, h_0) relative to the center of the vehicle's front axle.

The magnitude of the longitudinal, lateral, vertical parameters obtained from the calculation of the measurement values during the study showed different parameter values for each definition of the same parameter from the two types of vehicle loading. In bus vehicles without passengers, the coordinate system of the center of gravity relative to the center of the front wheel axle is (2194.92; 7.11; 1327.97) mm, while the coordinate system for vehicles with full passengers is (2388.52; 13.04; 1251). ,72) mm.

This change in position is evident in the longitudinal and vertical directions, where the position of the center of gravity in the longitudinal direction shifts as far as 193.6 mm backwards. While the vertical direction, the position of the center of gravity as far as 76.24 mm down. The change in lateral direction is not significant < 6 mm. A significant change in the position of the center of gravity will affect the dynamics characteristics of the vehicle, especially when maneuvering [22], [23], [30]. Therefore, the position of the center of gravity of each vehicle must be known to predict the level of stability of the vehicle when operating on the road.

5. Conclusion

The research results are expressed in a coordinate system (x, y, z) which represents the longitudinal, lateral, and vertical distances to the center of the axle/front axle. The coordinate values for vehicles without passengers are (2194.92; 7.11; 1327.97) mm, while the coordinates of the center of gravity of vehicles with full passengers are (2388.52; 13.04; 1251.72) mm. Changes in the position of the center of gravity from no passengers to full passengers (30 passengers), the longitudinal direction shifts by 193.6 mm backwards. While the vertical direction, the position of the center of gravity as far as 76.24 mm down. Insignificant lateral direction change < 6 mm.

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