STABILITY AND CONTROL CHARACTERISTICS

OF

STRAIGHT TRUCKS AND TRUCK-TRAILER COMBINATIONS

Draft Report
for
Interjurisdictional Committee
on
Vehicle Weights and Dimensions

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ABSTRACT

The CCMTA/RTAC Vehicle Weights and Dimensions Study addressed stability and control and pavement loading issues of tractor-semitrailer and double trailer combinations. The national Memorandum of Understanding on Vehicle Weights and Dimensions translated the technical work into regulatory principles that all provinces have agreed to implement.

Each province also has a population of straight trucks and truck-trailer combinations that operate locally or regionally. These vehicles are much less homogeneous in configuration than the trucks used principally in interprovincial commerce. It is logical that these vehicles should be subject to the same performance criteria as the tractor-semitrailers and double trailer combinations already dealt with.

This report presents results of stability and control analysis of 25 different configurations of straight truck and truck-trailer combination, each of which is in use in at least one province or region of Canada. The analysis was conducted by means of computer simulation. It also included examination of the effects of the most significant vehicle configuration parameters on the stability and control responses.

This work is intended to contribute to development of regulatory principles for these classes of vehicle that all provinces can apply in the same manner as was done in the Vehicle Weights and Dimensions Study.

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1/ INTRODUCTION

The CCMTA/RTAC Vehicle Weights and Dimensions Study addressed the stability and control characteristics of the principal heavy truck configurations in use for interprovincial trucking in Canada [1]. Regulatory principles were developed to control the internal dimensions that are important to stability and control for tractors, semitrailers and converter dollies, and for the important combinations of these vehicle units [2,3]. These principles were derived by a rational process, and were intended to be applied by agreement in a uniform manner across many jurisdictions. The subsequent Memorandum of Understanding on Vehicle Weights and Dimensions resulted in agreement among the provinces on truck weight and dimension regulations for tractor-semitrailer and A-, B- and C-train double trailer configurations [4].

All provinces have trucks of other configurations than the tractor-semitrailer, A-, B- or C-train. These are economically efficient as a consequence of a province's own legislation, or that legislation in combination with the legislation of neighbouring jurisdictions. The technical portion of the Weights and Dimensions Study did not by any means cover the range of vehicle combinations that have arisen from the current legislation of the provinces, and perhaps also some influence from some border states. The mandate of that study was to address only those significant configurations that would operate interprovincially on the principal highways of the nation, not the configurations unique to one province or one region of the country.

Now that regulatory principles have been adopted for some truck configurations, the Interjurisdictional Committee on Vehicle Weights and Dimensions has identified a need to investigate the range of trucks in use in more detail. The objective was to develop a technical basis for extending the regulatory principles to all trucks, of any configuration. This would provide a basis for regulation that will ensure comparable levels of safety are achieved for trucks in both interprovincial and intraprovincial operation. The Weights and Dimensions Study developed an appropriate methodology [5]. It has already been applied and extended in a recent study of multi-axle tractor-semitrailers peculiar to Ontario and Quebec [6]; in New Zealand [7]; and more recently, in the United States [8].

The principal truck configurations not covered by the Vehicle Weights and Dimensions Study are the straight truck and the truck-trailer combination. These are common in all provinces, but tend to be local-use vehicles. There is therefore not the "lowest common denominator" unifying effect on configuration that tends to be seen amongst tractor-semitrailers and double trailer combinations, which commonly have to operate across two or more jurisdictions. The actual configurations and weight and dimension limits for trucks and truck-trailer combinations are not at all uniform across the provinces. Not only are there significant differences in regulations between provinces, there are also privileges or exemptions for some specific commodities, or for equipment such as end dump trailers, that are superimposed on those regulations.

Earlier studies of straight trucks and the truck-trailer combination have identified the principal parameters of importance to the stability and control of these vehicles [9,10]. However, these studies have addressed configurations that are found only in some parts of the United States, and are not significant in Canada. The first part of this study therefore was to identify the truck and truck-trailer combinations that are important in Canada. Twenty-five different basic configurations were identified, as follows :

1/ Six straight trucks;
2/ Six truck-pony trailer combinations;
3/ Seven truck-full trailer combinations;
4/ Three tractor-semitrailer-pony trailer combinations; and
5/ Three light truck-trailer combinations.

This report presents findings of a technical study of the stability and control characteristics of these twenty-five straight trucks and truck-trailer combinations. A range of variation on important parameters, such as wheelbase, hitch offset, drawbar length, axle configuration, and front axle load, was also conducted. Some trucks or trailers were fitted with liftable axles, and self-steering axles were considered as an alternative. This study was conducted to provide technical input to issues important to the extension of the regulatory principles developed by the Weights and Dimensions Study for tractor-semitrailers and doubles to all vehicle combinations. The study does not address pavement or bridge loading issues of these configurations, because it is believed that the technical work of the Weights and Dimensions Study, and the Memorandum of Understanding on Vehicle Weights and Dimensions, already provides the appropriate constraints.

2/ VEHICLE CONFIGURATIONS

2.1/ Naming Convention

A naming convention was developed to describe axle units and hitches. The codes for the axle units of a vehicle unit describe that vehicle unit. When vehicle units are coupled together to form a combination vehicle, the hitch codes and vehicle unit codes together identify the combination. The convention is as follows :

Hitch Type

1 - fifth wheel, so towed vehicle unit is a semitrailer
4 - single hitch, so towed vehicle unit is an A-dolly or pony trailer
5 - double hitch, so towed vehicle unit is a C-dolly

Axle Type

A - single liftable axle
C - self-steering axle with nominal properties
D - fixed dual axle unit
M - fixed triple axle unit
F - free-castering self-steering axle
I - fixed single axle unit
S - single front steering axle
T - twin front steering axle
U - raised liftable axle

This convention describes a vehicle indirectly, because the type of the towing or towed vehicle unit is implied by the type of hitch. Thus, configuration SAD4I1D represents a truck-trailer combination made up as follows :

1/ SAD has a single steering axle (S), a single liftable axle (A), and a tandem drive axle (D), so it is a 4-axle straight truck ;
2/ 4I is towed by a pintle hook (4), and has a single axle (I), so it is a single axle A-dolly ; and
3/ 1D is towed by a fifth wheel (1), and has a tandem axle (D), so is a tandem axle semitrailer.

2.2/ Straight trucks

The six straight trucks selected are shown in Figure 1. Such vehicles are widely used as dump trucks, and in other body styles for payloads such as garbage, construction materials and bulk liquids, and as vans. The characteristic of most of these vehicles is a high front axle load, up to 9000 kg (19841 lb), a tandem drive axle with a heavy duty walking beam suspension rated at 20000 kg (44000 lb) or more, a drive axle spread of 1.53 m (60 in), and a short rear overhang of 0.76 m (30 in). The payload weight of these trucks is shared between the front axle and the drive axles.

The single 3-axle straight truck, configuration SD, has a wheelbase of 5.08 m (200 in) and a 4.88 m (16 ft) long box.

The four 4-axle straight trucks each had a 5.79 m (19 ft) long box, but different axle arrangements. Configuration TD has a twin steer front axle with a leaf spring suspension rated at 20000 kg (44000 lb), a wheelbase of 5.23 m (206 in), and an overall length of 8.79 m (28.84 ft).

Configuration SAD has a wheelbase of 6.02 m (237 in) and its second ("pusher") axle is a liftable axle, located 2.54 m (100 in) in front of the leading axle of the drive tandem.

Configuration SDA has its fourth ("tag") axle as a liftable axle located 2.54 m (100 in) behind the trailing axle of the drive tandem.

Configuration SM is essentially the same as either configuration SAD or configuration SDA, except that its rear three axles are equally spaced, have a nominal spread of 3.06 m (120 in), and are assumed to share the load equally.

The single 5-axle straight truck, configuration TM, has a twin steer front axle similar to that of configuration TD and has a wheelbase of 5.99 m (236 in). The tridem drive axle arrangement is the same as in configuration SM. The overall length of the vehicle is 10.32 m (33.86 ft).

2.3/ Truck-Pony Trailer Combinations

A pony trailer, or stiff-poled pup trailer, has a rigid drawbar fixed to the frame of the trailer that is connected to a hitch on the towing truck. Its axles are usually arranged symmetrically about the centre of the box. The intention is that a generally uniform load will result in little load transfer to the towing truck. However, if the trailer's load centre of gravity (c.g.) is not exactly balanced over its axles, a vertical load will be transmitted through the hitch to the truck. There may also be significant load transfer across the hitch when a truck-pony trailer combination is driven over undulating terrain. The term "pony" is generally applied only to a tandem axle trailer, but it is extended here for convenience to include all trailers having a rigid drawbar fixed to the frame of the trailer, without consideration of the number or location of axles. A truck-pony trailer combination has one articulation point, at the hitch of the truck. A pony trailer is usually attached by a pintle hook or ball hitch, so it lacks the roll resistance that a semitrailer has at the fifth wheel connection to a tractor.

The six truck-pony trailer combinations selected are shown in Figure 2. Three of the six are drawn by the 3-axle straight truck SD, one by the 4-axle straight truck SAD, and two by the 4-axle straight truck SM.

Configuration SD4D consists of the straight truck SD and a pony trailer with a 4.88 m (16 ft) long box supported by a 1.83 m (72 in) spread tandem axle centred in the middle of the box.

Configuration SD4M also uses the straight truck SD, but with a pony trailer with a 5.79 m (19 ft) long box supported by a 3.05 m (120 in) spread triple axle centred in the middle of the box.

Configuration SD4AD also uses the straight truck SD, and its pony trailer has the same box as SD4M. However, a fixed tandem axle is placed towards the rear of the box, and a liftable axle is centred beneath the front of the box, 2.54 m (100 in) ahead of the leading axle of the tandem axle. This is not a true pony trailer.

Configuration SAD4D employs the 4-axle straight truck SAD towing the same 4.88 m (16 ft) long tandem axle pony trailer as configuration SD4D.

Configuration SM4D employs the 4-axle straight truck SM towing the same 4.88 m (16 ft) long tandem axle pony trailer as configuration SD4D.

Configuration SM4M also employs the 4-axle straight truck SM, but towing the same 5.79 m (19 ft) pony trailer with a tridem axle as used in configuration SD4M.

2.4/ Truck-Full Trailer Combinations

A full trailer consists of a trailer converter dolly and a semitrailer, or is an integral unit where the front axle unit is permanently attached to the trailer, usually by means of a turntable. A truck-full trailer combination has two articulation points, one at the truck hitch and one at the trailer articulation point. A full trailer lacks the roll resistance of a semitrailer, because it is attached by a pintle hook or ball hitch, rather than a fifth wheel. Where the full trailer is one integral unit, the drawbar is hinged at the frame carrying the front axle unit to permit coupling to the towing truck, and to avoid load transfer between the two vehicle units. Where a single axle converter dolly is used to make up a full trailer, the drawbar must always be a rigid part of the dolly frame so that the dolly will stand up when the trailer is detached from the truck. However, where a tandem axle converter dolly is used, the drawbar may be hinged, or may be a rigid part of the dolly frame. In the latter case, there may be significant load transfer between the two vehicle units when driven over undulating terrain.

The seven truck-full trailer combinations selected are shown in Figure 3. They include 5-, 6-, 7-, and 8-axle combinations drawn by the 3-axle straight truck SD, and 7-axle and 8-axle combinations drawn by the 4-axle straight truck SAD.

Configuration SD4I1I consists of the truck SD and a 5.18 m (17 ft) long 2-axle full trailer. The trailer is attached to a single hitch at the back of the truck by an A-dolly with a tongue length of 2.84 m (112 in).

Configuration SD4I1D consists of the truck SD and the same A-dolly as configuration SD4I1I, but with a 7.31 m long trailer supported by a dual axle unit with an axle spread of 1.83 m (72 in).

Configuration SD4D1D consists of the truck SD, a tandem axle A-dolly with a tongue length of 3.61 m (142 in) and a 9.12 m (30 ft) long tandem axle trailer with a 1.83 m (72 in) axle spread.

Configuration SD4I1AD consists of the truck SD, a tandem axle A-dolly and a 3-axle semitrailer. The tongue length of the dolly is 2.84 m (112 in) and the axle spread of the dolly tandem is 1.53 m (60 in). The trailer is 9.12 m (30 ft) long and has a tandem axle with a 1.83 m (72 in) spread, A liftable axle is located 2.54 m (100 in) ahead of the lead axle of the trailer tandem axle. This configuration appears primarily to be used for haul of refuse containers.

Configuration SD45CI consists of the truck SD towing a 2-axle trailer through a hinged drawbar that has a single hitch at the back of the truck but has a double hitch at the front of the trailer. The hitch arrangement at the trailer end effectively decouple pitching between trailer and the towing truck. It also eliminates the stress in the drawbar when the combination is moving on a surface having an undulating profile. The trailer has a box length of 4.88 m (16 ft). It is supported by a self steering axle at the front of the trailer and a single fixed axle at the rear.

Configuration SAD4I1D consists of the truck SAD and the same single axle A-dolly and tandem axle trailer as configuration SD4I1D, except that the tongue length of the dolly is 3.25 m (128 in).

Configuration SAD4D1D consists of the truck SAD and the same single axle A-dolly and tandem axle trailer as configuration SD4I1D, except that the tongue length of the dolly is 3.61 m (142 in).

2.5/ Tractor-Semitrailer-Pony Trailer Combinations

The three tractor-semitrailer-pony trailer combinations selected are shown in Figure 4. These double trailer combinations are not A-, B- or C-trains, they are a unique hybrid configuration. A key feature in this is the pony trailer, which has a much shorter wheelbase and a more rearward location of the load centre of gravity than the second semitrailer of a B-train. These combinations have two points of articulation, at the tractor fifth wheel and the semitrailer hitch, like a B-train, and one less than an A-train. However, the pony trailer lacks the roll resistance that is available to the second trailer of the B-train.

Configuration SD1D4D consists of a 3-axle tractor, a tandem axle semitrailer and a tandem axle pony trailer. The tractor has a wheelbase of 5.08 m (200 in) and a tandem drive axle with a spread of 1.53 m (60 in). The semitrailer has a 8.53 m (28 ft) long box and a dual axle unit with a spread of 1.83 m (72 in) and a walking beam suspension rated at 20000 kg (44000 lb). The pony trailer is the same as that used in configuration SD4D, connected to a pintle hook on the back of the semitrailer.

Configuration SD1D4M consists of the same tractor and semitrailer as configuration SD1D4D, but with the 5.79 m (19 ft) tridem axle pony trailer used in configuration SD4M.

Configuration SD1M4D consists of the same tractor and pony trailer units as configuration SD1D4D, but has a 10.06 m (33 ft) tridem axle semitrailer.

2.6/ Light Truck-Trailer Combinations

Three light truck-trailer combinations were selected, as shown in Figure 5. These trucks have a moderate front axle load and a long rear overhang, and are typically used for lower density commodities than the truck SD described above. The majority of the payload is carried by the drive axles, with only a small part transferred to the front axle. The light truck has a 5.89 m (232 in) wheelbase, and a tandem drive axle with 1.53 m (60 in) spread. The rear overhang is 2.29 m (90 in). It is most often seen with a van body style, though it is used in all body styles for carriage of small amounts of most commodities.

Configuration SD4I1I uses the above truck, a single axle A-dolly with a tongue length of 2.72 m (107 in), and a single axle trailer with a 6.7 m (22 ft) long box.

Configuration SD5I1I uses the same truck and trailer as configuration SD4I1I, but replaces the A-dolly with a C-dolly having the same drawbar length. The double drawbar configuration of the C-dolly provides roll coupling between the truck and trailer that is not available from the conventional A-dolly.

Configuration SD4D uses the same truck as above but replaces the trailer with a 4.88 m (16 ft) long pony trailer having a fixed distance of 1.53 m (60 in) between the back of the truck and the front of the pony trailer.

3/ COMPUTER SIMULATION METHODOLOGY

3.1/ Program

A PC version of the yaw/roll program in use at Ontario Ministry of Transportation was used for stability and control analysis of the various vehicle configurations [11,12]. Mainframe and minicomputer versions have been used extensively in previous simulation studies, and have been shown to provide reasonable agreement with tests [13] for a wide range of truck combinations. Other more recent tests conducted by the Ministry of a straight truck, as yet unpublished, have shown excellent agreement with the simulation.

3.2/ Performance measures

Eight measures were used to characterize vehicle performance. These were based on definitions and performance levels from the CCMTA/RTAC Vehicle Weights and Dimensions Study [3].

A/ **Static Roll Threshold** is the lateral acceleration of the power unit at which a roll-coupled unit of the truck will just roll over in a steady turn. The recommended minimum roll threshold was 0.4 g [3].

B/ **High-Speed Offtracking** is the lateral offset between the path of the steer axle of the power unit, and the path of the last axle of the truck, in a moderate steady turn of 0.2 g lateral acceleration. The recommended maximum high-speed offtracking was 0.46 m (18 in) [3].

C/ **Load Transfer Ratio** is the fractional change in load between left- and right-hand side tires in an evasive manoeuvre. It indicates how close the truck came to lifting off all of the tires on one side. The recommended maximum load transfer ratio was 0.6 [3].

D/ **Transient High-Speed Offtracking** is the peak overshoot in lateral position of the last axle of the truck from the path of the front axle of the power unit in an evasive manoeuvre, an indication of potential intrusion into an adjacent lane of traffic. The recommended maximum transient high-speed offtracking was 0.8 m (31.5 in) [3].

E/ **Rearward Amplification** is the ratio of the lateral acceleration of the rearmost unit of a combination vehicle, to the lateral acceleration of the power unit, in an evasive manoeuvre, This is an indication of the inherent stability of the combination. The higher the rearward amplification, the lower the stability of the vehicle. No limit has been set for this measure, but a value above between 1.5 and 2.0 is regarded as marginal, and a value in excess of 2.0 is considered unacceptable. Any combination having a rearward amplification over 1.5 is quite responsive.

F/ **Low-Speed Offtracking** is the extent of inboard offtracking of the rearmost axle of the truck combination, from the path of the front axle of the power unit, in a 90 degree right-hand intersection turn. The recommended maximum low-speed offtracking was 5.25 m (17.2 ft), that arises from a 4.8 m (190 in) wheelbase tractor drawing a 12.5 m (41 ft) wheelbase semitrailer in the same turn.

G/ **Friction Demand** is a measure of the resistance of multiple truck and trailer axles to travel around a tight-radius turn such as at an intersection, and describes the minimum level of tire-pavement friction necessary at the power unit drive axles for the vehicle to make a turn without jackknife. The recommended maximum friction demand was 0.1 [3]. The equivalent lateral friction coefficient developed as a performance measure during the Weights and Dimensions Study for tractor-semitrailers and double trailer combinations [5] is not applicable for single unit straight trucks. Instead, the maximum slip angle at the drive axles has been selected as the performance measure for ranking purposes. The rationale is that, in a turning manoeuvre, the direction of vehicle motion is being changed by a turning moment generated from tire side forces arising from sideslip angles developed at the drive axle tires. The higher the sideslip angle required to make a certain turn, the more difficult it will be for the vehicle to negotiate the curve on a slippery surface. The relationship between friction demand and maximum sideslip angle, illustrated in Figure 76 for some multi-axle tractor semitrailers examined in a recent study [6], is used as the basis to establish a value for this performance measure. A range from 4.0 to 6.0 deg is considered acceptable at this time. It is recognized that this is not a particularly satisfactory performance measure, as it does not relate directly to highway safety in the way that (say) rollover threshold does, nor can it readily be visualized, as can offtracking. Nevertheless, it was the most meaningful criterion that could be found that would provide a consistent means of distinguishing between the low-speed turning performance of these vehicles.

H/ **Understeer coefficient** is a measure of how aggressively a truck responds to steering in a moderately severe turn. The understeer coefficient is evaluated for each vehicle in a steady turn at a lateral acceleration of 0.25 g. A positive value indicates is understeer, whereas a negative value means the vehicle oversteer. It is however not clear-cut as to what range of understeer coefficient should be deemed acceptable. The understeer coefficient was obtained from a closed-loop manoeuvre, where the steering wheel angle was prescribed and the driver model was not used. A negative understeer value may not mean that the vehicle is outright unstable, as the driver in reality might be able to compensate for it. It is certainly fair to say that, within the lower marginal range of understeer coefficient, that one truck with lower understeer than another would be expected to be more difficult to control over an entire working day. In this report, an understeer sensitivity that lies between -0.1 and 0.1 rad/g is treated as marginal but acceptable. The selection of this range is somewhat arbitrary [8]. A low, or negative, value of the understeer coefficient is of concern. If the vehicle becomes unstable in yaw at a speed or lateral acceleration lower than the roll threshold, it limits the useable manoeuvring envelope of the vehicle.

These performance measures were determined from three manoeuvres, using the same methodology as that used in the CCMTA/RTAC Vehicle Weights and Dimensions Study [1,5]. A vehicle path was defined for each manoeuvre, and a driver model was used to cause the vehicle to follow that path. Measures A, B and H were obtained from a high-speed turn made at 100 km/h, where the truck made a spiral entry into a curve of radius 393.3 m (1290.3 ft), drove along the curve at a lateral acceleration of 0.2 g for 10 s, then made a spiral turn at a steadily increasing steer rate of 2 deg/s at the steering wheel until loss of control occurred. Measures C, D and E were obtained from a high-speed evasive manoeuvre made at 100 km/h, which consisted of a 2.11 m (6.92 ft) sidestep due to one cycle of sinusoidal lateral acceleration of amplitude 0.15 g at the power unit. Measures F and G were obtained from a 90 degree right-hand turn, made at 8.8 km/h, and of radius 14 m (45.93 ft) at the centre of the power unit left front wheel. This radius is used for geometric design of intersections. It is somewhat larger than the 10.06 m (33 ft) radius used in the CCMTA/RTAC Vehicle Weights and Dimensions Study [5], which represents about a full-lock steer for a typical truck steering system where a set-back front axle is not used. The 14 m radius has previously been used for such a manoeuvre [6].

Measures B, D, E and F are not significant for straight trucks. Measure G may be significant for combinations having widely spread axles on a pony trailer. It, or some modification, may also be significant for 4-axle straight trucks and combinations drawn by a 4-axle straight truck, where the truck has more than two axle units.

Subsequent to the recommendation of performance measures during the CCMTA/RTAC Vehicle Weights and Dimensions Study [2,5], the same methodology has been applied in at least one U.S. study [8]. That study recommended the following values for the performance measures used here :

A/ Static Roll Threshold : 0.38 g
B/ High-Speed Offtracking : 0.3 m (1 ft)
C/ Load Transfer Ratio : None
D/ Transient High-Speed Offtracking : None

E/	Rearward Amplification	: 1.4
F/	Low-Speed Offtracking	: 5.18 m (17 ft)
G/	Friction Demand	: 0.20
H/	Understeer coefficient	: 0.1 rad/g.

Note also that some of the conditions varied slightly from those used in this study. The high-speed manoeuvres were conducted at 88 km/h (55 mph); the understeer coefficient was evaluated in a turn of 0.3 g lateral acceleration; and the low-speed offtracking used a radius of 12.5 m (41 ft) at the centre-line of the front axle.

3.3/ Vehicle Data

Vehicle dimensions and mass properties were obtained to a necessary level of detail by interviews with manufacturers and users of the types of equipment addressed by this study. This was supplemented by some measurements commissioned at a fixed truck inspection station on Highway 401 near Toronto. The baseline trucks generally used axle loads and axle spacings typical of Ontario. All trailers were limited to the axle loads given in the Memorandum of Understanding on Vehicle Weights and Dimensions [4].

The vehicle component properties were based on the data files produced during the CCMTA/RTAC Vehicle Weights and Dimensions Study [5], and other reliable sources [14]. In addition, properties of three tires that are typically used in this class of vehicle were obtained. A dataset for a 457 mm (18 in) front axle tire was provided by the tire manufacturer. The properties of a 355 mm (14 in) front axle tire, and a 279 mm (11 in) drive axle tire were measured under contract on the flatbed tire test machine at the University of Michigan Transportation Research Institute as part of this work.

Fixed axles on all vehicle units were assumed to have typical leaf spring suspensions. Liftable axles were assumed to have a typical air suspension and were assigned a specific load.

The vehicle configurations described in Section 2 above are widely used in the construction and refuse industries. Aggregate, having a density of 2242 kg/cu m (140 lb/cu ft), was used as the payload for these vehicles, except for the light truck-trailer combinations, where a general freight payload of density 544 kg/cu m (34 lb/cu ft) was used. The load was always distributed in such a way that the assigned axle loads were attained. If necessary, the load was biassed to one end of the vehicle unit to achieve this.

There is a very wide range of equipment and components in use on truck and truck-trailer combinations. The vehicles selected for this study were made generic, rather than specific to any one manufacturer, user, or regulatory environment. They did, of course, include configurations whose range is known to be limited within a few provinces. Since this study is a comparison of vehicle characteristics, selection of components or equipment is of lesser importance. Any uniform change in equipment would not be expected to cause a significant change in the ranking of vehicles. Of course, any particular truck might perform either better, or worse, than its generic cousin of this analysis, depending upon its selection of equipment.

3.4/ Parametric Studies

The principal factors affecting the stability and control of straight trucks and truck-trailer combinations are available from the literature [1,9,10]. Six areas were identified for parametric study :

1/ Straight truck front axle load
2/ Trailer drawbar length
3/ Truck hitch offset and trailer drawbar length proportions, for a fixed inter-axle spacing
4/ Trailer wheelbase
5/ Liftable axle type
6/ Liftable axle location

The range of parametric study was not strictly limited. However, it was assumed, for example, that it was unlikely that front axle loads would be allowed to exceed the 9000 kg (19841 lb) currently allowed in Ontario and other provinces. It was also assumed that the minimum inter-axle spacings allowed either by current Ontario regulations, or the Memorandum of Understanding on Vehicle Weights and Dimensions, would continue to serve as limits for choice of such parameters as minimum drawbar length. Finally, it was assumed gross weight would not be allowed to exceed 62500 kg.

Where more than two axle units were used on a vehicle unit, the additional axle unit was treated as a single liftable axle for the baseline vehicle. This leads to the same problems of turning that have previously been identified for multi-axle semitrailers [1,6]. These problems are simply addressed in practice by raising the liftable axle whenever it is necessary to make a tight turn, which overloads the remaining axles, the pavement, short span bridges, and the deck structures of bridges of most forms of construction. The case of raised liftable axles was considered. The alternative of a self-steering axle was considered for each liftable axle. Each liftable axle was replaced with a self-steering axle that was steered by the frictional torque generated at the tire-road interface when the vehicle changed direction. A typical automotive steer self-steering axle, having moderate centering force and high Coulomb friction in the steer mechanism, was used. When the self-steering mechanism was made nearly free-castering, with low centering force and low Coulomb friction, it became representative of a turntable steer axle.

Each of the twenty five truck configurations was first simulated using a set of nominal dimensions, a configuration designated as the baseline configuration. Some of the configurations were subjected to additional simulation by using a range of values for the parameters of interest that were identified above. In each case, only one parameter was varied at a time. Where a parameter was to be varied from its nominal value, reasonable values were selected for its lower and upper limits. Simulation runs were then made using these extreme values. If the truck passed and failed the same set of performance measures at the lower, nominal and upper values of the parameter, then no further work was done as performance of that truck was clearly not sensitive to that particular parameter. However, if there was a change in the performance measures satisfied for a given parameter, then additional runs were made for other values of the parameter within this range of interest were made, to define a boundary that limited the performance.

Table 1 shows the complete simulation matrix for the various truck configurations of this study. Details of the baseline and parametric values for each truck configuration are presented in Appendix A.

Table 1/ Simulation Matrix

Truck Config'n	Parameter						
	Base-line	Drwbar Length	Hitch Offset	Wheel -base	Axle Spread	Axle Type	Axle Load
SD	X			X			
SAD	X				X	X	
SDA	X				X	X	
SM	X			X	X		X
TD	X			X			
TM	X			X	X		
SD4D	X	X	X				
SD4AD	X	X	X			X	
SAD4D	X	X	X				
SD4M	X	X					
SM4D	X	X	X				
SM4M	X						
SD4D (V)	X	X	X				
SD4I1I	X	X	X	X			
SD4D1D	X	X	X	X			
SAD4D1D	X	X	X	X			
SD4I1D	X	X	X	X			
SAD4I1D	X	X	X	X			
SD4I1AD	X						X
SD45CI	X	X	X				
SD4I1I (V)	X	X	X				
SD5I1I (V)	X	X	X				
SD1D4D	X						
SD1M4D	X						
SD1D4M	X						

4/ RESULTS

The results of simulation runs for baseline vehicles are presented first by groups of vehicles of similar configuration. The results of important parametric variations are then presented. Finally, the results for all trucks and the entire range of parameters are assessed to provide an overall comparison of their characteristics.

4.1/ Straight Trucks

Tables 2, 3 and 4 present values of performance measures for all straight trucks.

Figure 6 shows that all the straight trucks have no difficulty in meeting the recommended maximum high speed offtracking in a circular turn of 0.46 m. Indeed, the high speed offtracking for this class of vehicle is unimportant. The highest value, 0.466 m for configuration SDA, arises because it has the shortest wheelbase and the most rearward load centre of gravity.

Figure 7 shows the rollover threshold of these straight trucks. As a result of the relatively low height of the centre of gravity, all except the twin steer configurations have rollover thresholds above 0.4 g. The extra front axle of the twin steer truck accrues considerably more payload to the truck. However, the position of the cargo box is such that the load must be biassed towards the front of the box in order to utilize fully the available front axle load. This means the load centre of gravity is higher than it would be if a "water-level" load were possible. Further, the front axle generally has a relatively low stiffness, in order to provide a good ride quality for the driver. The additional roll stiffness this axle provides does not come close to compensating for the additional roll moment due to the greater payload and its elevated centre of gravity, so the roll threshold of the truck is significantly diminished,

Figure 8 shows the steering sensitivity of the straight trucks in the high-speed circular turn. For the straight trucks, configurations TD, TM and SDA are oversteer with sensitivities of -0.031, -0.006 and -0.024 rad/g respectively, whereas configurations SD, SAD and SM are understeer with sensitivities of 0.002, 0.019 and 0.034 rad/g respectively. However, the understeer sensitivity evaluated at 0.25 g lateral acceleration for configuration SDA is very misleading because some drastic response occurred before the vehicle reached a lateral acceleration of 0.25 g during the high speed circular turn. Review of the time history response indicated that the vehicle was extremely oversteer around 0.2 g and that the steer angle of the vehicle had to be reversed in order to keep the vehicle on the curve. Thus the vehicle was practically yaw unstable in the circular turn manoeuvre. A 4-axle concrete truck with a similar axle arrangement as that of configuration SDA has been identified to possess a high degree of oversteer properties [20], in part because of lack of control of the load on it's self-steering tag axle.

Both the lateral load transfer ratio and the transient offtracking are well within the performance criteria of 0.6 and 0.8 m, respectively, for all the straight trucks. The lateral load transfer ratio is shown in Figure 9, and lies between 0.492 and 0.563. The high speed transient offtracking is shown in Figure 10, and lies between 0.273 and 0.387 m, except again for Configuration SDA, which is 0.566 m, for the same reasons as outlined above.

Figure 11 shows the low speed offtracking for all the straight trucks in the right-hand turn was much less than the 5.25 m of the 14.63 m (48 ft) semitrailer with a dual axle unit and a 12.5 m (41 ft) wheelbase. Low-speed offtracking is not an issue for these trucks.

In the case of friction demand, maximum slip angle at the drive axles has been selected as the performançe measure for ranking purposes, as discussed above. Figure 12 shows the maximum sideslip angle at the drive axle, which ranges from a low of 4.093 degrees for configuration SD to a high of 8.742 degrees for configuration TM.

4.2/ Truck-Pony Trailer Combinations

Tables 5, 6, and 7 present all the performance measures for the various truck-pony trailer combinations.

Figure 13 shows that the high-speed offtracking of the truck-pony trailer combinations is fairly close to the performance criterion of 0.46 m. They range from 0.394 m for configuration SD4D, to 0.525 m for configuration SD4AD.

Like the straight trucks, the payload density for these truck-pony trailer is relatively high so that the resulting overall centre of gravity height for these vehicle units is relatively low . Figure 14 shows that the rollover thresholds for all the truck-pony trailer combinations are above 0.4 g, ranging from 0.420 g to 0.471 g. In all cases, the truck rolled over before the pony trailer.

Figure 15 shows that the understeer sensitivity ranges from -0.044 for configuration SD4D to 0.027 for configuration SD4M. Generally, the addition of a pony trailer appears to degrade the understeer coefficient of the straight truck by a small amount. Combinations SD4D, SAD4D and SD4AD are oversteer, while combinations SM4D, SD4M and SM4M are understeer. No yaw instability was identified for these vehicles below their respective rollover thresholds.

The axle location of the pony trailer results in a trailer with a relatively short wheelbase, and a rearward biassed load, which generally results in a high response to transient high-speed manoeuvres. It is therefore not unexpected to find that the transient responses of the truck-pony trailer combinations are high. Figure 16 shows that the lateral load transfer ratio ranges from 0.654 for configuration SD4AD to 0.993 for configuration SD4M, which is close to the state of rolling over. These values are generally much higher than the performance measure of 0.6. In this manoeuvre, the pony trailer would roll over before the truck, in all cases. Figure 17 shows rearward amplification for these trucks lies between 1.758 and 2.790. Any value between 1.5 and 2.0 is regarded as marginal, and values in excess of 2.0 are considered unacceptable. Figure 18 shows the transient high-speed offtracking ranges from 0.738 m for configuration SM4M to 1.124 m for configuration SD4M. Again these values are generally much higher than the criterion of 0.8 m. Rearward amplification represents the inherent lateral/directional stability of the truck combination. In Table 6, it is seen to correlate closely with the load transfer ratio and transient high-speed offtracking, measures that are more readily understood in terms of highway safety.

Because of the short effective wheelbase of the pony trailers, Figure 19 shows that the low-speed offtracking, ranging from 1.254 to 2.742 m, is well below the criterion of 5.25 m. However, the short wheelbase also translates into a high friction demand in a tight turn. Figure 20 shows the maximum sideslip angle at the truck drive axle ranges from 6.772 degrees to 10.107 degrees. The pony trailer always increased the friction demand of the truck that was towing it. This means that with the nominal dimensions for the truck-pony trailers examined in this analysis, the trucks may be susceptible to jackknife in a tight turn on a very slippery roadway.

4.3/ Truck-Full Trailer Combinations

Tables 8, 9 and 10 summarize the performance measures for all the baseline truck-full trailer combinations.

Figure 21 shows the high speed offtracking for all the truck-full trailer combinations. With one more articulation point than the truck-pony trailer, the rearmost axle of the truck-full trailers tracks more outboard than the truck-pony trailer in a steady circular turn. The high speed offtracking of the truck-full trailers are higher than the performance criterion of 0.46 m except for configuration SD4I1I (dump). They range from a low of 0.449 m for configuration SD4I1I to a high of 0.820 m for configuration SD5I1I.

Figure 22 shows the rollover threshold for all the truck-full trailer combinations. Generally, these trailers are longer per ton of payload than the pony trailers, so their payload centre of gravity is lower. Therefore, like the truck-pony trailers, rollover does not appear to be a major concern for these configurations. The rollover thresholds of these vehicles are all higher than the performance criterion of 0.4 g. They range from 0.416 g for configuration SAD4D1D to 0.554 g for configuration SD5I1I.

Figure 23 shows the understeer sensitivity for all the truck-full trailer combinations. This indicates that most of the truck-full trailer configurations are oversteer with understeer sensitivity lie between -0.042 and 0.11 rad/g. The analysis also reveals that configuration SD5I1I has a very high oversteer property around 0.2 g which would make the vehicle difficult to control in high-speed turning manoeuvres. In retrospect, the truck and the self-steering C-dolly combination of configuration SD5I1I is similar to configuration SDA, which was found to be yaw unstable in high-speed turning manoeuvres.

Figure 24 shows the load transfer ratio for the truck-full trailer combinations. These range from a low of 0.455 for SD5I1I to a high of 0.843 for configuration SD4I1I (van), and all are higher than 0.6 except for configuration SD5I1I.

Figure 25 shows the rearward amplification for the truck-full trailer combinations. These range from 1.833 to 2.230.

Figures 26 shows the transient offtracking of the truck-full trailer configurations. These lie between 0.761 to 1.303 m, and most are considerably higher than the recommended value of 0.8 m.

Contrary to the results of the transient performance measures, most of the truck-full trailer combinations have no difficulty in meeting both the low speed offtracking and friction demand in a low speed right hand turn manoeuvre. Figure 27 shows that the low speed offtracking is between 1.688 and 3.444 m, well below that of 5.25 m for the baseline tractor-semitrailer. Figure 28 shows the maximum sideslip angle of the truck ranges from a low of 4.098 degrees for configuration SD4I1I (dump) to a high of 11.001 degrees for configuration SD5I1I.

4.4/ Tractor-Semitrailer-Pony Trailer Combinations

Tables 11, 12 and 13 present all the performance measures computed for the tractor-semitrailer-pony trailer combinations.

These double trailer combinations are similar to A-train doubles, except that the second trailer has one less articulation point. Their performance measures should therefore be similar to that of the A-train doubles. Figure 29 shows that the high-speed offtracking in the circular turn was slightly higher than the recommended value of 0.46 m. Figure 30 shows that the rollover threshold was well above 0.4 g for all these combinations, largely because the trailer length was sufficient to depress the payload centre of gravity height. Figure 31 shows the understeer sensitivity lies between -0.025 and -0.018 rad/g. No yaw instability was detected below the rollover threshold for any of these combinations.

Performance measures obtained from the evasive manoeuvre for these tractor-semitrailer-pony trailer combinations are slightly higher than the recommended criteria. Figure 32 shows the lateral load transfer ratios, which lie between 0.715 and 0.734. Figure 33 shows the rearward amplifications, which range from 2.343 to 2.475, and Figure 33 shows the transient offtracking lay between 0.948 and 1.020 m.

All three double trailer combinations met the performance criteria for the low-speed right-hand turn. Figure 35 shows the low speed offtracking ranged from 3.572 to 4.047 m, and Figure 36 shows the friction demand ranged from 0.023 to 0.109.

4.5/ Parametric Analysis

This section presents the significant effects of front axle load, truck wheelbase, drawbar length, trailer length (trailer wheelbase), hitch offset and axle steering property on the performance measures for the various configurations. In many cases, where a configuration either met or failed to meet some performance measure, it also either met or failed to meet the same performance measure for all values within the range of variation of most of the parameters.

Front axle load determines in part the amount of payload that can be carried by a straight truck. A reduction in loading at the front axle will decrease the payload and decrease the overall centre of gravity height of the vehicle. Figure 37 shows that reduction in front axle load increases the rollover threshold of the configuration SD.

The baseline straight truck configurations in this study all have high front axle loads. Space for the engine and cab require the box to be located too far aft of the front axle to achieve the specified axle loads with a uniform payload distribution. This results in a load biassed towards the front, which has a higher centre of gravity than would occur if the payload could be loaded at a uniform level, a "water-level" load. Increase in wheelbase allows an increase in box length, which allows a more uniform load distribution. Figure 38 shows how this increase in box length increases the rollover threshold of configuration SD.

In general, the longer the wheelbase of a vehicle unit, the lower is the vehicle's response in the high speed and transient manoeuvres. The length of either the pony-trailer drawbar or the dolly drawbar of the full-trailer determines the effective wheelbase of the corresponding vehicle unit. Figures 39 to 50 show the influence of drawbar length on the transient response and maximum sideslip angle of several truck-pony trailer and truck-full trailer combinations. Similar trends can be found in various configurations. The lateral load transfer ratio, transient offtracking, rearward amplification and maximum sideslip angle are all reduced as the length of the drawbar is increased.

For a fixed inter-vehicle unit distance, placement of the hitch location determines the effective wheelbase of the trailing unit. Zero hitch offset is defined at the geometric centre of the last axle group of the towing unit. Figures 51 to 64 show the influence of hitch offset on the transient response and maximum sideslip angle of various truck-trailer configurations. Again, similar trends are found for the various configurations. The smaller the hitch offset, the lower are the responses in lateral load transfer, transient offtracking, rearward amplification and maximum sideslip angle.

Figures 65, 66 and 67 show the effect of trailer length, which effectively is trailer wheelbase, on the transient responses for configuration SAD4I1D. The lateral load transfer, transient offtracking and rearward amplification all decrease as the length of the trailer is increased, while the low-speed offtracking increases.

Figures 68 to 75 show the influence of axle steering properties on the transient responses and maximum sideslip angle for various truck-trailer configurations. As the freedom to steer is increased, from one end of the spectrum in which the axle is fixed or non-steering, to a free-castering axle, offtracking, rearward amplification, lateral load transfer ratio are reduced, whereas the transient offtracking is reduced initially and then increases as the axle approaches free-castering.

4.6/ Conclusions from Results

This section summarizes simply the principal performance measures that the various trucks and truck-trailer combinations fail. Table 14 is a scoresheet, for purposes of distinguishing between the performance of the various trucks and truck combinations.

Amongst the baseline straight trucks, the twin steer configurations TD and TM clearly have poorer rollover characteristics than the others, and the tridem drive axle configurations SM and TM clearly have poorer friction demand characteristics than the others. Configuration SDA, with a liftable tag axle, clearly has poorer handling characteristics than the others. The behaviour of this configuration becomes even worse if the tag axle is allowed to become self-steering, and it may become uncontrollable in some circumstances if the load on the liftable axle is not properly controlled [20]. Configuration SAD does better with a self-steering axle than a fixed liftable axle, but that axle must be propoerly located, and that location may not be such as to give maximum gross weight under current regulations. However, at present, many typical trucks of this configuration have rather poor loadability, which results in inadequate front axle loads and dramatic drive axle overloads, even if the liftable axle load is reasonably controlled. This configuration may be satisfactory where it can be designed with the proper load distribution for its mission, and control of the liftable axle can be assured. The only configuration that reasonably meets all performance measures is the standard three axle straight truck, with one front steering axle and a tandem drive axle.

All the baseline truck-pony trailers exhibit rather high responses in the evasive manoeuvre. The pony trailer tends to reduce the understeer coefficient and increase the friction demand of the straight truck that is towing the pony trailer. As a group, therefore, they cannot be recommended.

Among the baseline truck-full trailers, the use of a C-dolly, or any similar double drawbar hitch, clearly results in a major deficiency in the handling properties of the vehicle. This study must re-affirm the recommendation of another recent study, that use of a C-dolly, or any similar double drawbar hitch, should be strictly prohibited for the truck-trailer combination [18]. All baseline configurations of truck-full trailer combination also exhibit rather high responses in the evasive manoeuvre. Where a tandem axle dolly is used, it tends to reduce the understeer coefficient and increase the friction demand, in the same way as the pony trailer. As a group, therefore, these combinations are also difficult to recommend. They are, however, in fairly widespread use, like certain A-train double trailer combinations.

The tractor-semitrailer-pony trailer is a hybrid combination vehicle. It has the same number of articulation points as a B-train, but its second trailer lacks roll resistance in the same way as does that of an A-train. The baseline configurations also have high responses in the evasive manoeuvre, largely because the pony trailer has a short wheelbase, has a rearward bias of its load, and is much lighter than the semitrailer.

Hitch offset has a very strong effect on the rearward amplification response of all combination vehicles. This should be controlled to the absolute minimum possible value, to reduce the effect of rearward amplification. Increased drawbar length and increased trailer wheelbase both also reduce the effect of rearward amplification, but are not as strong parameters in this regard as hitch offset. The performance of the truck-pony trailer and truck-full trailer can be improved if sufficiently large dimensions can be prescribed.

Table 14/ Summary of Results

Truck Config'n	Performance Measure					
	Roll-over	H-s offtk	Under-steer	Load trans	Fric demand	Load-ablty
SD	+			++	++	
SAD				+	-	--
SDA	+	--	--	+	-	--
SM	++			++	--	
TD	--			-		--
TM	--			+	--	
SD4D	+	++		--	-	
SD4AD		-		-	-	
SAD4D		-	-	--	-	--
SD4M		+		--	--	
SM4D	++	++	-	--	--	
SM4M	++		-	-	--	
SD4D (V)	+	-		--	-	
SD4I1I	+			--		
SD4D1D	+	--		-	-	
SAD4D1D		--		-	-	--
SD4I1D	+	-		-		
SAD4I1D		--		-	-	--
SD4I1AD		-		-		
SD45CI				-		
SD4I1I (V)	+	--		--		
SD5I1I (V)	++	--	--	-	--	
SD1D4D	++	-		-		
SD1M4D	++	-		-	-	
SD1D4M	++	-		-		

Legend

--	indicates major deficiency in performance
-	indicates slight deficiency in performance
+	indicates performance slightly better than criterion
++	indicates performance much better than criterion
Blank	indicates performance close to criterion, or unimportant

5/ DISCUSSION OF RELATED VEHICLE CONFIGURATION ISSUES

There are a number of other issues related to configuration of the trucks and truck combinations studied in this report that are of significance, but which were not part of the study. These issues all appear pertinent to the development of regulatory principles, and regulatory proposals, for the vehicles under consideration.

5.1/ Current Regulations

This section is drawn from the literature [15], and no attempt has been made to determine if there have been any changes since the publication of this reference in 1987. Notwithstanding any inaccuracy due to change since 1987, the intent of this section is merely to illustrate the diversity in important parameters that may affect the configuration of trucks and truck-trailer combinations.

The length limits on straight trucks, full trailers, truck-trailer combinations, and drawbars are summarized in Table 15. As with any such table, there are numerous exceptions or special conditions. Quebec limits straight truck overall length to 11.0 m (36 ft) if the rear overhang exceeds 5.0 m (16.4 ft). Full trailer length includes the drawbar in Ontario, but presumably excludes it in provinces where a 14.65 m length is allowed. A truck-trailer combination in B.C. may have an overall length of 23.0 m (75 ft 6 in) if it has two or more articulation points. There may be other exceptions on a commodity, season or special permit basis.

The maximum allowable front steering axle load plays a major part in the selection and configuration of straight trucks, as discussed below. The front steering axle load limits for straight trucks are summarized in Table 16. There are a very wide range of exceptions and special conditions on this table, many more than appear from the table itself. Most provinces limit the allowable front axle load to the manufacturer's front axle rating. All have limits based in some way on tire rating and axle spacing. Several have lower limits in the spring thaw period, and others have higher limits in the winter. There are also other exceptions on a commodity, road class, vehicle type or special permit basis.

5.2/ Weight and Dimension Policy

Some truck-trailer combinations, and the tractor-semitrailer-pony trailers, can generate gross weight or volume that could make them a competitive alternative either to the tractor-semitrailer or the B-train. There may indeed be some commodities and specialized markets where these combinations may already be the vehicle of choice, perhaps for operational reasons. However, in general, if any of these combinations is given any advantage over the current preferred vehicle, whether a 5- or 6-axle

Table 15/ Length limits

Province	Truck length	Trailer length	Truck+ trailer	Drawbar length
Newfoundland	12.5	14.65	20.0	
P.E.I.	12.2		21.0	3.66
Nova Scotia	12.5	14.65	21.0	5.0
New Brunswick	12.5	14.65	21.0	
Quebec	12.5	14.65	23.0	
Ontario	12.5	12.5	23.0	
Manitoba	12.5	12.5	21.5	
Saskatchewan	12.5	12.5	23.0	
Alberta	12.5	12.5	23.0	
B.C.	12.5	12.5	20.0	5.0
Yukon	12.5	13.5	22.0	
N.W.T.	12.5	12.5	21.5	

Table 16/ Front steering axle loads

Province	Tire load	Front Axle	Twin steer
Newfoundland	10.0	9000	17000
P.E.I.	10.7	9000	
Nova Scotia		9000	17000
New Brunswick	10.7	9000	17000
Quebec		8500	17000
Ontario	11.0	9000	18000
Manitoba	9.0	8190	16000
Saskatchewan	9.0	5500	11000
Alberta	9.0	7300	13600
B.C.	11.0	9100	17000
Yukon	11.0	9000	18000
N.W.T.	8.0	6500	12128

tractor-semitrailer, or a B- or C-train, in any one of box length, cube, gross weight, or axle capacity, then that combination may become at least a viable alternative, if not the vehicle of preference. This is evident in California, where a particular 5-axle truck-trailer combination has a slightly higher gross weight than the corresponding tractor-semitrailer. Because of this advantage, it has become widely used, not just in that state, but throughout the western United States, even though it's stability and control properties are notoriously poorer than that of the tractor-semitrailer [9].

5.3/ Box Length

The box length dimension has been adopted for regulation of the load carrying length of semitrailers and A-, B- and C-trains. The definition is as follows :

> "Box length" means the longitudinal dimension from the front of the cargo carrying unit to its rear, including load, exclusive of any extension in the length caused by auxiliary equipment or machinery at the front that is not designed for the carriage of load."

This definition may not be entirely clear for a straight truck. The term "front of the cargo carrying unit" could be interpreted as the front bumper of the truck, rather than the front of the cargo box. This may be a problem where a diagram cannot be used to illustrate clearly the intent.

All provinces already provide both straight trucks and full trailers with adequate length that a truck-trailer combination could be longer than either the overall length limit of 23 m (75 ft 6 in) under the Memorandum of Understanding [4], or 25 m (82 ft) as adopted by the western provinces. It is believed that these maximum available lengths would be utilized infrequently in most provinces. An example where maximum lengths, and maximum box length, would be important might be van-type truck-trailers for pulpwood chip haul in British Columbia or other provinces with a large paper industry.

In any case, it is suggested that box length, in the sense of front of truck cargo box to rear of trailer cargo box, may not be a good dimension to use for regulation of the length of truck-trailer combinations. First, the typical commodities that move in these combinations are heavy and do not generally demand the maximum box length. Second, the typical inter-axle spacing demanded for bridge load allowance results in a substantial gap between the truck and trailer.

5.4/ Full Trailer Length

It is evident at this time that some provinces regulate full trailer length from the front of the drawbar to the rear of the trailer, and others may simply use the box length in the same sense as it is used for a semitrailer. If the overall length of a full trailer is to be regulated, it must be made clear which dimension is to be used. If it is from the front of the drawbar to the rear of the trailer, then this should also clearly include the case of a full trailer composed of an A-dolly and a semitrailer.

5.5/ Loadability

The term "loadability" is used here to describe conceptually the ease with which a truck can be loaded with a particular commodity. If a truck has proper axle load distribution with a uniformly distributed ("water-level") load, then it has good loadability for a bulk commodity. If the axle arrangement requires a biassed load for proper axle load distribution, then the loadability may be poor. Similarly, the loadability of any truck with a shipment consisting of several pieces of differing size and weight may also be poor, because it is difficult to judge where each piece should go.

The maximum allowable front steering axle load plays a major part in the selection and configuration of straight trucks. In particular, the combination that gives minimum inter-axle spacing, or wheelbase, or whatever dimension is used to determine maximum gross weight, effectively determines the minimum box length for a dump truck. If this configuration has an axle arrangement that is not compatible with this minimum box length, then the vehicle will have poor loadability. It is evident that some of the straight trucks in this study, such as those with twin steer or a pusher axle, have rather poor loadability. This is simply because the relationship of the box to the available axle load distribution makes it difficult to put the full load on the front axle without an extremely biassed load. This is, of course, not a problem for specialized trucks such as cement mixers, that should be designed for proper allowable load distribution.

5.6/ End-dump Trailers

Many of the trucks and combinations included in this study are widely used in end-dump applications. Some of the commodities carried, such as grains, often seem to be dumped on level paved surfaces that provide a sound footing for the trailer. However, aggregates and garbage are examples of commodities that are often dumped on uneven ground that provides anything but a sound footing at some times of the year. The length of the trailer, allied to the likelihood of a portion of the load "hanging up" at the front of the trailer, are an additional off-highway static rollover hazard for this class of equipment. Clearly, greater trailer length, or increased load bias toward the front of the trailer due to poor loadability, both increase the probability of rollover while dumping. However, a shorter trailer for stability while dumping runs counter to the need for greater wheelbase for improved dynamic performance, and for greater length for greater gross weight of the bulk commodity under the pertinent bridge load allowance. These contradictory requirements need to be recognized and carefully weighed in regulatory development.

5.7/ Drawbars, Hitches and Secondary Attachment

The related issues of drawbars and hitches have always been a concern for the C-dolly and C-train [16, 17]. A recently completed study has addressed this concern [18], and standards have now been set [19]. While hitch loads have not been assessed in this study, it is clear that a trailer having a rigid drawbar and two or more widely spaced axles, or a tandem axle converter dolly with a rigid drawbar, may exert considerable vertical force on its hitch as the vehicle traverses terrain having an undulating profile. In particular, as a vehicle passes over a crest, these forces will be in the upward direction. It has already been noted that the latches of many pintle hooks are not designed to resist upward vertical loads, and hence may have little more than nominal capacity in this direction [17, 18]. This issue would be addressed if a "fishmouth" style hitch was used, or the drawbar was hinged.

Another aspect of the dynamic stability of vehicle combinations arises when there is slack, or backlash, in the hitch coupling the trailer to the truck. This would be compounded by slack at the fifth wheel where a full trailer is composed of an A-dolly and a semitrailer. Slack in couplings is believed to diminish substantially the stability of combination vehicles in certain circumstances, such as when the vehicle is coasting, or as it crests a hill and goes momentarily from tension to compression. It is for this reason that pintle hooks of the "no-slack" type are customarily used on A-train double and triple trailer combinations. There is no obvious reason why hitches having this characteristic should not also be used for these combinations.

The requirements, methods of attachment and strength for secondary attachments, safety chains or cables, are closely related to the topics of drawbars and hitches. These three areas are related both to stability and safety of combination vehicles. While there may not be evidence of serious problems at this time, recent work has identified cases where special attention is necessary over and above the normal manufacturers conservatism in rating hitches. This subject is an area upon which there could, and should, be uniformity between provinces. It is believed that jurisdictions generally have rather vague requirements for drawbars, hitches and secondary attachments. The province of Ontario currently has had a regulation for some time, prescribing general requirements in this area. It is currently under review for compatibility with the regulatory obligations of the Memorandum of Understanding on Vehicle Weights and Dimensions, and the National Safety Code. The text of this regulation is included as Appendix B, as an example. This could serve as the a basis for development of regulatory principles for all provinces.

5.8/ "Other" Double Trailer Combinations

The Memorandum of Understanding on Vehicle Weights and Dimensions carefully defines the A-, B- and C-train double trailer combinations, and specifies their allowable weight and dimension limitations. The tractor-semitrailer-pony trailer combination studied here is an example of a double trailer combination that is not an A-train, or a B-train, or a C-train. There are others, too, using such hitches as :

1/ a linked articulation device;
2/ a crossed double drawbar;
3/ a forced steering double drawbar dolly;
4/ a non-steering double drawbar dolly;
5/ a self-steering double drawbar dolly that does not meet the requirements for a C-dolly; and
6/ probably several other examples of the ingenuity of the designer of specialized truck equipment.

Whether these devices provide the double trailer combination with desirable or undesirable stability and control properties is not relevant. The point is that a considerable number of different hitching systems exist that are presently undefined from a vehicle configuration point of view. Even if they were defined, some individuals might perceive benefit in developing hitching devices that were undefined. The system of regulation should, therefore, recognize that there is a class of "other" double trailer combinations.

Currently, the B-train and C-train have been given preferred status to the A-train, by virtue of greater gross weight and box length allowances. The A-train has status, but the "other" double trailer combinations have no status. If the A-train were included in the "other" category, then only the B- and C-trains would have status. A process, similar to that followed for the C-train, could then be used to bring configurations of merit from the "other" category to defined status.

6/ CONCLUSIONS

The stability and control characteristics of twenty five straight trucks and truck-trailer combinations have been evaluated against performance criteria similar to those developed in the CCMTA/RTAC Vehicle Weights and Dimensions Study.

The following conclusions have been drawn from this analysis :

1/ Vehicle rollover is not an issue for these configurations because of their relatively low overall centre of gravity height in typical high gross weight applications, except for straight trucks having twin steer.

2/ Low speed offtracking is not an issue for the truck-trailer combinations, within the current allowable dimensions for the vehicle units, and the allowable overall length.

3/ Any truck with more than two axles, other than the front steering axle, or any truck-pony trailer where the pony trailer has more than two axles, does not meet the friction demand criterion.

4/ Use of a tag axle severely degrades the yaw stability of the straight truck, especially when the axle is either liftable or self-steering.

5/ Use of a C-dolly, or other double drawbar dolly, in a truck-trailer combination also severely degrades the yaw stability of the straight truck.

6/ The truck-pony trailer, truck-full trailer and tractor-semitrailer-pony trailer all have high response to a high-speed evasive manoeuvre.

7/ Response to a high-speed evasive manoeuvre is sensitive to hitch offset, dolly drawbar length and trailer wheelbase. In general, the longer the dolly drawbar or trailer wheelbase, or the shorter the hitch offset from the centre of the truck's axle centre, the lower the response.

7/ RECOMMENDATIONS

The following recommendations are based on the technical work of this, and consideration of some broader issues discussed above :

1/ A straight truck should be prohibited from using a variable load axle, or a self-steering axle, in the "tag" position to the rear of the drive axles.

2/ A straight truck should be prohibited from towing a full trailer that uses either a C-dolly, or any other form of double drawbar hitch.

3/ Twin steer front axles should be discouraged on straight trucks, especially for high centre of gravity payloads.

4/ Tridem drive axles should be discouraged on straight trucks.

5/ Straight trucks with pusher axles that are liftable and not self-steering should be discouraged. This configuration should only be considered if tight controls for liftable and self-steering axles can be developed and proven, and if proper loadability can be assured.

6/ The response of all truck-pony trailer, truck-full trailer and tractor-semitrailer-pony trailer combinations to an evasive manoeuvre is high, and a similar gross weight constraint should be applied to these vehicles as is applied to the A-train double trailer combination.

7/ An "other" category should be created to encompass all combinations that are not A-, B- or C-trains.

8/ The hitch offset on the truck should be regulated to the minimum practical, and less than the value of 1.8 m (72 in) used for A-trains. Current minimum values of inter-axle spacing should then result in an adequate drawbar length.

9/ A standard should be set for the minimum upward vertical load capacity of the hitch, where the towed pony trailer or converter dolly has more than one axle a rigid drawbar.

10/ Hitches of the "no-slack" type should be used.

11/ A uniform standard should be set for drawbars, hitches and secondary attachments.

12/ Rules for configuration of vehicles should consider their loadability for all reasonable missions for which the vehicle might be configured.

13/ A limitation on trailer length, based on stability while dumping, should be considered for end-dump trailers.

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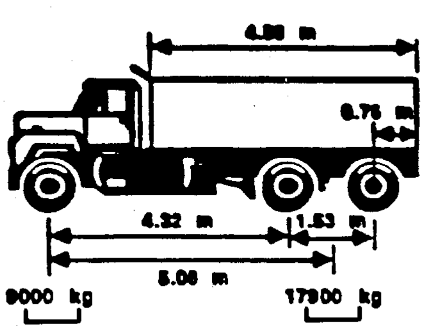
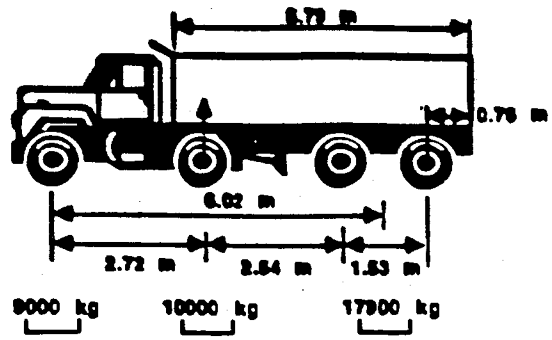
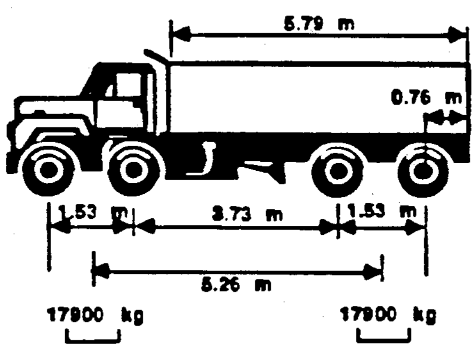


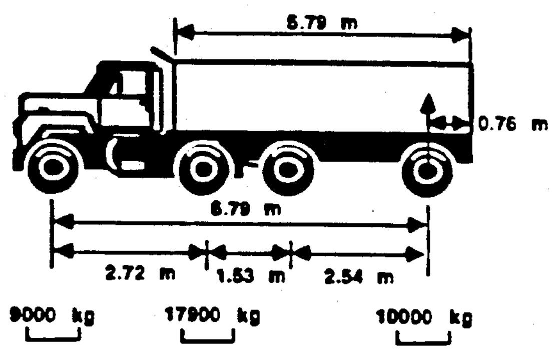
Dimensions of 3-axle Straight-Truck Configuration SD



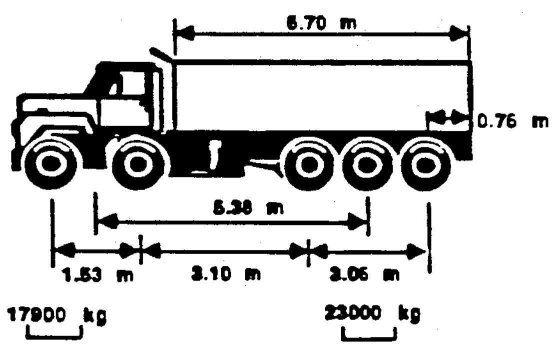
Dimensions of 4-axle Straight-Truck Configuration SAD



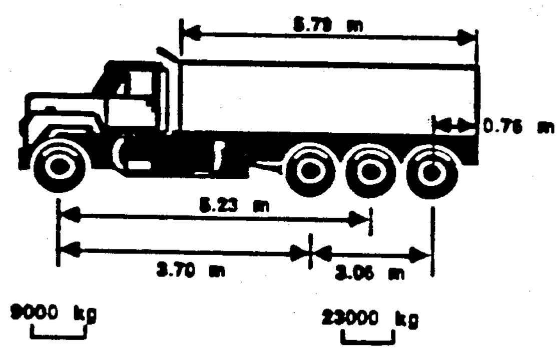
Dimensions of 4-axle Straight-Truck Configuration TD



Dimensions of 4-axle Straight-Truck Configuration SDA

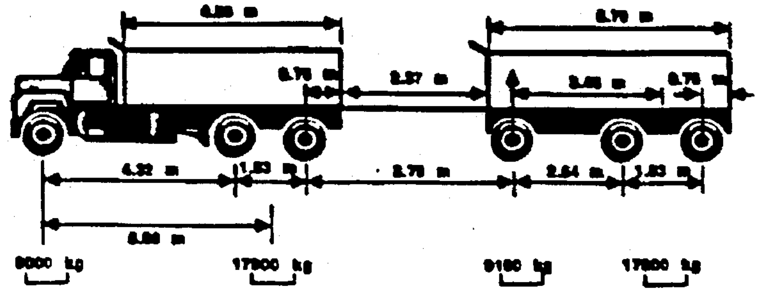


Dimensions of 5-axle Straight-Truck Configuration TM

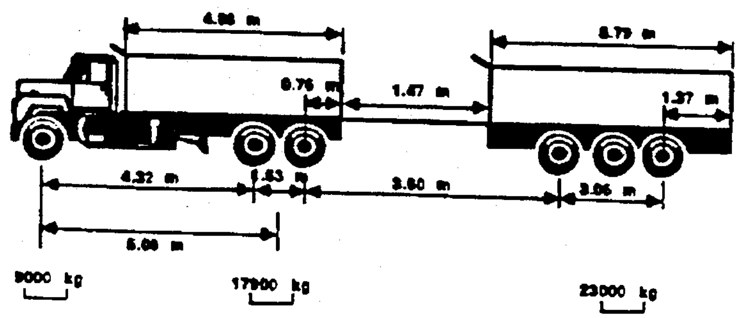


Dimensions of 4-axle Straight-Truck Configuration SM

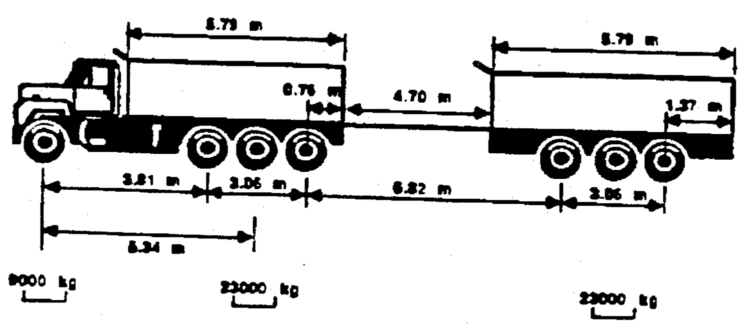
Figure 1/ Dimensions of the straight truck configurations



Dimensions of Truck-Pony Trailer
Configuration SD4AD

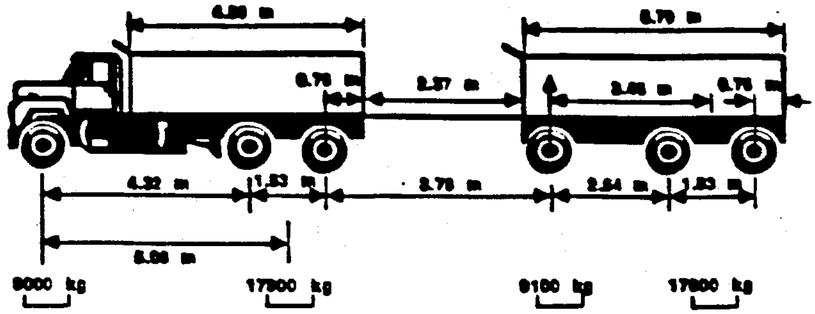


Dimensions of Truck-Pony Trailer
Configuration SD4M



Dimensions of Truck-Pony Trailer
Configuration SM4M

Figure 2/ Dimensions of the truck-pony trailer configurations
..........continued



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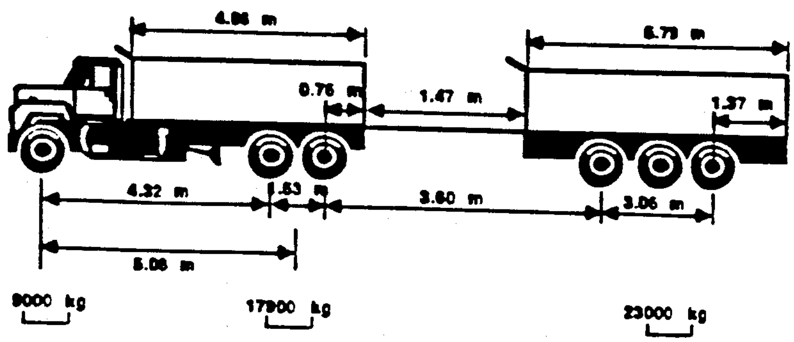
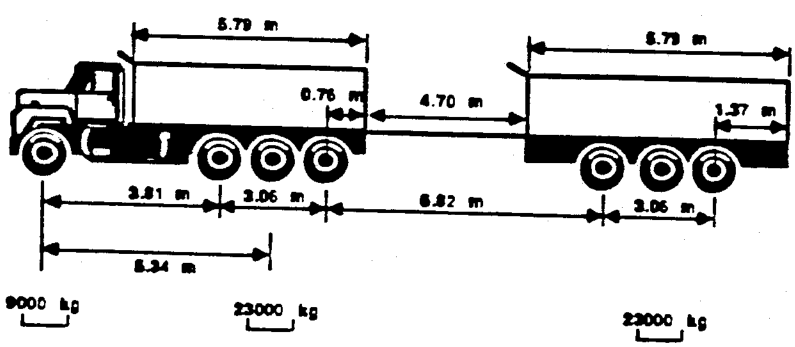
Configuration SD4AD

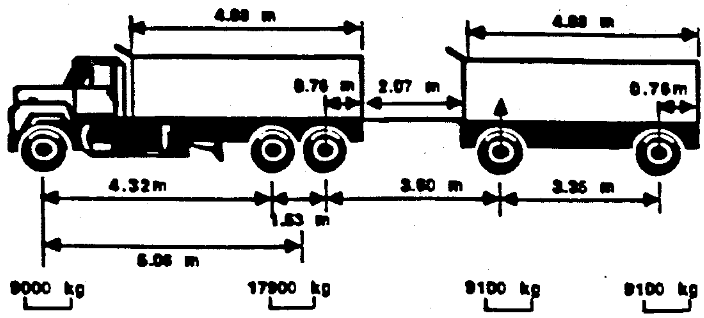


Dimensions of Truck-Pony Trailer
Configuration SD4M



Dimensions of Truck-Pony Trailer
Configuration SM4M

Figure 2/ Dimensions of the truck-pony trailer configurations
..........continued



Dimensions of Truck-Full Trailer
Configuration SD45CI

Figure 2/ Dimensions of the truck-pony trailer configurations ....continued

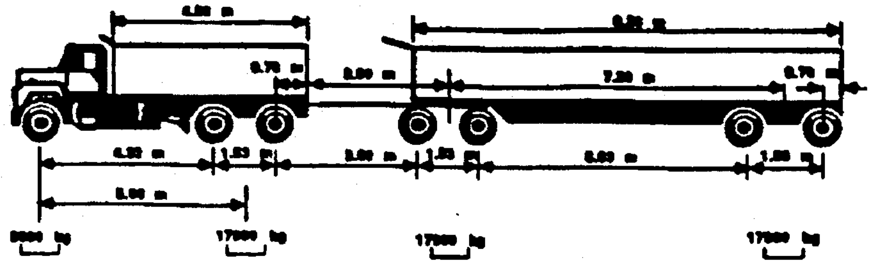


Figure 13/ Dimensions of Truck-Full Trailer
Configuration SD4D1D

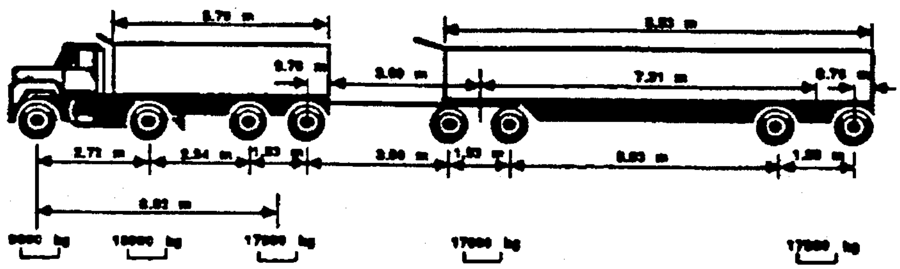


Figure 14/ Dimensions of Truck-Full Trailer
Configuration SAD4D1D

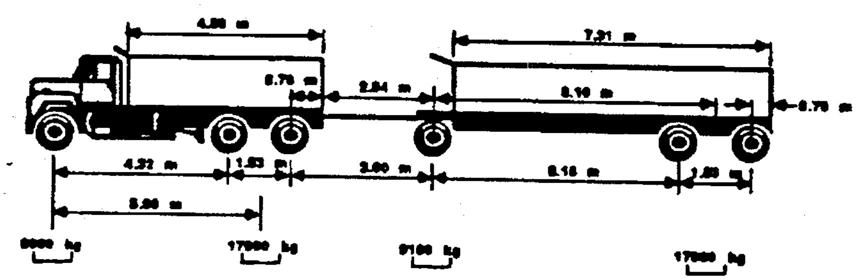


Figure 15/ Dimensions of Truck-Full Trailer
Configuration SD4I1D

Figure 3/ Dimensions of the truck-full trailer configurations

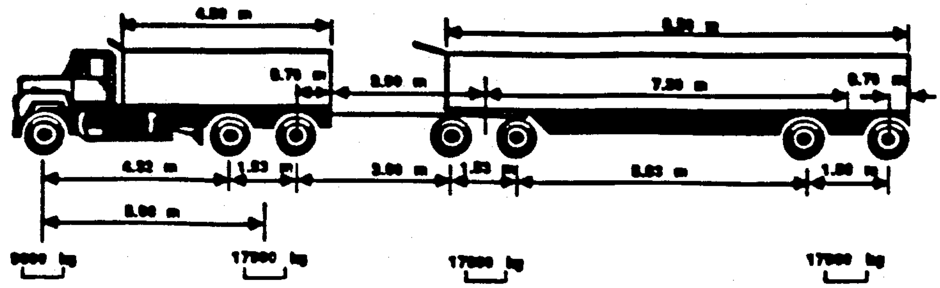


Figure 13/ Dimensions of Truck-Full Trailer Configuration SD4D1D

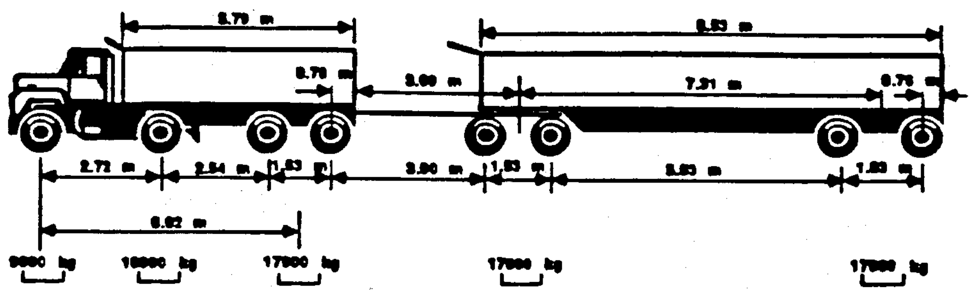


Figure 14/ Dimensions of Truck-Full Trailer Configuration SAD4D1D

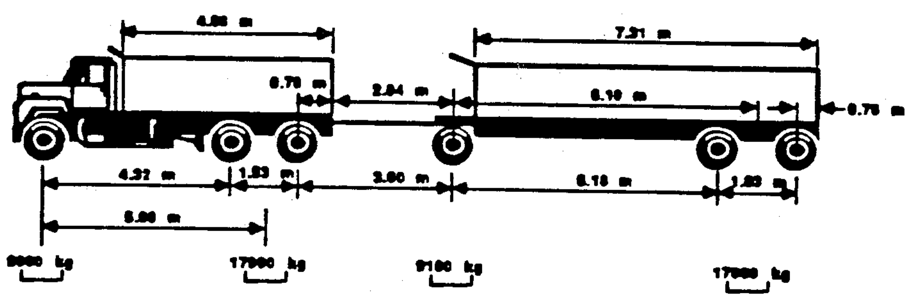
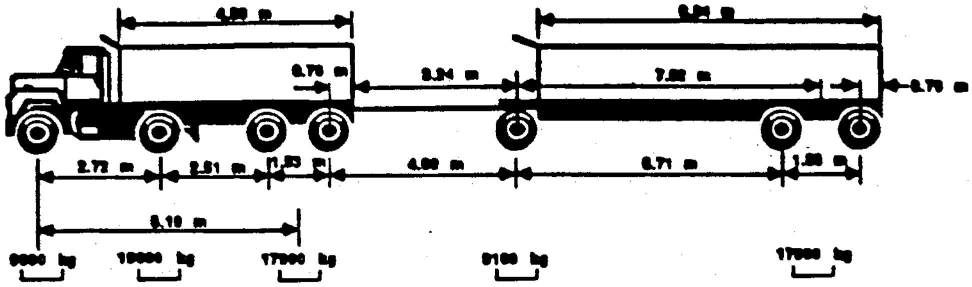
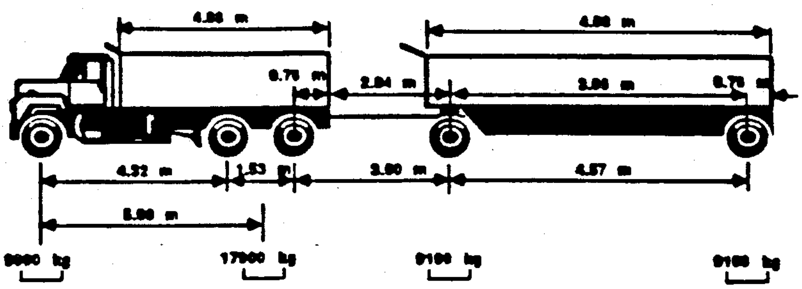


Figure 15/ Dimensions of Truck-Full Trailer Configuration SD4I1D

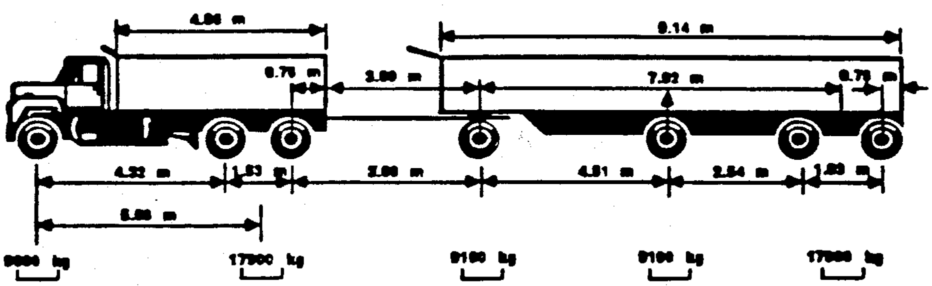
Figure 3/ Dimensions of the truck-full trailer configurations



Dimensions of Truck-Full Trailer
Configuration SAD4I1D

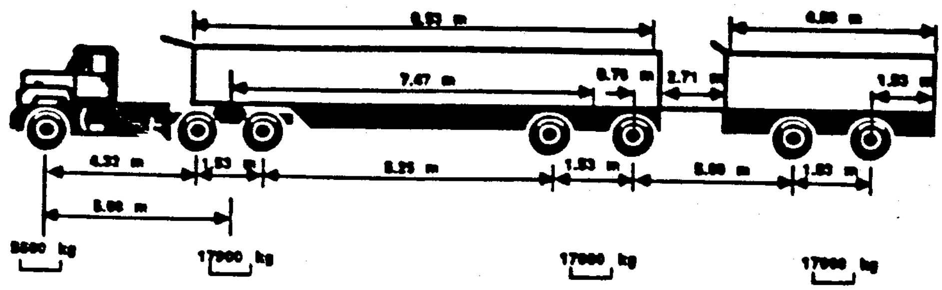


Dimensions of Truck-Full Trailer
Configuration SD4I1I

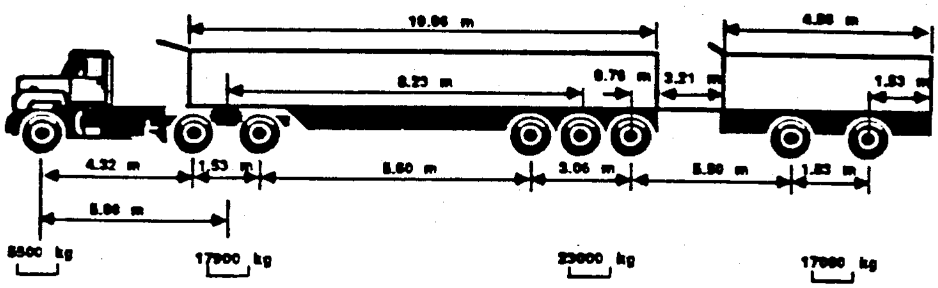


Dimensions of Truck-Full Trailer
Configuration SD4D1AD

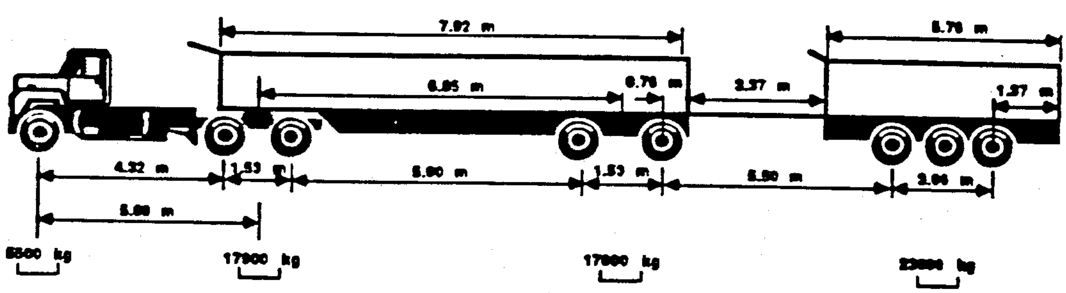
Figure 3/ Dimensions of the truck-full trailer configurations ....continued



Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1D4D

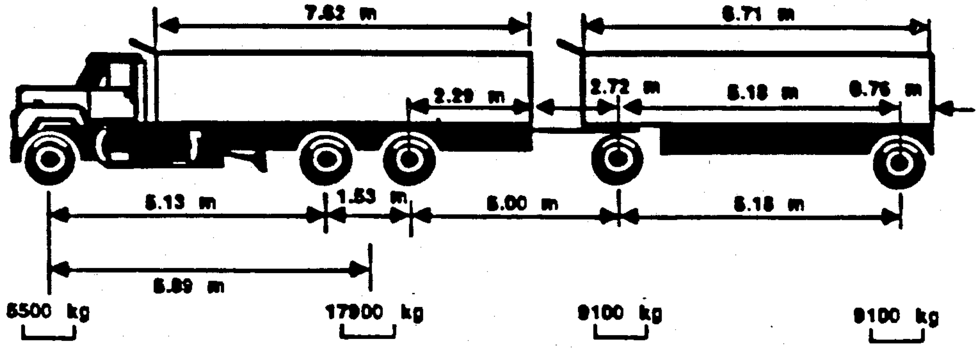


Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1M4D

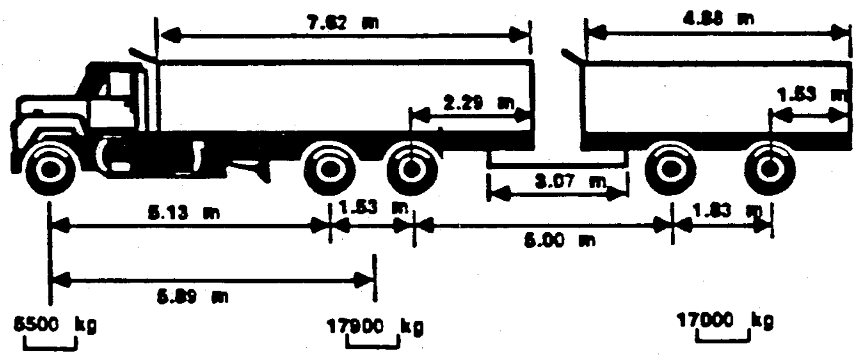


Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1D4M

Figure 4/ Dimensions of the tractor-semitrailer pony trailer configurations



Dimensions of Truck-Full Trailer Configuration SD4I1I and SD5I1I



Dimensions of Truck-Pony Trailer Configuration SD4D

Figure 5/ Dimensions of the light truck trailer configurations

APPENDIX A

Detailed Specifications of Vehicle Configurations

Configuration SD

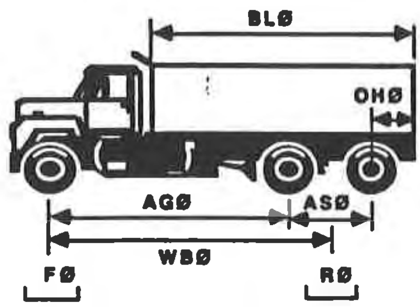


Figure 1/ Dimensions of 3-axle Straight-Truck Configuration SD

Baseline Specifications

Weights (kg)		Target Axle Load	
Truck Tare	9163	FO	9000
Payload	17645	RO	17900
GVW	26807		

Dimensions (m)

WBO	Wheelbase	5.08
AGO	Axle Separation	4.32
ASO	Tandem Spread	1.53
BLO	Box Length	4.88
OHO	Rear Overhang	0.76

Notes

1/ The baseline configuration SD has a tandem drive axle.

2/ Wheelbase of the truck will be increased from a low of 4.47 m to a high of 5.39 m, accompanied by a corresponding change in box length.

3/ Three rear tandem axle spreads, ranging from 1.22 to 1.83 m, will be examined with the baseline configuration.

4/ Three front axle loads will also be studied with the baseline vehicle by varying the payload distribution and the front tire type.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Truck Wheelbase (m)			
2.11 WBO = 4.47 (4.27 m box)	Y	Y	Y
2.12 WBO = 5.08 (4.88 m box)	Y*	Y	Y*
2.13 WBO = 5.38 (5.18 m box)	Y	Y	Y
3.00 Axle Spread (m)			
3.10 Rear Tandem			
3.11 ASO = 1.22	Y	Y	Y
3.12 ASO = 1.53	Y*	Y*	Y*
3.13 ASO = 1.83	Y	Y	Y
4.00 Front Axle Loading (kg)			
4.10 Front Axle Loading			
4.11 FO = 5500	Y	Y	Y
4.12 FO = 7000	Y	Y	Y
4.13 FO = 9000	Y*	Y*	Y*

Configuration SAD

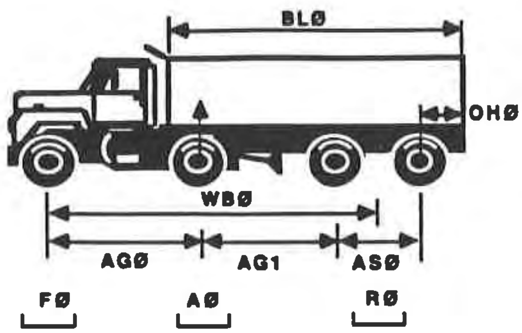


Figure 3/ Dimensions of 4-axle Straight-Truck Configuration SAD

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	10614	FO	9000
Payload	26172	AO	10000
GVW	36786	RO	17900

Dimensions (m)

WBO	Wheelbase	6.02
AGO	Axle Spacing	2.72
AG1	Axle Spacing	2.54
ASO	Tandem Spread	1.53
BLO	Box Length	5.79
OHO	Rear Overhang	0.76

Notes

1/ The pusher axle of configuration SAD is equipped with an air suspension.

2/ The location of the pusher axle will be varied between 2.29 to 3.05 m behind the front steering axle. The payload will be adjusted to achieve the maximum axle loads within reasonable distribution profile.

3/ Four different pusher axle arrangements will be examined:
 1/ an airlift axle in the down position;
 2/ an airlift axle in the up position;
 3/ a self-steering axle having nominal properties; and
 4/ a free castering self-steering axle.
 The fixed axle will be fitted with dual tires while the self-steering axles will be fitted with 18 inch single tires. No limitation will be imposed on the steer angle of the self-steering axles.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Axle Group Spacing (m)			
2.11 AG1 = 2.29	Y	Y	Y
2.12 AG1 = 2.72	Y*	Y*	Y*
2.13 AG1 = 3.05	Y	Y	Y
3.00 Pusher Axle Arrangement			
3.10 Pusher Axle			
3.11 Fixed	Y*	Y*	Y*
3.12 Airlift Up	Y	Y	Y
3.13 Self-steering	Y	Y	Y
3.14 Free-castering	Y	Y	Y

Configuration SDA

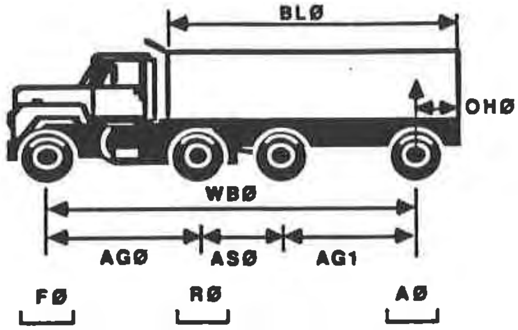


Figure 4/ Dimensions of 4-axle Straight-Truck Configuration SDA

Baseline Specifications

Weights (kg)

Truck Tare	10614
Payload	26081
GVW	36695

Target Axle Loads

F0	9000
R0	17900
A0	10000

Dimensions (m)

WB0	Wheelbase	6.79
AG0	Axle Spacing	2.72
AG1	Axle Spacing	2.54
AS0	Tandem Spread	1.53
BL0	Box Length	5.79
OH0	Rear Overhang	0.76

Notes

1/ The tag axle of configuration SDA is an airlift axle located behind the truck drive axle.

2/ By fixing the wheelbase of the vehicle, the location of the drive axle will be varied behind the front axle with an axle to axle spacing between 2.29 and 3.05 m. The payload distribution will be adjusted to maintain the proper loading at various axles within reasonable load profile.

3/ Four different tag axle arrangements will be examined:
1/ an airlift axle in the down position;
2/ an airlift axle in the up position;
3/ a self-steering axle having nominal properties; and
4/ a free castering self-steering axle.
The fixed axle will be fitted with dual tires while the self-steering axles will be fitted with 18 inch single tires. No limitation will be imposed on the steer angle of the self-steering axles.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Axle Group Spacing (m)			
2.11 AGO = 2.29	Y	Y	Y
2.12 AGO = 2.72	Y*	Y*	Y*
2.13 AGO = 3.05	Y	Y	Y
3.00 Axle Arrangement			
3.10 Axle #4			
3.11 Fixed	Y*	Y*	Y*
3.12 Airlift Up	Y	Y	Y
3.13 Self-steering	Y	Y	Y
3.14 Free-castering	Y	Y	Y

Configuration SM

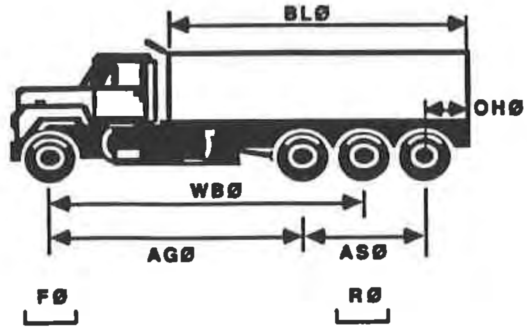


Figure 5/ Dimensions of 4-axle Straight-Truck Configuration SM

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	11000	FO	9000
Payload	20321	RO	23000
GVW	31320		

Dimensions (m)

WBO	Wheelbase	5.23
AGO	Axle Separation	3.70
ASO	Tridem Spread	3.06
BLO	Box Length	5.79
OHO	Rear Overhang	0.76

Notes

1/ The baseline configuration SM uses a tridem drive axle unit that is assumed to have a load sharing suspension.

2/ Wheelbase of the truck will be increased from 5.24 m to 5.84 m. Box location will be shifted to maintain a rear overhang of 0.76 m. Proper axle loads will be maintained by redistributing the payload.

3/ Three rear tridem axle spreads ranging from 2.44 to 3.67 m will be examined with the baseline configuration using a constant wheelbase. Payload distribution will be adjusted to maintain proper axle loads.

4/ Three front axle loads will also be studied with the baseline vehicle specified in 4.11 to 4.13.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Truck Wheelbase (m)			
2.11 WBO = 5.23 (5.79 m box)	Y*	Y*	Y*
2.12 WBO = 5.53 (6.09 m box)	Y	Y	Y
2.13 WBO = 5.84 (6.40 m box)	Y	Y	Y
3.00 Axle Spread (m)			
3.10 Rear Tridem			
3.11 ASO = 2.44	Y	Y	Y
3.12 ASO = 3.05	Y*	Y*	Y*
3.13 ASO = 3.67	Y	Y	Y
4.00 Axle Loading (kg)			
4.10 Front Axle Load			
4.11 FO = 5500	Y	Y	Y
4.12 FO = 7000	Y	Y	Y
4.13 FO = 9000	Y*	Y*	Y*

Configuration TD

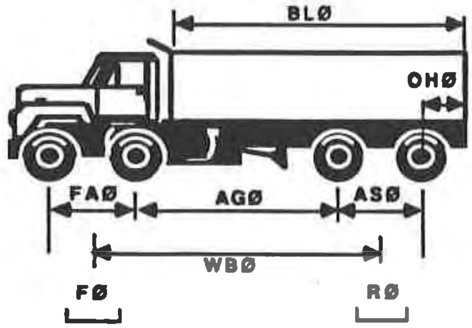


Figure 2/ Dimensions of 4-axle Straight-Truck Configuration TD

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	10727	FO	17000
Payload	24040	RO	17900
GVW	34767		

Dimensions (m)

WBO	Wheelbase	5.23
AGO	Axle Separation	3.70
FAO	Tandem Spread	1.53
ASO	Tandem Spread	1.53
BLO	Box Length	5.79
OHO	Rear Overhang	0.76

Notes

1/ The baseline configuration TD employs a twin steer front axle.

2/ Wheelbase of the truck will be increased from a low of 4.62 m to a high of 5.84 m.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Truck Wheelbase (m)			
2.11 WBO = 4.62 (5.18 m box)	Y	Y	Y
2.12 WBO = 5.23 (5.79 m box)	Y*	Y*	Y*
2.13 WBO = 5.84 (6.40 m box)	Y	Y	Y

Configuration TM

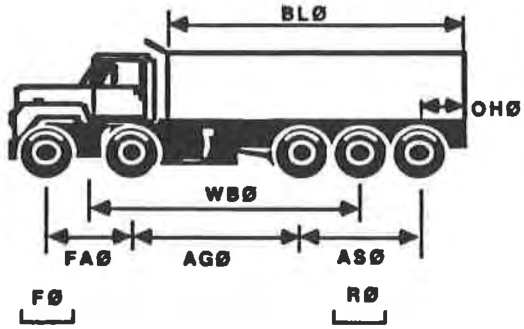


Figure 6/ Dimensions of 5-axle Straight-Truck Configuration TM

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	11861	FO	17000
Payload	27034	RO	23000
GVW	38895		

Dimensions (m)

WBO	Wheelbase	5.99
AGO	Axle Separation	3.70
FAO	Tandem Spread	1.53
ASO	Tridem Spread	3.06
BLO	Box Length	7.32
OHO	Rear Overhang	0.76

Notes

1 The baseline configuration TM represents another version of the twin steering heavy haul truck with a tridem drive axle.

2 Wheelbase of the truck will be increased from a low of 4.79 m to a high of 5.99 m by using a progressively longer box length.

3 Three different axle spacings at the drive axle will be examined with the baseline configuration as specified in 3.11 to 3.13.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Truck Wheelbase (m)			
2.11 WBO = 4.79 (6.10 m box)	Y	Y	Y
2.12 WBO = 5.38 (6.70 m box)	Y	Y	Y
2.13 WBO = 5.99 (7.32 m box)	Y*	Y*	Y*
3.00 Axle spacing (m)			
3.10 Tridem drive axle spacing			
3.11 AS1 = 2.40 (R1 = 21000 kg)	Y	Y	Y
3.12 AS1 = 3.06 (R1 = 23000 kg)	Y*	Y*	Y*
3.13 AS1 = 3.60 (R1 = 24000 kg)	Y	Y	Y

Configuration SD4D

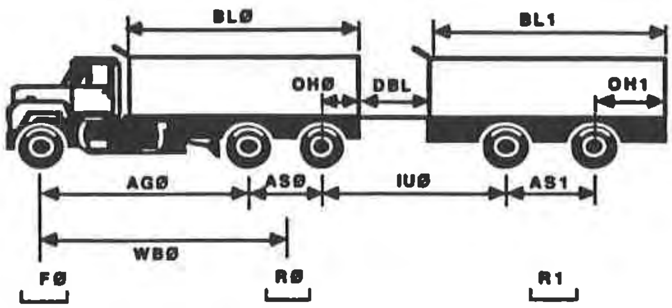


Figure 7/ Dimensions of Truck-Pony Trailer Configuration SD4D

Baseline Specifications

Weights (kg)

Truck Tare	14308
Payload	29612
GVW	43920

Target Axle Loads

FO	9000
RO	17900
R1	17000

Dimensions (m)

WBO	Wheelbase	5.08
AGO	Axle Separation	4.32
ASO	Tandem Spread	1.53
AS1	Tandem Spread	1.83
BLO	Box Length	4.88
IUO	Inter-vehicle distance	3.60
BL1	Box Length	4.88
OHO	Rear Overhang	0.76
OH1	Rear Overhang	1.53
DBL	Drawbar length	1.31

Notes

1/ The baseline configuration SD4D represents a typical three axle dump truck, configuration SD, towing a tandem axle pony trailer.

2/ Drawbar length of the pony trailer will be increased from the baseline value of 1.31 m to 3.71 m resulting in inter-axle spacings from 3.60 m to 6.00 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-axle spacing of 3.60 m as defined in 3.11 to 3.13 below. Hitch offset is zero when the hitch is located at the centre-line of the last axle group.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Pony drawbar length (m)			
2.11 DBL = 1.31 (IUO = 3.6 m)	Y*	Y*	Y*
2.12 DBL = 1.71 (IUO = 4.0 m)	Y	Y	Y
2.13 DBL = 2.71 (IUO = 5.0 m)	Y	Y	Y
2.14 DBL = 3.71 (IUO = 6.0 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/2.84	Y	Y	Y
3.12 HTH/DBL=0.76/2.08	Y	Y	Y
3.13 HTH/DBL=1.53/1.31	Y*	Y*	Y*

Configuration SAD4D

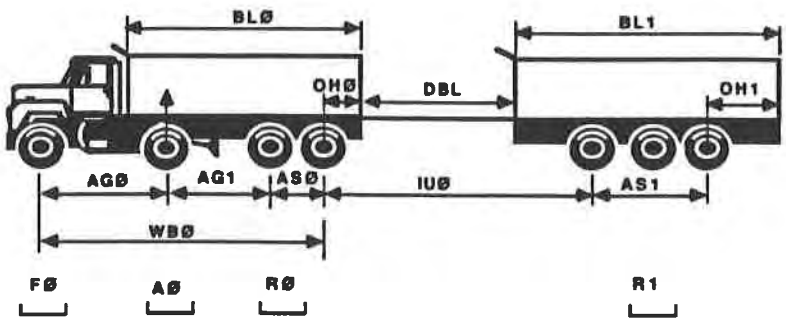


Figure 8/ Dimensions of Truck-Pony Trailer Configuration SAD4D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	15760	F0	9000
Payload	38139	A0	10000
		R0	17900
		R1	17000
GVW	53899		

Dimensions (m)

WB0	Wheelbase	6.02
AG0	Axle Separation	2.72
AG1	Axle Separation	2.54
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.83
BL0	Box Length	4.88
IU0	Inter-vehicle distance	5.63
BL1	Box Length	5.79
OH0	Rear Overhang	0.76
OH1	Rear Overhang	1.53
DBL	Drawbar length	3.34

Configuration SM4D

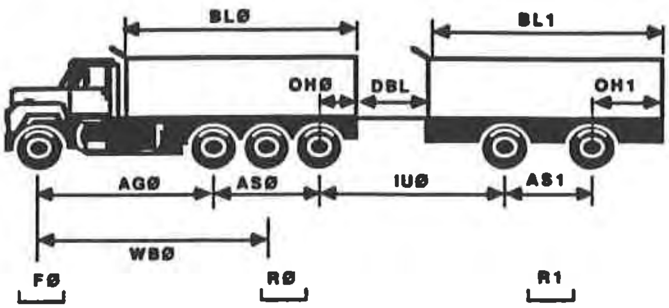


Figure 9/ Dimensions of Truck-Pony Trailer Configuration SM4D

Baseline Specifications

Weights (kg)

Truck Tare	16146
Payload	32288
GVW	48434

Target Axle Loads

F0	9000
R0	23000
R1	17000

Dimensions (m)

WB0	Wheelbase	5.26
AG0	Axle Separation	3.73
AS0	Tridem Spread	3.06
AS1	Tandem Spread	1.83
IU0	Inter-vehicle distance	3.60
BL0	Box Length	5.79
BL1	Box Length	4.88
OH0	Rear Overhang	0.76
OH1	Rear Overhang	1.53
DBL	Drawbar length	1.31

Notes

1/ The baseline configuration SAD4D consists of the four axle truck, configuration SAD, towing a tandem axle pony trailer. The pusher axle on the truck employs a self-steering axle.

2/ Drawbar length of the pony trailer will be increased from the baseline value of 3.34 m to 4.21 m resulting in inter-axle spacings from 5.63 m to 6.50 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-axle spacing of 5.63 m as defined in 3.11 to 3.13 below.

Parameter Variations	Performance Measures A'B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Pony drawbar length (m)			
2.11 DBL = 3.34 (IUO = 5.63 m)	Y*	Y*	Y*
2.12 DBL = 3.71 (IUO = 6.0 m)	Y	Y	Y
2.13 DBL = 4.21 (IUO = 6.5 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/4.87	Y	Y	Y
3.12 HTH/DBL=0.76/4.11	Y	Y	Y
3.13 HTH/DBL=1.53/3.34	Y*	Y*	Y*

Configuration SD4AD

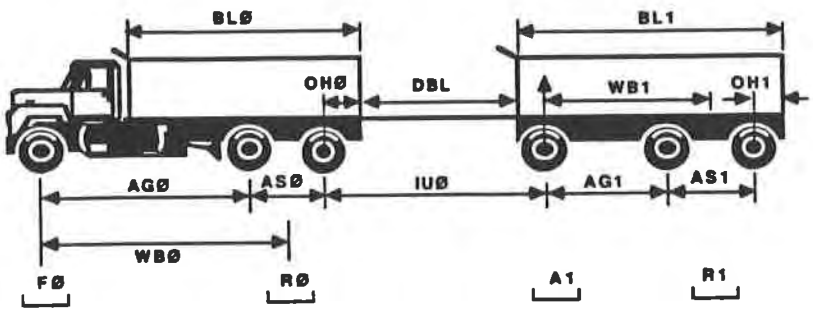


Figure 10/ Dimensions of Truck-Pony Trailer Configuration SD4AD

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	14821	FO	9000
Payload	37407	RO	17900
		A1	9100
		R1	17000
GVW	52228		

Dimensions (m)

WBO	Wheelbase	5.08
WB1	Wheelbase	3.46
ASO	Tandem Spread	1.53
AS1	Tandem Spread	1.83
AGO	Axle Separation	4.32
AG1	Axle Separation	2.54
IUO	Inter-vehicle distance	3.78
BLO	Box Length	4.88
BL1	Box Length	5.79
OHO	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.36

Notes

1/ The baseline configuration SM4D has a four axle dump truck, configuration SM, towing a tandem axle pony trailer. The pony trailer is attached to the truck by a single pintle connection through a rigid drawbar that is fixed to the frame of the pony trailer.

2/ Drawbar length of the pony trailer will be increased from the baseline value of 1.31 m to 3.71 m resulting in inter-vehicle unit distance between 3.60 m and 6.00 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.60 m as defined in 3.11 to 3.13 below.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Pony drawbar length (m)			
2.11 DBL = 1.31 (IUO = 3.6 m)	Y*	Y*	Y*
2.12 DBL = 1.71 (IUO = 4.0 m)	Y	Y	Y
2.13 DBL = 2.71 (IUO = 5.0 m)	Y	Y	Y
2.14 DBL = 3.71 (IUO = 6.0 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/3.50	Y	Y	Y
3.12 HTH/DBL=1.53/1.97	Y	Y	Y
3.13 HTH/DBL=2.29/1.31	Y*	Y*	Y*

Notes

1/ The baseline configuration SD4AD represents a typical three axle dump truck towing a pony trailer that is supported by an air spring axle in the front and a tandem axle at the rear. The pony trailer is attached to the back of the truck by a single pintle connection through a rigid drawbar that is attached to the frame of the trailer.

2/ Drawbar length of the pony trailer will be increased from a low of 2.36 m to a high of 4.58 m resulting in inter-vehicle unit distance between 3.78 m and 6.00 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.78 m as defined in 3.11 to 3.13 below.

4/ Three different axle arrangements will be examined for the front axle of the pony trailer :
1/ an airlift axle in the down position;
2/ a self-steering axle having nominal properties; and
3/ a free castering self-steering axle.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Length			
2.10 Pony drawbar length (m)			
2.11 DBL = 2.36 (IUO = 3.78 m)	Y*	Y*	Y*
2.12 DBL = 3.08 (IUO = 4.5 m)	Y	Y	Y
2.13 DBL = 3.58 (IUO = 5.0 m)	Y	Y	Y
2.14 DBL = 4.58 (IUO = 6.0 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/4.54	Y	Y	Y
3.12 HTH/DBL=0.76/3.78	Y	Y	Y
3.13 HTH/DBL=1.53/3.01	Y*	Y*	Y*
4.00 Axle type			
4.10 Axle #4			
4.11 Fixed axle	Y*	Y*	Y*
4.12 Self-steering axle	Y	Y	Y
4.13 Free castering axle	Y	Y	Y

Configuration SD4M

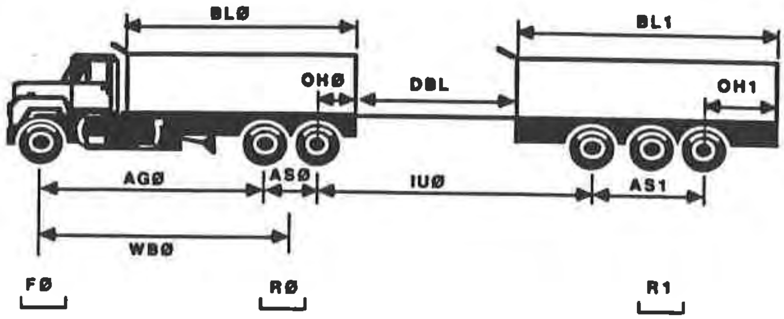


Figure 11/Dimensions of Truck-Pony Trailer Configuration SD4M

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	15381	F0	9000
Payload	34452	R0	17900
		R1	23000
GVW	49833		

Dimensions (m)

WB0	Wheelbase	5.08
AG0	Axle Separation	4.32
AS0	Tandem Spread	1.53
AS1	Tandem Spread	3.06
IU0	Inter-vehicle distance	3.60
BL0	Box Length	4.88
BL1	Box Length	5.79
OH0	Rear Overhang	0.76
OH1	Rear Overhang	1.37
DBL	Drawbar length	1.47

Notes

1/ The baseline configuration SD4M represents a three axle dump truck towing a tridem axle pony trailer. A single pintle connection is used to attach the trailer to the truck through a rigid drawbar that is fixed to the trailer frame.

2/ Three tridem axle spacing will be examined for the pony trailer ranging from 2.44 m to 3.67 m.

3/ Drawbar length of the pony trailer will be increased from the baseline value of 1.48 m to 4.38 m resulting in inter-vehicle unit distance between 3.60 m and 6.50 m.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Axle spacing (m)			
2.10 Tridem axle			
2.11 AS1=2.44 R1=21000	Y	Y	Y
2.12 AS1=3.06 R1=23000	Y*	Y*	Y*
2.13 AS1=3.67 R1=24000	Y	Y	Y
3.00 Length			
3.10 Pony drawbar length (m)			
3.11 DBL = 1.48 (IUO = 3.6 m)	Y*	Y*	Y*
3.12 DBL = 2.38 (IUO = 4.5 m)	Y	Y	Y
3.13 DBL = 3.38 (IUO = 5.5 m)	Y	Y	Y
3.14 DBL = 4.38 (IUO = 6.5 m)	Y	Y	Y

Configuration SM4M

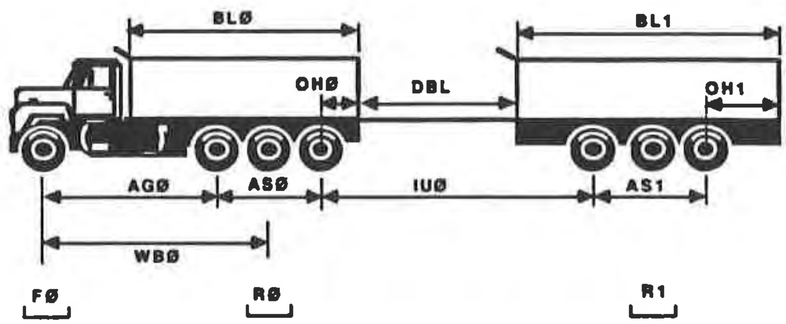


Figure 12/Dimensions of Truck-Pony Trailer Configuration SM4M

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	17421	F0	9000
Payload	37129	R0	23000
		R1	23000
GVW	54550		

Dimensions (m)

WB0	Wheelbase	5.23
AG0	Axle Separation	3.70
IU0	Inter-vehicle distance	5.50
AS0	Tandem Spread	3.06
AS1	Tandem Spread	3.06
BL0	Box Length	5.79
BL1	Box Length	5.79
OH0	Rear Overhang	0.76
OH1	Rear Overhang	1.37
DBL	Drawbar length	3.38

Notes

1/ The baseline configuration SM4M consists of a four axle dump truck, configuration SM, with a tridem drive axle towing a tridem axle pony trailer.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y

Configuration SD4D1D

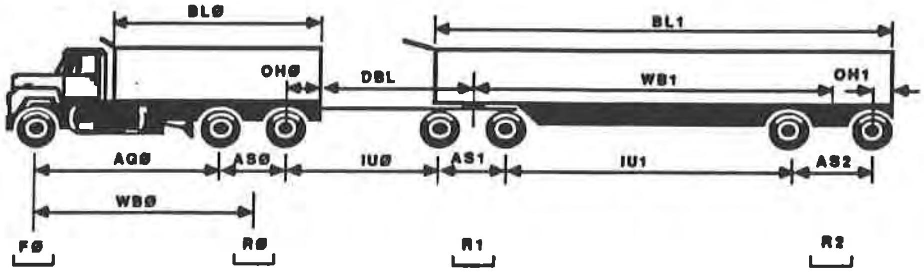


Figure 13/Dimensions of Truck-Full Trailer Configuration SD4D1D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	17191	F0	9000
Payload	43617	R0	17900
		R1	17000
		R2	17000
GVW	60808		

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	6.68
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.53
AS2	Tandem Spread	1.83
AG0	Axle Separation	4.32
IU0	Inter-vehicle distance	3.60
IU1	Inter-vehicle distance	5.00
BL0	Box Length	4.88
BL1	Box Length	9.12
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	3.60

Notes

1/ The baseline configuration SD4D1D consists of a three axle truck, configuration SD, towing a full trailer which is composed of a tandem axle A-converter dolly and a tandem axle semitrailer.

2/ Drawbar length of the A-converter dolly will be increased from the baseline 3.6 m to a high of 5.5 m resulting in inter-vehicle unit distance between 3.6 and 5.5 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.60 m as defined in 4.11 to 4.13 below.

4/ Trailer lengths of 8.54, 9.14 and 10.06 m will be used.

Parameter Variations		Performance Measures A B H	C D E	F G
1.00 Reference Vehicle		Y	Y	Y
2.00 Drawbar length				
2.10 Dolly drawbar length (m)				
2.11 DBL = 3.60	(IU0 = 3.6 m)	Y*	Y*	Y*
2.12 DBL = 4.00	(IU0 = 4.0 m)	Y	Y	Y
2.13 DBL = 5.00	(IU0 = 5.0 m)	Y	Y	Y
2.14 DBL = 5.50	(IU0 = 5.5 m)	Y	Y	Y
3.00 Hitch offset(m)				
3.10 Hitch/Drawbar				
3.11 HTH/DBL=0.00/5.13		Y	Y	Y
3.12 HTH/DBL=0.76/4.36		Y	Y	Y
3.13 HTH/DBL=1.53/3.60		Y*	Y*	Y*
4.00 Trailer length				
4.10 Semitrailer length (m)				
4.11 BL1 = 8.54	(IU1 = 4.4 m)	Y	Y	Y
4.12 BL1 = 9.12	(IU1 = 5.0 m)	Y*	Y*	Y*
4.13 BL1 = 10.06	(IU1 = 5.94 m)	Y	Y	Y

Configuration SAD4D1D

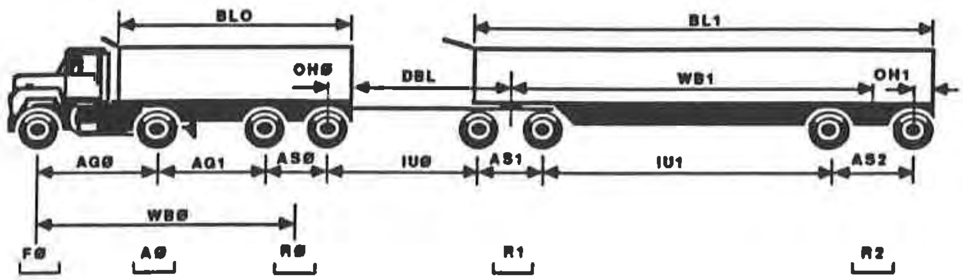


Figure 14/Dimensions of Truck-Full Trailer Configuration SAD4D1D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	18642	F0	9000
Payload	44744	A0	10000
		R0	17900
		R1	13300
		R2	13300
GVW	63386		

Dimensions (m)

WB0	Wheelbase	6.02
WB1	Wheelbase	6.70
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.53
AS2	Tandem Spread	1.83
AG0	Axle Separation	2.72
AG1	Axle Separation	2.54
IU0	Inter Unit Dist	3.60
IU1	Inter Unit Dist	5.02
BL0	Box Length	5.79
BL1	Box Length	9.14
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	3.60

Notes

1/ The baseline configuration SAD4D1D consists of the four axle truck, configuration SAD, towing a full trailer which is composed of tandem axle A-converter dolly and a tandem axle semitrailer. A self-steering axle will be used at the pusher axle location of the truck.

2/ Drawbar length of the A-converter dolly will be increased from the baseline 3.6 m to a high of 5.5 m resulting in inter-vehicle unit distance between 3.6 and 5.5 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.60 m as defined in 4.11 to 4.13 below.

4/ Trailer lengths of 8.54, 9.14 and 10.06 m will be used.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 3.60 (IU0 = 3.6 m)	Y*	Y*	Y*
2.12 DBL = 4.00 (IU0 = 4.0 m)	Y	Y	Y
2.13 DBL = 5.00 (IU0 = 5.0 m)	Y	Y	Y
2.14 DBL = 5.50 (IU0 = 5.5 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/5.13	Y	Y	Y
3.12 HTH/DBL=0.76/4.36	Y	Y	Y
3.13 HTH/DBL=1.53/3.60	Y*	Y*	Y*
4.00 Trailer length			
4.10 Semitrailer length (m)			
4.11 BL1 = 8.54 (IU1 = 5.63 m)	Y	Y	Y
4.12 BL1 = 9.14 (IU1 = 6.23 m)	Y*	Y*	Y*
4.13 BL1 = 10.06 (IU1 = 7.15 m)	Y	Y	Y

Configuration SD4I1D

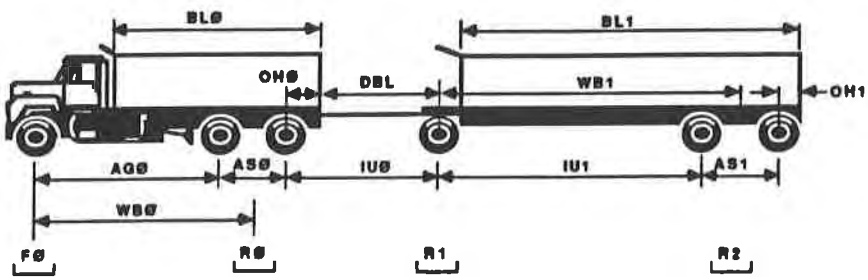


Figure 15/ Dimensions of Truck-Full Trailer Configuration SD4I1D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	15503	F0	9000
Payload	37404	R0	17900
		R1	9100
		R2	17000
GVW	52907		

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	6.10
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.83
AG0	Axle Separation	4.32
IU0	Inter-vehicle distance	3.60
IU1	Inter-vehicle distance	5.18
BL0	Box Length	4.88
BL1	Box Length	7.31
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.84

Notes

1/ The baseline configuration SD4I1D consists of a three axle truck, configuration SD, towing a full trailer that is composed of a single axle A-converter dolly and a tandem axle semitrailer.

2/ Drawbar length of the A-converter dolly will be increased from the baseline 2.35 m to a high of 3.35 m resulting in inter-vehicle unit distance between 3.6 and 4.0 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.60 m as defined in 4.11 to 4.13 below.

4/ Trailer length will be varied between 7.01 m and 8.23 m.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 2.35 (IU0 = 3.1 m)	Y	Y	Y
2.12 DBL = 2.85 (IU0 = 3.6 m)	Y*	Y*	Y*
2.13 DBL = 3.35 (IU0 = 4.1 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/4.35	Y	Y	Y
3.12 HTH/DBL=0.76/3.60	Y	Y	Y
3.13 HTH/DBL=1.53/2.84	Y*	Y*	Y*
4.00 Trailer length			
4.10 Semitrailer length (m)			
4.11 BL1 = 7.01 (IU1 = 5.79 m)	Y	Y	Y
4.12 BL1 = 7.31 (IU1 = 6.09 m)	Y*	Y*	Y*
4.13 BL1 = 8.23 (IU1 = 7.01 m)	Y	Y	Y

Configuration SAD4I1D

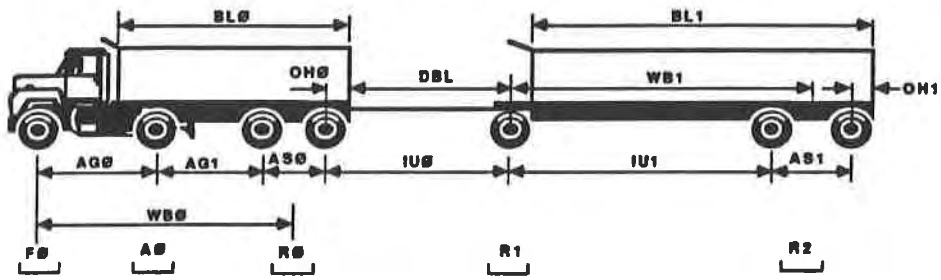


Figure 16/Dimensions of Truck-Full Trailer Configuration SAD4I1D

Baseline Specifications

Weights (kg)

Truck Tare	17930
Payload	44956
GVW	62886

Target Axle Loads

FO	9000
AO	10000
RO	17900
R1	9100
R2	17000

Dimensions (m)

WBO	Wheelbase	6.02
WB1	Wheelbase	7.62
ASO	Tandem Spread	1.53
AS1	Tandem Spread	1.83
AGO	Axle Separation	2.72
AG1	Axle Separation	2.54
IUO	Inter-vehicle distance	4.00
IU1	Inter-vehicle distance	6.71
BLO	Box Length	4.88
BL1	Box Length	8.84
OHO	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	3.24

Notes

1/ The baseline configuration SAD4I1D consists of the four axle truck, configuration SAD, towing a full trailer that is composed of a single axle A-converter dolly and a tandem axle semitrailer.

2/ Drawbar length of the A-converter dolly will be increased from the baseline 2.85 m to a high of 3.75 m resulting in inter-vehicle unit distance between 3.6 and 4.5 m.

3/ Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 4.00 m as defined in 4.11 to 4.13 below.

4/ Trailer length will be varied between 8.23 m and 9.45 m.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 2.85 (IU0 = 3.6 m)	Y	Y	Y
2.12 DBL = 3.25 (IU0 = 4.0 m)	Y*	Y*	Y*
2.13 DBL = 3.75 (IU0 = 4.5 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/4.76	Y	Y	Y
3.12 HTH/DBL=0.76/4.00	Y	Y	Y
3.13 HTH/DBL=1.53/3.23	Y*	Y*	Y*
4.00 Trailer length			
4.10 Semitrailer length (m)			
4.11 BL1 = 8.23 (IU1 = 6.10 m)	Y	Y	Y
4.12 BL1 = 8.84 (IU1 = 6.71 m)	Y*	Y*	Y*
4.13 BL1 = 9.45 (IU1 = 7.32 m)	Y	Y	Y

Configuration SD4I1I

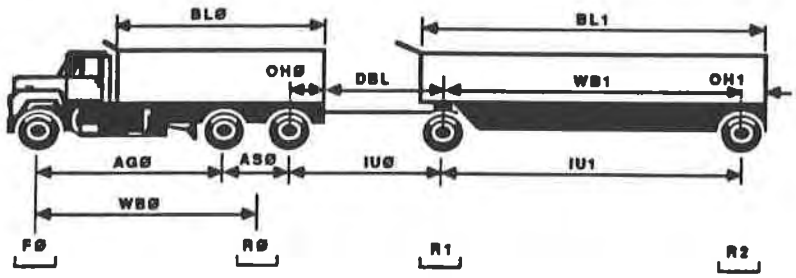


Figure 17/ Dimensions of Truck-Full Trailer Configuration SD4I1I

Baseline Specifications

Weights (kg)		**Target Axle Loads**	
Truck Tare	13522	F0	9000
Payload	31485	R0	17900
GVW	45007	R1	9100
		R2	9100

<u>Truck Dimensions (m)</u>

WB0	Wheelbase	5.08
WB1	Wheelbase	3.65
AS0	Tandem Spread	1.53
AG0	Axle Separation	4.32
IU0	Inter-vehicle distance	3.60
IU1	Inter-vehicle distance	3.65
BL0	Box Length	4.88
BL1	Box Length	5.18
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.84

Notes

1 The baseline configuration SD4I1I consists of a three axle truck, configuration SD, towing a full trailer which is composed of a single axle A-converter dolly and a single axle semitrailer.

2 Drawbar length of the A-converter dolly will be increased from the low of 2.34 m to a high of 4.24 m resulting in inter-vehicle unit distance between 3.1 and 5.0 m.

3 Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 3.60 m as defined in 4.11 to 4.13 below.

4 Trailer length will be varied between 5.18 m and 6.10 m.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 2.34 (IU0 = 3.1 m)	Y	Y	Y
2.12 DBL = 2.84 (IU0 = 3.6 m)	Y*	Y*	Y*
2.13 DBL = 3.34 (IU0 = 4.1 m)	Y	Y	Y
2.14 DBL = 4.24 (IU0 = 5.0 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/4.36	Y	Y	Y
3.12 HTH/DBL=0.76/3.60	Y	Y	Y
3.13 HTH/DBL=1.53/2.84	Y*	Y*	Y*
4.00 Trailer length			
4.10 Semitrailer length (m)			
4.11 BL1 = 5.18 (IU1 = 4.87 m)	Y*	Y*	Y*
4.12 BL1 = 5.49 (IU1 = 5.18 m)	Y	Y	Y
4.13 BL1 = 5.79 (IU1 = 5.49 m)	Y	Y	Y
4.14 BL1 = 6.10 (IU1 = 5.79 m)	Y	Y	Y

Configuration SD4I1AD

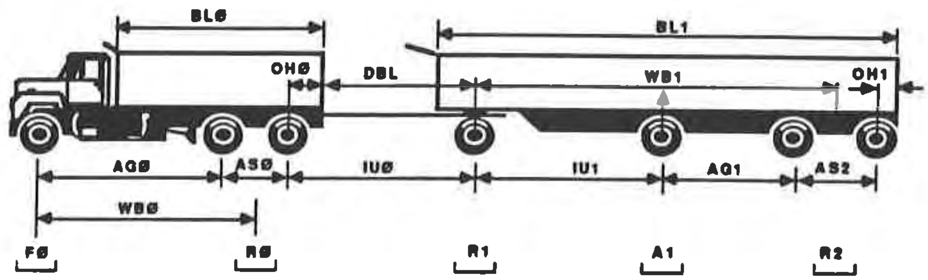


Figure 18/Dimensions of Truck-Full Trailer Configuration SD4D1AD

Baseline Specifications

Weights (kg)

Truck Tare	17648
Payload	44361
GVW	62009

Target Axle Loads

F0	9000
R0	17900
R1	9100
A1	9100
R2	17000

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	7.92
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.83
AG0	Axle Separation	4.32
IU0	Inter-vehicle distance	3.60
IU1	Inter-vehicle distance	4.51
AG1	Axle Separation	2.50
BL0	Box Length	4.38
BL1	Box Length	9.14
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.84

Notes

1/ The baseline configuration SD4D1AD consists of the three axle truck, configuration SD, towing a full trailer which is composed of a single axle A-converter dolly and a semitrailer with a belly axle and a tandem axle.

2/ Four different belly axle arrangements will be examined:
1/ an airlift axle in the down position;
2/ an airlift axle in the up position;
3/ a self-steering axle having nominal properties; and
4/ a free castering self-steering axle.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Axle type			
2.10 Pusher axle location			
2.11 Fixed airlift axle down	Y*	Y*	Y*
2.12 Airlift axle up	Y	Y	Y
2.13 Self-steering axle	Y	Y	Y
2.14 Free-castering axle	Y	Y	Y

Configuration SD1D4D

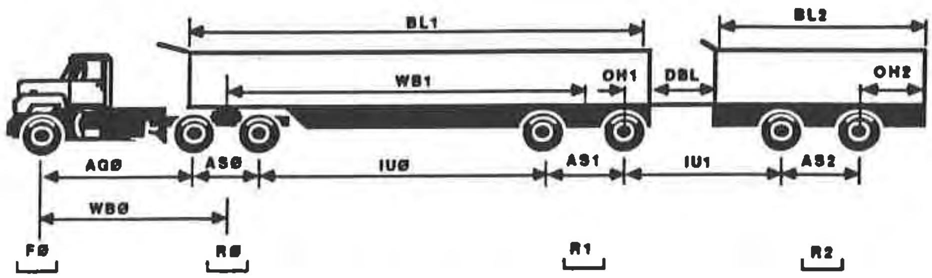


Figure 19/ Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1D4D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	19426	F0	5500
Payload	38049	R0	17900
GVW	57475	R1	17000
		R2	17000

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	7.47
AG0	Axle Separation	4.32
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.53
AS2	Tandem Spread	1.83
IU0	Inter-vehicle distance	5.26
IU1	Inter-vehicle distance	5.00
BL1	Box Length	8.53
BL2	Box Length	4.88
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
OH2	Rear Overhang	1.53
DBL	Drawbar length	2.71

Notes

1 The baseline configuration SD1D4D consists of a three axle tractor towing a tandem axle semitrailer towing a tandem axle pony trailer.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y

Configuration SD1M4D

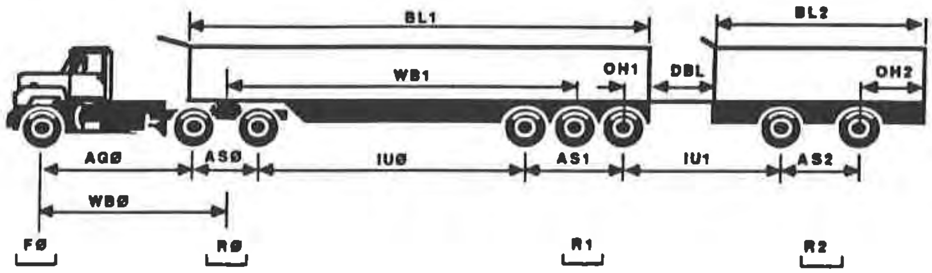


Figure 20/ Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1M4D

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	21785	F0	5500
Payload	41677	R0	17900
GVW	63462	R1	23000
		R2	17000

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	8.23
AS0	Tandem Spread	1.53
AS1	Tandem Spread	3.06
AS2	Tandem Spread	1.83
AG0	Axle Separation	4.32
IU0	Inter Unit Dist	5.56
IU1	Inter Unit Dist	5.50
BL1	Box Length	10.06
BL2	Box Length	4.88
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
OH2	Rear Overhang	1.53
DBL	Drawbar length	3.21

Notes

1 The baseline configuration SD1M4D consists of a three axle tractor towing a tridem axle semitrailer towing a tandem axle pony trailer.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y

Configuration SD1D4M

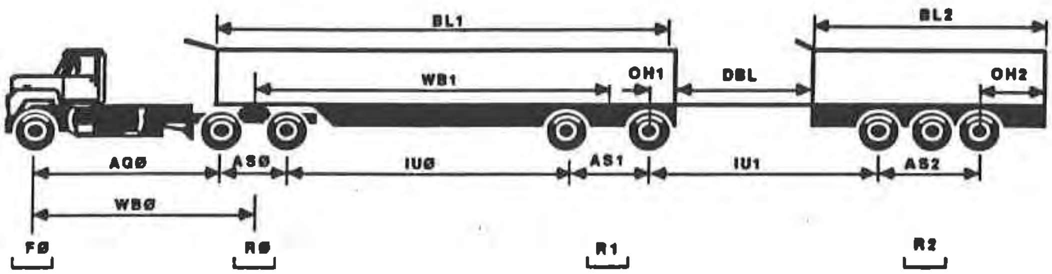


Figure 21/ Dimensions of Truck-Semitrailer - Pony Trailer Configuration SD1D4M

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	20224	F0	5500
Payload	43280	R0	17900
GVW	63504	R1	17000
		R2	23000

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	7.47
AS0	Tandem Spread	1.53
AS1	Tandem Spread	1.53
AS2	Tridem Spread	3.06
AG0	Axle Separation	4.32
IU0	Inter Unit Dist.	5.26
IU1	Inter Unit Dist.	5.50
BL1	Box Length	8.53
BL2	Box Length	5.79
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
OH2	Rear Overhang	1.37
DBL	Drawbar length	3.37

Notes

1/ The baseline SD1D4M configuration consists of a three axle tractor towing a tandem axle semitrailer towing a tridem axle pony trailer.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y

Configuration SD4I1I (VAN)

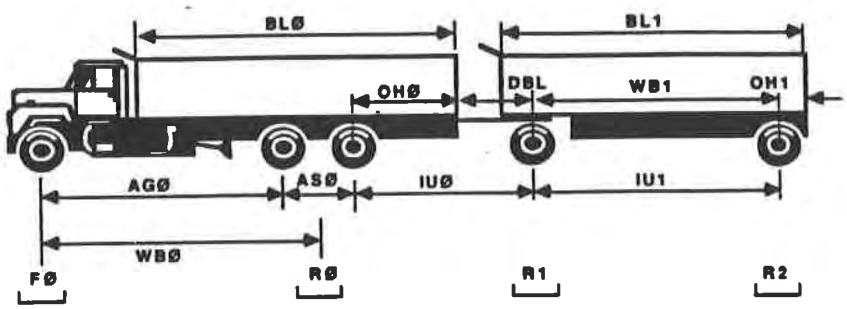


Figure 22/Dimensions of Truck-Full Trailer Configuration SD4I1I and SD5I1I

Baseline Specifications

Weights (kg)

Truck Tare	14798
Payload	26732
GVW	41530

Target Axle Loads

FO	5500
RO	17900
R1	9100
R2	9100

Dimensions (m)

WBO	Wheelbase	5.89
WB1	Wheelbase	5.18
ASO	Tandem Spread	1.53
AGO	Axle Separation	5.13
IUO	Inter Unit Dist	5.00
IU1	Inter Unit Dist	5.18
BLO	Box Length	7.62
BL1	Box Length	6.71
OHO	Rear Overhang	2.29
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.72

Notes

1/ The baseline configuration SD4I1I consists of a three axle van type truck towing a full trailer which is composed of a single axle A-converter dolly and a single axle van type semitrailer.

2 Drawbar length of the A-converter dolly will be increased from the baseline of 2.22 m to 3.22 m resulting in an inter-vehicle unit distance between 4.5 and 5.5 m.

3 Several hitch offset positions will also be investigated based on the baseline inter-vehicle unit distance of 5.00 m as defined in 3.11 to 3.13 below.

Parameter Variations	Performance Measures A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 2.22 (IUO = 4.5 m)	Y	Y	Y
2.12 DBL = 2.72 (IUO = 5.0 m)	Y*	Y*	Y*
2.13 DBL = 3.22 (IUO = 5.5 m)	Y	Y	Y
3.00 Hitch offset(m)			
3.10 Hitch/Drawbar			
3.11 HTH/DBL=0.00/5.76	Y	Y	Y
3.12 HTH/DBL=1.53/4.23	Y	Y	Y
3.13 HTH/DBL=3.05/2.71	Y*	Y*	Y*

Configuration SD5I1I (VAN)

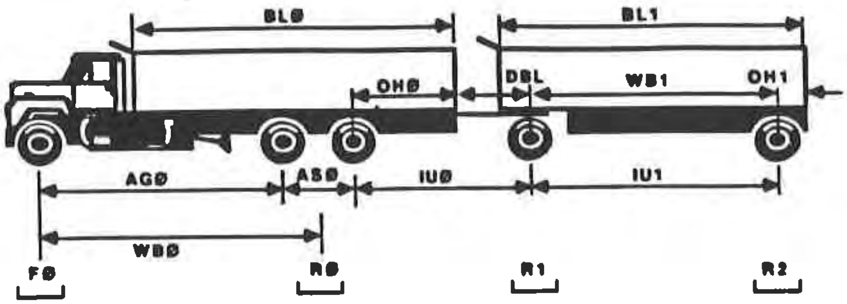


Figure 22/Dimensions of Truck-Full Trailer Configuration SD4I1I and SD5I1I

Baseline Specifications

Weights (kg)		Target Axle Loads	
Truck Tare	14866	F0	5500
Payload	26732	R0	17900
GVW	41598	R1	9100
		R2	9100

Dimensions (m)

WB0	Wheelbase	5.89
WB1	Wheelbase	5.18
AS0	Tandem Spread	1.53
AG0	Axle Separation	4.42
IU0	Inter-vehicle distance	5.00
IU1	Inter-vehicle distance	5.18
BL0	Box Length	7.62
BL1	Box Length	6.71
OH0	Rear Overhang	2.29
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.72

Notes

1/ The baseline configuration SD5I1I consists of a three axle van type truck towing a full trailer which is composed of a single axle C-converter dolly and a single axle van type semitrailer.

2/ Drawbar length of the C-converter dolly will be increase from the baseline of 2.22 m to 3.22 m resulting in an inter-vehicle unit distance between 4.5 and 5.5 m.

3/ Two arrangements will be considered for the dolly axle :
1/ a self-steering axle having nominal properties; and
2/ a free castering self-steering axle.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Dolly drawbar length (m)			
2.11 DBL = 2.22 (IUO = 4.5 m)	Y	Y	Y
2.12 DBL = 2.72 (IUO = 5.0 m)	Y*	Y*	Y*
2.13 DBL = 3.22 (IUO = 5.5 m)	Y	Y	Y
3.00 Axle type			
3.10 Dolly axle location			
3.11 Self-steering axle	Y*	Y*	Y*
3.12 Free-castering axle	Y	Y	Y

Configuration SD45CI

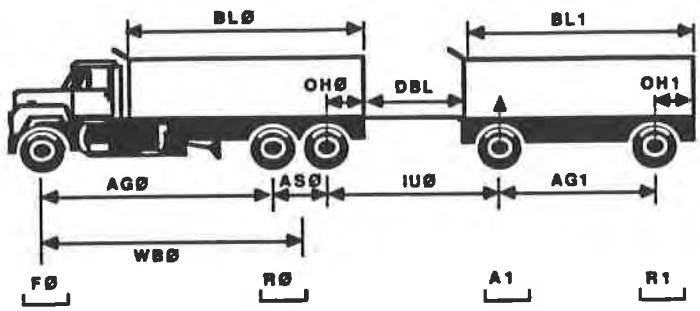


Figure 23/ Dimensions of Truck-Full Trailer Configuration SD45CI

Baseline Specifications

Weights (kg)

Truck Tare	14322
Payload	30787
GVW	45109

Target Axle Loads

F0	9000
R0	17900
R1	9100
R2	9100

Dimensions (m)

WB0	Wheelbase	5.08
WB1	Wheelbase	3.35
AS0	Tandem Spread	1.53
AG0	Axle Separation	4.32
IU0	Inter Unit Dist.	3.60
BL0	Box Length	4.88
BL1	Box Length	4.88
OH0	Rear Overhang	0.76
OH1	Rear Overhang	0.76
DBL	Drawbar length	2.07

Notes

1/ The baseline configuration SD45CI consists of a three axle dump truck, configuration SD, towing a full trailer which is supported by a single axle at both end. The trailer is attached to the truck by a rigid drawbar assembly that employs a single pintle connection at the truck end and a double pintle connection at the trailer end. The purpose of this drawbar arrangement is to minimize stress in the drawbar and to prevent load transfer between the truck and the trailer when it is moving on an undulating terrain with significant drop in height.

2/ Length of the rigid drawbar will be increased from 1.47 m to 2.47 m resulting in an inter-vehicle unit distance between 3.0 to 4.0 m.

3/ Three axle arrangements will be considered at the front axle of the trailer: a fixed axle; a self-steering axle similar to the Ceschi self-steering axle; and a free-castering axle.

Parameter Variations	**Performance Measures** A B H	C D E	F G
1.00 Reference Vehicle	Y	Y	Y
2.00 Drawbar length			
2.10 Drawbar length (m)			
2.11 DBL = 1.47 (IUO =3.0 m)	Y	Y	Y
2.12 DBL = 2.07 (IUO =3.6 m)	Y*	Y*	Y*
2.13 DBL = 2.47 (IUO =4.0 m)	Y	Y	Y
3.00 Axle type			
3.10 Axle #4			
3.11 Fixed axle	Y	Y	Y
3.12 Self-steering axle	Y*	Y*	Y*
3.13 Free-castering axle	Y	Y	Y

Table 2/ Performance measures of the straight truck configurations in the high speed circular turn.

config	type	rollover	undercf	tr offtr(m)
TD	BASE	0.324	-0.031	0.291
TM	BASE	0.364	-0.006	0.290
SAD	BASE	0.416	0.019	0.302
SDA	BASE	0.441	-0.024	0.466
SD	BASE	0.445	0.002	0.232
SM	BASE	0.463	0.034	0.242

Table 3/ Performance measures of the straight truck configurations in the high speed lane change.

config	type	ltr	tr offtr(m)
SD	BASE	0.492	0.273
SM	BASE	0.455	0.280
TM	BASE	0.544	0.286
TD	BASE	0.646	0.295
SAD	BASE	0.541	0.387
SDA	BASE	0.563	0.566

Table 4/ Performance measures of the straight truck configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
SD	BASE	4.093	0.979
TD	BASE	4.167	1.354
SAD	BASE	5.474	1.263
SDA	BASE	6.154	0.543
SM	BASE	8.645	1.148
TM	BASE	8.742	1.476

Table 5/ Performance measures of the truck-pony trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr (m)
SD4D	BASE	0.441	-0.007	0.394
SM4D	BASE	0.471	0.022	0.403
SD4M	BASE	0.437	0.027	0.448
SM4M	BASE	0.468	0.019	0.475
SAD4D	BASE	0.42	-0.010	0.514
SD4D	BASE	0.431	-0.044	0.521
SD4AD	BASE	0.424	-0.042	0.525

Table 6/ Performance measures of the truck-pony trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SM4M	BASE	0.662	1.758	0.735
SD4AD	BASE	0.654	1.962	0.899
SD4D	BASE	0.862	2.041	0.974
SAD4D	BASE	0.746	2.133	0.886
SD4D	BASE	0.831	2.266	0.790
SM4D	BASE	0.833	2.299	0.803
SD4M	BASE	0.993	2.790	1.124

Table 7/ Performance measures of the truck-pony trailer configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
SD4D	BASE	6.772	1.814
SD4D	BASE	6.776	1.277
SAD4D	BASE	6.928	2.270
SD4AD	BASE	7.943	2.045
SD4M	BASE	9.275	1.254
SM4D	BASE	9.882	1.331
SM4M	BASE	10.107	2.742

Table 8/ Performance measures of the truck-full trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr (m)
DSD4I1I	BASE	0.442	-0.001	0.449
SD45CI	BASE	0.432	-0.042	0.512
SD4I1D	BASE	0.439	-0.001	0.514
SD4D1D	BASE	0.438	-0.007	0.556
SD4I1AD	BASE	0.447	-0.001	0.565
SAD4D1D	BASE	0.416	0.004	0.596
SAD4I1D	BASE	0.419	0.014	0.629
VSD4I1I	BASE	0.442	-0.038	0.642
SD5I1I	BASE	0.554	0.110	0.820

Table 9/ Performance measures of the truck-full trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SD5I1I	BASE	0.455	2.062	0.761
DSD4I1I	BASE	0.763	2.230	0.865
SD45CI	BASE	0.652	1.967	0.881
SD4I1D	BASE	0.704	1.966	0.931
SAD4D1D	BASE	0.694	1.908	0.989
SD4D1D	BASE	0.733	1.833	1.019
SAD4I1D	BASE	0.689	1.897	1.060
SD4I1AD	BASE	0.708	1.942	1.069
VSD4I1I	BASE	0.843	1.972	1.303

Table 10/ Performance measures of the truck-full trailer configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
DSD4I1I	BASE	4.098	1.688
SD45CI	BASE	5.998	2.078
SD5I1I	BASE	11.001	2.268
VSD4I1I	BASE	4.277	2.354
SD4I1D	BASE	4.116	2.494
SD4I1AD	BASE	4.147	2.856
SD4D1D	BASE	6.227	3.038
SAD4D1D	BASE	7.017	3.274
SAD4I1D	BASE	5.539	3.444

Table 11/ Performance measures of the tractor-semitrailer pony trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr(m)
SD1D4D	BASE	0.662	-0.025	0.536
SD1M4D	BASE	0.641	-0.018	0.551
SD1D4M	BASE	0.599	-0.022	0.554

Table 12/ Performance measures of the tractor-semitrailer pony trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SD1D4D	BASE	0.734	2.475	0.948
SD1M4D	BASE	0.715	2.343	0.953
SD1D4M	BASE	0.729	2.410	1.020

Table 13/ Performance measures of the tractor-semitrailer pony trailer configurations in the los speed right hand turn.

config	type	fridmd	ls offtr(m)
SD1D4D	BASE	0.032	3.572
SD1M4D	BASE	0.109	4.047
SD1D4M	BASE	0.023	3.692

Table 5/ Performance measures of the truck-pony trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr (m)
SD4D	BASE	0.441	-0.007	0.394
SM4D	BASE	0.471	0.022	0.403
SD4M	BASE	0.437	0.027	0.448
SM4M	BASE	0.468	0.019	0.475
SAD4D	BASE	0.42	-0.010	0.514
SD4D	BASE	0.431	-0.044	0.521
SD4AD	BASE	0.424	-0.042	0.525

Table 6/ Performance measures of the truck-pony trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SM4M	BASE	0.662	1.758	0.738
SD4AD	BASE	0.654	1.962	0.899
SD4D	BASE	0.862	2.041	0.974
SAD4D	BASE	0.746	2.133	0.886
SD4D	BASE	0.831	2.266	0.790
SM4D	BASE	0.833	2.299	0.803
SD4M	BASE	0.993	2.790	1.124

Table 7/ Performance measures of the truck-pony trailer configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
SD4D	BASE	6.772	1.814
SD4D	BASE	6.776	1.277
SAD4D	BASE	6.928	2.270
SD4AD	BASE	7.943	2.045
SD4M	BASE	9.275	1.254
SM4D	BASE	9.882	1.331
SM4M	BASE	10.107	2.742

Table 8/ Performance measures of the truck-full trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr (m)
DSD4I1I	BASE	0.442	-0.001	0.449
SD45CI	BASE	0.432	-0.042	0.512
SD4I1D	BASE	0.439	-0.001	0.514
SD4D1D	BASE	0.438	-0.007	0.556
SD4I1AD	BASE	0.447	-0.001	0.565
SAD4D1D	BASE	0.416	0.004	0.596
SAD4I1D	BASE	0.419	0.014	0.629
VSD4I1I	BASE	0.442	-0.038	0.642
SD5I1I	BASE	0.554	0.110	0.820

Table 9/ Performance measures of the truck-full trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SD5I1I	BASE	0.455	2.062	0.761
DSD4I1I	BASE	0.763	2.230	0.865
SD45CI	BASE	0.652	1.967	0.881
SD4I1D	BASE	0.704	1.966	0.931
SAD4D1D	BASE	0.694	1.908	0.989
SD4D1D	BASE	0.733	1.833	1.019
SAD4I1D	BASE	0.689	1.897	1.060
SD4I1AD	BASE	0.708	1.942	1.069
VSD4I1I	BASE	0.843	1.972	1.303

Table 10/ Performance measures of the truck-full trailer configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
DSD4I1I	BASE	4.098	1.688
SD45CI	BASE	5.998	2.078
SD5I1I	BASE	11.001	2.268
VSD4I1I	BASE	4.277	2.354
SD4I1D	BASE	4.116	2.494
SD4I1AD	BASE	4.147	2.856
SD4D1D	BASE	6.227	3.038
SAD4D1D	BASE	7.017	3.274
SAD4I1D	BASE	5.539	3.444

Table 11/ Performance measures of the tractor-semitrailer pony -trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr(m)
SD1D4D	BASE	0.662	-0.025	0.536
SD1M4D	BASE	0.641	-0.018	0.551
SD1D4M	BASE	0.599	-0.022	0.554

Table 12/ Performance measures of the tractor-semitrailer pony trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SD1D4D	BASE	0.734	2.475	0.948
SD1M4D	BASE	0.715	2.343	0.953
SD1D4M	BASE	0.729	2.410	1.020

Table 13/ Performance measures of the tractor-semitrailer pony trailer configurations in the los speed right hand turn.

config	type	fridmd	ls offtr(m)
SD1D4D	BASE	0.032	3.572
SD1M4D	BASE	0.109	4.047
SD1D4M	BASE	0.023	3.692

Table 8/ Performance measures of the truck-full trailer configurations in the high speed circular turn.

config	type	rollover	undercf	hs offtr (m)
DSD4I1I	BASE	0.442	-0.001	0.449
SD45CI	BASE	0.432	-0.042	0.512
SD4I1D	BASE	0.439	-0.001	0.514
SD4D1D	BASE	0.438	-0.007	0.556
SD4I1AD	BASE	0.447	-0.001	0.565
SAD4D1D	BASE	0.416	0.004	0.596
SAD4I1D	BASE	0.419	0.014	0.629
VSD4I1I	BASE	0.442	-0.038	0.642
SD5I1I	BASE	0.554	0.110	0.820

Table 9/ Performance measures of the truck-full trailer configurations in the high speed lane change.

config	type	ltr	ramp	tr offtr(m)
SD5I1I	BASE	0.455	2.062	0.761
DSD4I1I	BASE	0.763	2.230	0.865
SD45CI	BASE	0.652	1.967	0.881
SD4I1D	BASE	0.704	1.966	0.931
SAD4D1D	BASE	0.694	1.908	0.989
SD4D1D	BASE	0.733	1.833	1.019
SAD4I1D	BASE	0.689	1.897	1.060
SD4I1AD	BASE	0.708	1.942	1.069
VSD4I1I	BASE	0.843	1.972	1.303

Table 10/ Performance measures of the truck-full trailer configurations in the low speed right hand turn

config	type	fridmd	ls offtr(m)
DSD4I1I	BASE	4.098	1.688
SD45CI	BASE	5.998	2.078
SD5I1I	BASE	11.001	2.268
VSD4I1I	BASE	4.277	2.354
SD4I1D	BASE	4.116	2.494
SD4I1AD	BASE	4.147	2.856
SD4D1D	BASE	6.227	3.038
SAD4D1D	BASE	7.017	3.274
SAD4I1D	BASE	5.539	3.444