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ROAD TRANSPORTATION SAFETY IN GHANA: AN ASSESSMENT OF THE VARIABILITY OF ARTICULATED TRAILER DESIGN PARAMETERS

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ABSTRACT

Road transport is the most dominant means of travel in Ghana due to its comparative advantages in terms of accessibility, flexibility and rapidity. Road users have limited knowledge on the operations and maneuverability of articulated trailer vehicles thus making them susceptible to accidents when sharing the road with these trailers. This study seeks to identify the dimensional characteristics used in the design and fabrication of articulated trailers and to create awareness about the variability in these designs. The data used for analyses were obtained from DAF, Benz, Kumasi Suame Magazine, and Takoradi Kokompe Articulated Trailers. Three categories of the above mentioned articulated trailer vehicles namely normal trailer, semi- trailer and double trailer were identified and their height, breadth, length, mass, engine capacity and aspect ratios acquired. Statistical analysis of the differences in the uniformity of the trailers was performed using the one-way ANOVA (F–TEST). Results show that DAF CF 65 has the best mass-capacity ratio of 92.5 kg/kW in the normal trailer category, DAF CF 75 has the best mass-capacity ratio of 81.5 kg/kW in the semi- trailer category, while in the double trailer category, DAF CF 85, Benz Astros, and Takoradi Kokompe have the same mass capacity ratio of 125.7 kg/kW. This suggests that, DAF trailers can pull more load, have a lower tendency of break down and are safer for other users to overtake.

Keywords: Road Transportation, Safety, Variability; Articulator Trailer, F Distribution.

1. INTRODUCTION

Road transport is the predominant mode of transport in Ghana, accounting for 94% of freight and 97% of passenger traffic movements (Owusu-Bio, *et al*., 2016). Road freight transportation in Ghana has seen intense growth in recent years and is primarily carried out by articulated trailers (Mensah, *et al*., 2014). There are a variety of articulated trailer combinations such as the full trailer, semi- trailer, double trailer,

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simple trailer and pole trailer depending on the need to be met. The design of an articulator has a great bearing on its efficiency and safety. Carstensen *et al.*, 2002 states that design parameters such as the dimension of the truck, which includes, the length, breadth, and the breaking ability goes a long way to influence it susceptibility to accidents. Several other road users have limited knowledge on the design parameters of articulator trailers thus making them vulnerable to accidents when sharing the road with the articulator trailers. Blower (1999), Holm (1970), Jujnovich, Roebuck, Odhams, and David (2008), Prem (2014), Simiński (2011) and Zöbel, Polock, and Wojke (2003) investigating faults relating to trucks and car crashes observed that the propensities for crashes involving articulated trailers to cause fatalities are higher than those relating to only automobiles. The authors further determined that about 1.0% of articulated trailer related accidents in the year 2009 led to fatalities as compared to 0.5% for car crashes. Articulated vehicles tend to exhibit unstable motions when subjected to hostile road situations. Four possible effect that can occur under these unstable circumstances include, jack-knife, trailer swing, yaw motion, and rollover (Stevenson & Ridley, 2005; Tian & Jia, 2006; Wang, 2015). These unstable motions make it imperative that other road users recognise the variability of the design of the articulated trailer and protect themselves and others from possible accidents. This study seeks to identify the risk factors associated with the design and fabrication of articulated trailers and to create awareness about the variability in these designs. The objectives of this study are: (i) to obtain the dimensions, mass, and engine capacity of selected foreign and locally made articulated trailers, and (ii) to compare these parameters to assess the size and the variability between the selected foreign and locally made articulated trailers.

2. DESIGN OF ARTICULATED TRAILER PARAMETERS

Trailers mostly operating in Ghana are the DAF, Benz, Man Diesel, Kumasi Suame, Jospong, Takoradi Kokompe and the Kantanka. This study focuses on two of the most commonly used foreign trailers (DAF and Benz) and two most locally manufactured trailers (Takoradi Kokompe and Kumasi Suame). Though a variety of trailers from the above mentioned manufacturers exist, three classes of trailers namely the normal trailer, the semi- trailer and the double trailer were used in this study as they are the predominantly used trailers in Ghana. Five trailers from each class of the three trailers mentioned above were used in this study and the articulated trailer dimensions were designed and measured. The length of the normal trailer was designed as the horizontal distance depicted as “A” in figure 1. Similarly, the length of the semi-trailer and double trailers were also designed as the horizontal distance depicted as “A” in figures 2 and 3 respectively. The height of the normal trailer, semi - trailer, and the double trailer, depicted by ‘B’ in figures 1, 2 and 3, was designed as the perpendicular distance between the horizontal surface in line with lowest point of the trailer to the horizontal surface in line with the apex of the trailer. The breadth of the normal trailer, semi - trailer, and the double trailer, was designed as the horizontal distance between the two most remote perpendicular ends parallel with the longitudinal section of the trailer as depicted by ‘C’ in Figure 4.

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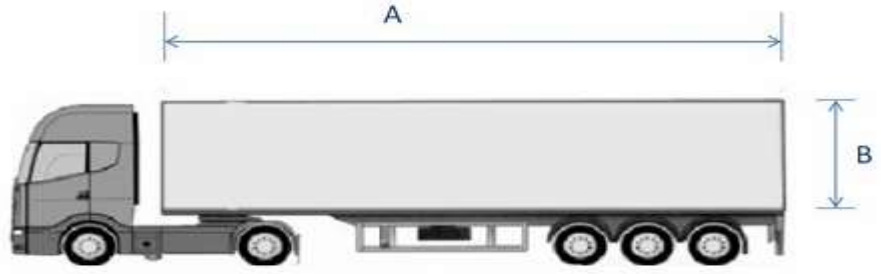

Figure 1: Designed Dimension of Length and Height - Normal Trailer

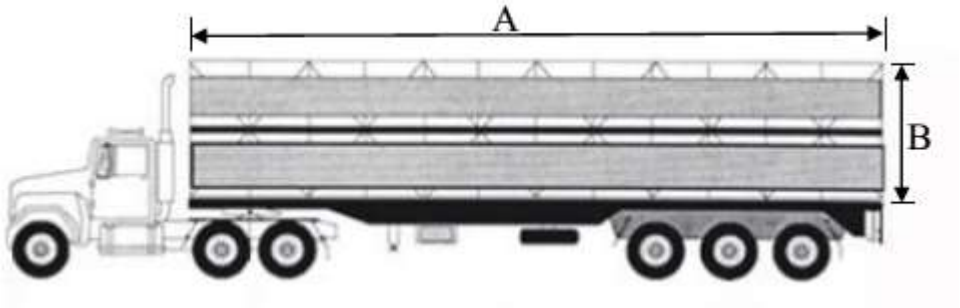

Figure 2: Designed Dimension of Length and Height - Semi - Trailer

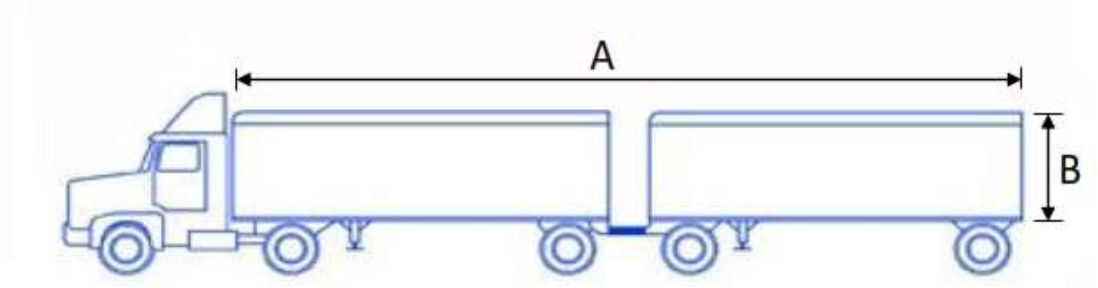

Figure 3: Designed Dimension of Length and Height - Double Trailer

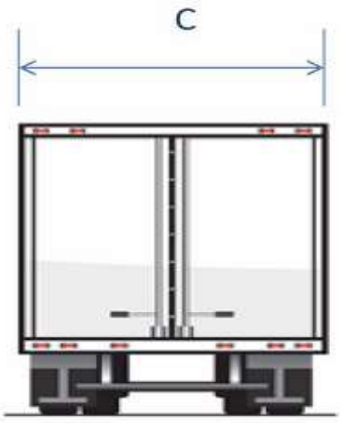

Figure 4: Designed Dimension of Breadth – Selected Trailers

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3. MEASUREMENT AND ANALYSIS OF DESIGN PARAMETERS

The length, breadth and height of the normal trailers, semi - trailers, and the double trailers for the DAF, Benz, Kumasi Suame and Takoradi Kokompe Trailers were measured using a standard measuring tape as depicted by 'A', 'B', and 'C' in figures 1, 2, 3, and 4. Five different trailers from each of the types named above were measured. The measurement were done for each of the three classes of the trailers. The mean and standard deviation of the length, breadth, and height measurements for each class of the trailers were reported as shown in Tables 1 - 3. The mass was measured using weighing bridge. Each trailer was packed on the weighing bridge and their mass read and recorded. The mean mass for each class of the trailers were also recorded as shown in tables 1 – 3. The engine capacities were read from the inner portion of the driver's door where vehicle manufacturing information has been provided. The mean engine capacity for each class of the trailers were recorded as shown in tables 1 – 3. The aspect ratio of a vehicle is a factor that defines how safe it is to overtake a vehicle on the road. It is the ratio of the length-to-breadth of the trailer (L/B). According to Chandra (2004), Davis, (1949), Underwood (1991), Wikman, et'al (1998), the width and lanes of roads are standardized and designed depending on the type of vehicles and the speed expected on the road. The time it takes for a vehicle to overtake a trailer is a function of the length of the trailer. This implies that a trailer which has a large aspect ratio has a length that is relatively far higher than the breadth making it more risky to overtake. The results of the aspect ratio for each class of the trailers are also presented in Tables 1-3 Statistical analysis of the differences in the uniformity of the trailers was performed using the one-way ANOVA (F– Distribution). The data analysis pack built in Microsoft Excel® 2013 was used for the ANOVA.

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Table 1: Average Measurements of Normal Trailer Parameters

	DAF CF 65	Benz Arocs	Kokompe	Suame
Mass (kg)	24000	30000	32000	30500
Engine Capacity (kW)	265	265	265	265
MCR (kg/kW)	92.83	113.21	120.75	115.09
Length (m)	13.9 ± 0.61	13.14 ± 1.29	15.2 ± 2.61	15.4 ± 2.01
Height (m)	1.4 ± 0.1	1.4 ± 0.26	1.5 ± 0.1	1.5 ± 0.1
Breadth (m)	2.4 ± 0.1	2.5 ± 0.1	2.67 ± 0.31	2.5 ± 0.1
Aspect Ratio (L/B)	5.78 ± 0.15	5.22 ± 0.57	5.73 ± 0.63	6.18 ± 0.88

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Table 2: Average Measurements of Semi -Trailer Parameters

	DAF CF 75	Benz Atego	Kokompe	Suame
Mass (kg)	15000	16000	19000	20000
Engine Capacity (kW)	184	184	184	184
MCR (kg/kW)	81.52	86.96	103.26	108.7
Average (m)	5.23 ± 0.46	5.46 ± 0.19	7.16 ± 0.21	6.88 ± 0.49
Height (m)	1.4 ± 0.08	1.32 ± 0.17	1.5 ± 0.08	1.5 ± 0.08
Average (m)	2.4 ± 0.08	2.5 ± 0.08	2.5 ± 0.08	2.5 ± 0.08
Aspect Ratio (L/B)	2.19 ± 0.26	2.19 ± 0.14	2.87 ± 0.15	2.76 ± 0.24

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Table 3: Average Measurements of Double Trailer Parameters

	DAF CF 85	Benz Astro	Kokompe	Suame
Mass (kg)	44000	44000	44000	50000
Engine Capacity (kW)	350	350	350	350
MCR (kg/kW)	125.71	125.71	125.71	142.86
Length (m)	22.58 ± 0.17	22.42 ± 0.98	26.3 ± 0.59	25.4 ± 1.64
Height (m)	1.56 ± 0.25	1.42 ± 0.09	1.6 ± 0.08	1.5 ± 0.08
Breadth(m)	2.4 ± 0.08	2.5 ± 0.08	2.68 ± 0.25	2.5 ± 0.08
Aspect Ratio (L/B)	9.42 ± 0.38	8.99 ± 0.59	9.93 ± 0.7	10.18 0.79

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4.0 RESULTS AND DISCUSSION

4.1 Comparison of Mean of Breadth and Aspect Ratio

Table 4 shows the comparison of the means of the breadth and the aspect ratios for the normal, semi, and double trailers. The results indicate that there are no significant differences in the breadths of the normal trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at 95% confidence level since each of the confidence intervals in the breadth dimension include zero. The Aspect Ratio of the normal trailer indicated that each of the confidence intervals of the aspect ratios include zero, there is therefore no significant differences in the aspect ratios of the normal trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at 95% confidence level (Table 4). This suggests that other road users are exposed to the same risk when overtaking any of the types of normal trailers mentioned above granting that all road safety conditions are observed. In comparing the breadth and aspect ratio of semi-trailers, Table 4 indicates that there are no significant differences in the breadths of the semi- trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at 95% confidence level since each of the confidence intervals in the breadth dimension include zero. The following deductions may be drawn from the confidence intervals of the aspect ratios of the semi - trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at 95% confidence level: (a) there are no significant differences between the aspect ratios of the semi - trailers of Benz and DAF, (b) the differences in the aspect ratios of the semi - trailers of DAF and Takoradi Kokompe are significant, (c) the differences between the aspect ratios of the semi - trailers of DAF and Kumasi Suame are not significant, (d) the differences in the aspect ratios of the semi - trailers of Benz and Takoradi Kokompe are significant, (e) the difference in the aspect ratios of the semi - trailers of Benz and Kumasi Suame are significant, (f) there are no significant differences between the aspect ratios of the semi - trailers of Takoradi Kokompe and Kumasi Suame. Road users risk overtaking the locally fabricated semi - trailers than the foreign trailers when subjected to the same conditions. However the risk of overtaking the DAF semi - trailer and the Takoradi Kokompe semi - trailer are the same granting that road safety conditions are observed.

Comparing the means of the breadth and the aspect ratios for the double trailers, Table 4 indicates that there are no significant differences in the breadths of the double trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at the 95% confidence level since each of the confidence intervals in the breadth dimension include zero. It can also be seen from Table 4 that there are no significant differences in the aspect ratios of the double trailers manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at the 95% confidence level since each of the confidence intervals of the aspect ratios include zero. This suggests that road users are exposed to the same risk in overtaking any of the double trailers mentioned above granting that road safety conditions are observed.

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Table 4: Comparison of Population Means for Trailer Classification

Parameter	Class of Trailer	Differences in Population Means ($\mu_1 - \mu_2$): DAF/ Benz	DAF/ Kokompe	DAF/ Suame	Benz/ Kokompe	Benz/ Suame	Kokompe/ Suame
Breadth(m)	***Normal Trailer***	0.1 ± 0.23	0.27 ± 0.52	0.1 ± 0.23	0.17 ± 0.52	0.1 ± 0.23	0.17 ± 0.52
Aspect Ratio		0.53± 0.95	0.1 ± 1.04	0.38 ± 1.43	0.43 ± 1.36	0.9 ± 1.68	0.48 ± 1.73
Breadth(m)	***Semi-Trailer***	0.1 ± 0.18	0.1 ± 0.18	0.1 ± 0.18	0.0 ± 0.18	0.0 ± 0.18	0.0 ± 0.18
Aspect Ratio		0.0 ± 0.47	0.68 ± 0.48	0.56 ± 0.57	0.68 ± 0.33	0.56 ± 0.44	0.12 ± 0.45
Breadth(m)	***Double Trailer***	0.1 ± 0.18	0.27 ± 0.42	0.1 ± 0.18	0.17 ± 0.42	0.0 ± 0.18	0.17 ± 0.42
Aspect Ratio		0.43 ± 1.13	0.51 ± 1.28	0.72 ± 1.4	0.94 ± 1.47	0.18 ± 1.58	0.24 ± 1.69

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4.2 Comparison of Uniformity of Trailer Design

In the normal trailer class, each of the F-values in the breadth dimension were found to be less than the critical F-Value of 19.00, there are therefore no significant differences in the uniformity of the breadths of the normal trailers manufactured by DAF, Benz, Takoradi Kokompe, and Kumasi Suame at the 95% confidence level. Given the fact that the F-values in the aspect ratio of the normal trailer were less than the critical F-value of 19.00, there is no significant difference in the uniformity of the aspect ratios of the normal trailers manufactured between DAF and Benz, DAF and Takoradi Kokompe, Benz and Takoradi Kokompe, Benz and Kumasi Suame, Takoradi Kokompe and Kumasi Suame at the 95% confidence level. An F-value of 34.42 was obtained in the comparison of the uniformity of the aspect ratio of DAF and Kumasi Suame. This is higher than the critical F-Value of 19.00 for DAF and Kumasi Suame, which suggests that there is a significant difference in the uniformity of the aspect ratios of the normal trailers manufactured by DAF and Kumasi Suame at the 95% confidence level. Road users are safer overtaking DAF, Benz, and Takoradi Kokompe normal trailers than overtaking the Kumasi Suame trailer. In comparing the uniformity of trailer designs for the semi - trailers, the F-values in the breadth dimension of the semi - trailer is less than the critical F-Value of 19.00, there are no significant differences in the uniformity of the breadths of the semi - trailers manufactured by DAF, Benz, Takoradi Kokompe, and Kumasi Suame at the 95% confidence level. The F-value in the semi- trailer class with respect to the aspect ratio is less than the critical F-Value of 19.00. This implies that there is no significant difference in the uniformity of the aspect ratios of the semi - trailer manufactured by DAF, Benz, Takoradi Kokompe and Kumasi Suame at the 95% confidence level. It can therefore be inferred that a road user is exposed to the same risk in overtaking any of these four semi - trailers granting that all road safety conditions are observed. In comparing the uniformity of the width and the aspect ratios for double trailers, it was observed that each of the F-values in the breadth dimension is less than the critical F-Value of 19.00, there are no significant differences in the uniformity of the breadths of the double-trailers manufactured by DAF, Benz, Takoradi Kokompe, and Kumasi Suame at the 95% confidence level. It can also be deduced that there are no significant differences in the uniformity of the aspect ratios of the double-trailers manufactured by DAF, Benz, Takoradi Kokompe, and Kumasi Suame at the 95% confidence level since each of the F-values in the aspect ratios is less than the critical F-Value of 19.00. Road users are exposed to the same risk in overtaking any of the above mentioned double trailers granting that road safety conditions are observed.

4.3 Comparison of Mass Capacity Ratio

One of the issues under this study is the overdesign of the locally manufactured trailers compared to the foreign manufactured trailers. Over design affects the actual cargo weight that the trailer can carry. A parameter that has been developed under this study is the Mass-Capacity-Ratio (MCR). A lower value of MCR is desirable since the trailer can pull more load than that of a high value per kW of power. It is also conceivable that a lower MCR will lead to better fuel consumption. Table 5, 6 and 7 provides the MCR for the trailers in the study. The results from the Table 5 indicate that for the normal trailer the DAF CF 65 has the best mass-capacity of 92.5 kg/kW followed by the Benz Arocs at 113.2 which is 22% heavier than the DAF. The Kumasi Suame trailer is 24% heavier and the Takoradi Kokompe trailer is 30% heavier. These results indicate that the DAF CF 65 is the most fuel efficient of the

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normal trailers and the least susceptible to break downs and toppling over while the Takoradi Kokompe trailer is least efficient and least safe if all the vehicles are subjected to the same load. The semi - trailer results shown in Table 6 indicate that the DAF CF 75 has the best mass-capacity of 81.5 kg/kW. The next is Benz Atego at 86.9 kg/kW which is 6.6 % heavier than the DAF. The Takoradi Kokompe trailer is next at 26.7% heavier and the worst is Kumasi Suame trailer which is 33.4% heavier. It can therefore be deduced that the DAF CF 75 is the most fuel efficient and least susceptible to breakdowns and toppling over while the Kumasi Suame semi-trailer is the worst fuel efficient and the most susceptible to breakdowns and toppling over if they are all subjected to the same load. For the double trailer results shown in Table 7, DAF CF 85, the Benz Astros and the Takoradi Kokompe trailers have the same MCR of 125.7kg/kW. The Kumasi Suame trailer is an outlier at 13.6% heavier than the rest. Therefore the Kumasi Suame trailer is the least safe compared to the other trailers.

Table 5: Mass-Capacity Ratios of Normal Trailers

	Normal Trailers			
	DAF CF 65	**Benz Arocs**	**Kokompe**	**Suame**
Mass (kg)	24600	30000	32000	30500
Capacity (kW)	265	265	265	265
Mass- Capacity Ratio (kg/kW)	92.8	113.2	120.8	115.1

Table 6: Mass-Capacity Ratios of Semi-Trailers

	Semi - Trailers			
	DAF CF 75	**Benz Atego**	**Kokompe**	**Suame**
Mass (kg)	15000	16000	19000	20000
Capacity (kW)	184	184	184	184
Mass-Capacity Ratio (kg/kW)	81.5	86.9	103.3	108.7

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Table 7: Mass-Capacity Ratios of Double Trailers

	Double Trailers			
	DAF CF 85	**Benz Astro**	**Kokompe**	**Suame**
Mass (kg)	44000	44000	44000	50000
Capacity (kW)	350	350	350	350
Mass-Capacity Ratio(kg/kW)	125.7	125.7	125.7	142.8

4. CONCLUSION

Twelve types of articulator vehicles, six foreign made and six locally made were characterized in terms of their length, height, weight and breadth. It was determined that there are no significant differences between the aspect ratios of Benz and DAF in the semi - trailer category. However the differences in the aspect ratios of semi - trailers of DAF and Takoradi Kokompe are significant. The differences between the aspect ratios of semi - trailers of DAF and Kumasi Suame are not significant though the differences in the aspect ratios of semi - trailers of Benz and Takoradi Kokompe are significant. The differences in the aspect ratios of semi - trailers of Benz and Kumasi Suame are significant. There are no significant differences between the aspect ratios of semi - trailers of Takoradi Kokompe and Kumasi Suame trailers. A parameter that has been developed under this study is the Mass-Capacity-Ratio (MCR). In the Normal Trailer category, DAF CF 65 has the best mass-capacity of 92.5 kg/kW followed by the Benz Arocs at 113.2 kg/kW which is 22% heavier than the DAF. The Kumasi Suame trailer is 24% heavier and the Takoradi Kokompe trailer is 30% heavier. In the Semi - trailer category, DAF CF 75 has the best mass-capacity of 81.5 kg/kW followed by the Benz Atego at 86.9 kg/kW which is 6.6 % heavier than the DAF. The Takoradi Kokompe trailer is 26.7% heavier and Kumasi Suame trailer is 33.4% heavier. In the Double Trailer category, DAF CF 85, Benz Astros, and Takoradi Kokompe trailers have the same MCR of 125.7. The articulator trailer from the Kumasi Suame is an outlier at 13.6% heavier than the rest of trailers considered. It also has a width greater than the width of trailers considered and can thus be considered hazardous.

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