

RECOMMENDED CHANGES IN FUTURE DESIGN VEHICLES FOR PURPOSES OF GEOMETRIC DESIGN OF U.S. HIGHWAYS AND STREETS

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ABSTRACT

The physical characteristics and proportions of vehicles of various sizes that use the highway represent a key control in highway geometric design. Nineteen specific design vehicles are presented in the 2004 edition of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets*, commonly known as the *Green Book*, to represent classes or categories of vehicles. Many highway agencies throughout the U.S. use the *Green Book* as their primary policy to guide the geometric design of their roadways. A design vehicle is not intended to represent an average or typical vehicle in its class but, rather, is intended to have larger physical dimensions and a larger minimum turning radius than most vehicles in its class. Thus, geometric design of the roadway to accommodate a specific design vehicle should accommodate most vehicles in the same class as the design vehicle, as well as nearly all vehicles in classes composed of smaller vehicles. This paper provides a brief review the design vehicles in the 2004 *Green Book* and recommends changes to the design vehicles for consideration in future editions of the *Green Book*. The reasons for these recommended changes are discussed. Recommended changes relate to single-unit trucks, single-trailer combinations, double-trailer trucks, and triple-trailer trucks.

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1 OVERVIEW OF DESIGN VEHICLES

The physical characteristics and proportions of vehicles of various sizes that use the highway represent a key control in highway geometric design. Specific design vehicles are presented in the *Green Book* (AASHTO, 2004) to represent categories of vehicles. A design vehicle is not intended to represent a typical vehicle in its class but, rather, is intended to have larger physical dimensions and a larger minimum turning radius than most vehicles in its class. Thus, geometric design of the roadway to accommodate a specific design vehicle should accommodate most vehicles in the same class as the design vehicle, as well as nearly all vehicles in classes composed of smaller vehicles. This paper reviews the design vehicles in the 2004 *Green Book* and recommends changes to the design vehicles for consideration in future editions. For more details on these recommendations, see *NCRHP Report 505: Review of Truck Characteristics as Factors in Roadway Design* (Harwood et al., 2003).

The 2004 *Green Book* presents design vehicle dimensions and turning radii for 19 design vehicles, including eight trucks. The appropriateness for the current and future truck fleet of each of the truck design vehicles are discussed below. In addition, other classes of trucks that may merit inclusion are discussed.

The *Green Book* does not specify which design vehicle should be selected for the design of any specific highway project. This is, and should be, a choice left to the designer who is familiar with local highway and traffic conditions. However, the *Green Book* does provide some general guidelines to designers on the appropriate selection of design vehicles.

2 FUTURE CHANGES TO THE U.S. TRUCK FLEET

This research was charged with assessing the effect on geometric design of both current and future truck populations. The current truck population was assessed using existing data sources such as the 1997 Vehicle Inventory and Use Survey (VIUS) and through field data collection. Future truck populations, however, are not known and can only be hypothesized. The factors that are reasonable to consider in hypothesizing future truck populations are: (1) the current truck population; (2) current trends in the truck population; and (3) the likelihood of specific future changes in truck size and weight laws or regulations. The 1982 Surface Transportation Assistance Act (STAA) required all states to permit trucks with single 14.6-m [48-ft] trailers and twin 8.7-m [28.5-ft] trailers to operate on the National Truck Network. Since

1982, combination trucks with single 16.2-m [53-ft] trailers have become common on the National Network (NN) in many states, and a few states permit combinations with trailers as long as 18.1 m [59.5 ft]. There has been some recent interest in Congress in eliminating trailers longer than 16.2 m [53 ft].

Many states, particularly in the West, allow Longer Combination Vehicles (LCVs) to operate, often under permit. LCVs include double combinations with trailers longer than 8.7 m [28.5 ft], B-train doubles (i.e., double combinations connected with a B-dolly), Rocky Mountain doubles (i.e., combinations with two trailers of unequal length), turnpike doubles (i.e., combinations of two long trailers), and triple-trailer combinations. LCVs are used primarily by segments of the trucking industry that haul bulky, low-density freight. The ability of states to permit new LCV operations has been frozen by Congress (i.e., limited to operations that were legal prior to the early 1990s), but LCV volumes are growing where they are permitted and could grow more if the Congressional freeze were ended.

The economics of the trucking industry strongly influence the demand for highway agencies to permit larger and heavier trucks to operate. Serious consideration has been given in recent years to allowing an increase in truck loads, without increase in axle loads, by adding more axles and spacing the axles differently to minimize potential impacts on structures and pavements.

TRB Special Report 267 *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles* (TRB, 2002) recommended that Federal law be changed to allow two specific truck types to operate under state permits:

- Six-axle tractor semitrailers with a maximum weight of 35,400 kg [90,000 lb]
- Double-trailer configurations with each trailer up to 10.1 m [33 ft] long; with seven, eight, or nine axles; and with a weight governed by the present federal bridge formula

The North American Free Trade Agreement (NAFTA) is likely to result in increased volumes of trucks entering the U.S. from Canada and Mexico, but NAFTA does not change the limits imposed by existing U.S. truck size and weight regulations.

3 SINGLE-UNIT TRUCKS

The current single-unit (SU) truck design vehicle is a 2-axle truck with an overall length of 9.2 m [30 ft] and a turning radius of 12.8 m [42 ft]. There is concern that this design vehicle is not representative of larger SU trucks. Based primarily on 1997 VIUS data, the vast majority of SU trucks on the road are 2-axle trucks, but the truck population also includes a substantial number of 3- and 4-axle SU trucks. Based on the number of 3- and 4-axle SU trucks and the vehicle miles traveled (VMT) by these trucks, a 3-axle SU design vehicle with a wheelbase of 7.6 m [25.0 ft] is recommended for inclusion in the *Green Book*, in addition to the current 2-axle SU design vehicle. Figure 1 illustrates the dimensions of this recommended design vehicle.

4 SINGLE-TRAILER COMBINATIONS

The 2004 *Green Book* includes four single-trailer combination design vehicles:

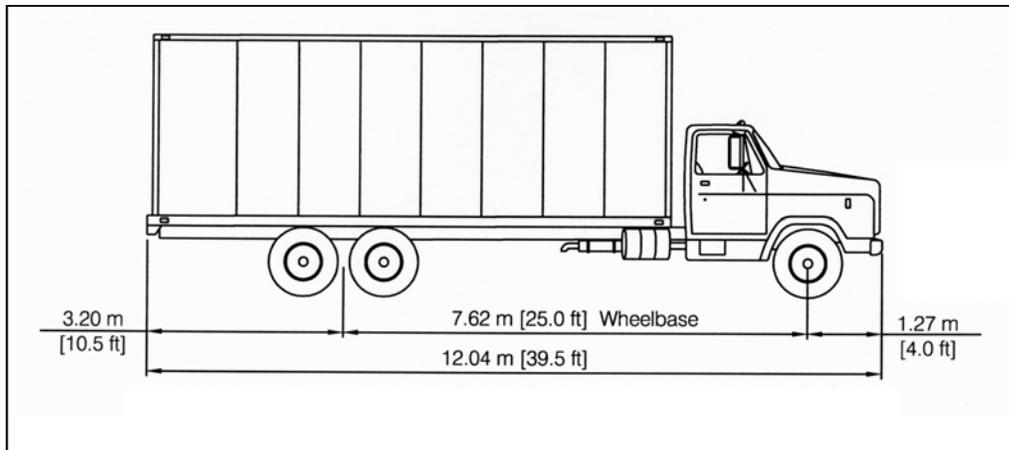


Figure 1. Dimensions of 3-axle single-unit (SU-8 [SU-25]) design vehicle.

- WB-12 [WB-40] design vehicle with a 10.1-m [33-ft] trailer
- WB-15 [WB-50] design vehicle with a 13.0-m [42.5-ft] trailer
- WB-19 [WB-62] design vehicle with a 14.6-m [48-ft] trailer
- WB-20 [WB-65 or WB-67] design vehicle with a 16.2-m [53-ft] trailer

The WB-12 [WB-40] and WB-15 [WB-50] are rarely seen today on highways, with some exceptions discussed below. The *Green Book* states that these design vehicles may be appropriate for design of local roads and streets. We would caution that this is only true if the locations under consideration *do not* serve the larger and more common combinations with 14.6-m [48-ft] and 16.2-m [53-ft] trailers.

Another use for the WB-12 [WB-40] design vehicle, although with a trailer other than a van, is as a container-carrying vehicle. These trailers are similar to flat-bed trailers, but are designed for carrying containers commonly loaded on ships and trains. We recommend that the WB-12 [WB-40] design vehicle be retained. The *Green Book* should state that this design vehicle is appropriate for local streets not used by larger tractor-semitrailers and for access roads to ports and train yards where container traffic might predominate.

The WB-15 [WB-50] design vehicle has a 13.0-m [42.5-ft] trailer. This trailer size, or similar trailers with lengths of 12.2 m [40 ft] or 13.7 m [45 ft], was quite common prior to the 1982 STAA. However, since the 1982 STAA mandated that states allow 14.6-m [48-ft] trailers on the NN, trailers in the 12.2 m [40 ft] to 13.7 m [45 ft] range have largely disappeared. Trucks in the length range of the WB-15 [WB-50] truck constitute only 8 percent of the population of single-semitrailer combination trucks. By contrast, single-semitrailer combination trucks with trailer lengths of 13.7 m [45 ft] or more, typically represented in design by either the WB-19 [WB-62] or a larger design vehicle, constitute over 65 percent of the single-semitrailer truck population. Since the situations in which the WB-15 [WB-50] is an appropriate design vehicle are very limited, it is recommended that this design vehicle be eliminated from the *Green Book*.

The WB-19 [WB-62] design vehicle was, at one time, nearly the largest tractor-semitrailer on the highway. The WB-20 [WB-65 or WB-67] with a 16.2-m [53-ft] trailer is now perhaps more common than the 14.6-m [48-ft] trailer. Consideration might be given to dropping the WB-

19 [WB-62] design vehicle since it has become less common, but we recommend that it be retained because it represents a vehicle size limit specified in Federal law to be allowed to operate anywhere on the NN, and it represents very closely the offtracking performance of longer trucks with their rear axles pulled forward to meet state kingpin to center of rear tandem (KCRT) distance requirements. The current WB-19 [WB-62] design vehicle has a KCRT distance of 12.3 m [40.5 ft]. The most common KCRT distance is 12.5 m [41 ft] because 19 states limit the KCRT distance to about 12.5 m [41 ft]. Therefore, it is recommended that the WB-19 [WB-62] design vehicle can be modified slightly in the next edition of the *Green Book* to incorporate this 12.5 m [41 ft] dimension. The revised WB-19 [WB-62] design vehicle is illustrated in Figure 2.

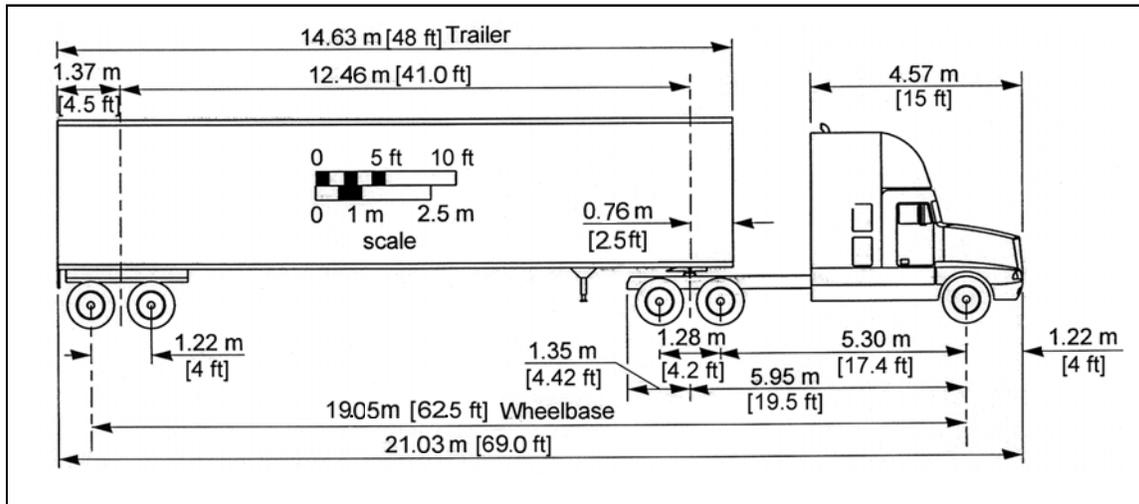


Figure 2. Recommended revisions to WB-19 [WB-62] design vehicle.

The WB-20 [WB-65] design vehicle can operate in most states on the NN and state routes. VIUS data indicate 22.4 percent of veh-mi by trucks are single semitrailers with lengths of 16.2 m [53 ft] or more. However, field data indicate that trucks with 16.2-m [53-ft] trailers constitute approximately 47 percent of all combination trucks. A principal reason why 16.2-m [53-ft] trailers are so common is that a significant number of loaded trucks do not weigh 80,000 lb. Trucks carrying low density cargo often “cube out” (i.e., their volume becomes filled) before they “gross out” (i.e., reach the gross vehicle weight limit).

The 2004 *Green Book* includes a design vehicle very similar to the WB-20 [WB-65], known as the WB-20 [WB-67]. The WB-20 [WB-67] design vehicle is identical to the WB-20 [WB-65] except that the rear tandem axle of the WB-20 [WB-67] is positioned closer to the rear of the truck. There is no good reason for both of these vehicles to be included in the *Green Book*, since they are merely variations of one another. It makes most sense to include the WB-20 [WB-67] design vehicle because it has a greater turning radius, greater offtracking, and greater swept path width than the WB-20 [WB-65]. While we recommend inclusion of the WB-20 [WB-67] design vehicle in the *Green Book*, this design vehicle will not be applied widely because 19 states limit the KCRT distance to a maximum of about 12.5 m [41 ft]. If a designer is considering the offtracking and swept path of a tractor-semitrailer combination truck with a 16.2-m [53-ft] trailer with the axles moved forward to maintain a 12.5-m [41-ft] KCRT distance, the WB-19 [WB-62] design vehicle should be used. The offtracking and swept path width of the WB-20 [WB-67]

design vehicle with its axles pulled forward is identical to the offtracking and swept path width of the revised WB-19 [WB-62].

Eight states permit trucks with trailer lengths greater than 16.2 m [53 ft] to operate on the NN. However, even in these states, trucks with trailer lengths greater than 16.2 m [53 ft] were found to be very rare. Thus, inclusion in the *Green Book* of a design vehicle with a trailer length greater than 16.2 m [53 ft] is not recommended at the present time. However, an appropriate design vehicle has been developed for future consideration should the number and proportion of trucks with trailers greater than 16.2 m [53 ft] in length increase. This design vehicle for possible future use is designated as the WB-22 [WB-71] design vehicle and is illustrated in Figure 3. This vehicle represents an incremental increase in size compared to the WB-20 [WB-65] and WB-20 [WB-67]. The WB-22 [WB-71] design vehicle has a 17.4-m [57-ft] trailer and a KCRT distance of 15.1 m [49.5 ft] and will offtrack substantially more than the other tractor-semitrailer design vehicles. However, many trucks with 17.4-m [57-ft] trailers operate with maximum 12.5-m [41-ft] KCRT distances to meet state limitations. The offtracking and swept path width of the WB-22 [WB-71] design vehicle with the axles pulled forward can be considered in design using the WB-19 [WB-62] design vehicle.

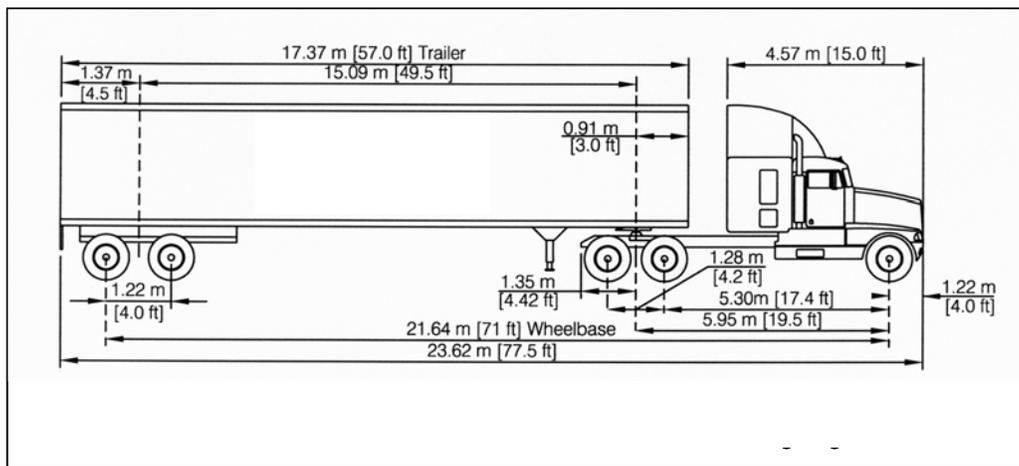


Figure 3. Dimensions of WB-22 [WB-71] design vehicle for possible future use.

It is possible that a future change in Federal law may allow states to issue permits for operation of 6-axle tractor-semitrailers with maximum weights up to 35,400 kg [90,000 lb]. Six-axle tractor-semitrailers can operate legally now. However, within current gross vehicle weight and axle limits, there is no particular advantage to using a 6-axle combination rather than a 5-axle combination. Six-axle tractor-semitrailers are likely to come into common use only if Federal law were to permit 6-axle trucks to carry greater loads than 5-axle trucks. Such a change in Federal law has been recently recommended in TRB Special Report 267 (TRB, 2002). A 6-axle tractor-semitrailer would have a single tractor steering axle, a tandem tractor drive axle, and a tridem (triple) axle at the rear of the trailer. While such a vehicle would be an important factor in pavement and bridge design, it would have little effect on geometric design because 6-axle tractor-semitrailers actually offtrack about 5 percent less than comparable 5-axle tractor-semitrailers (Elefteriadou et al., 1997). Therefore, the possible wider use of 6-axle tractor-semitrailer trucks does not constitute a reason to add a new *Green Book* design vehicle.

5 DOUBLE-TRAILER TRUCKS

5.1 Tractor/semitrailer/full trailer combinations

The *Green Book* includes two double-trailer trucks as design vehicles:

- WB-20D [WB-67D] with “twin” 8.7-m [28.5-ft] trailers
- WB-33D [WB-109D] with two 14.6-m [48-ft] trailers (i.e., a turnpike double)

The WB-20D [WB-67D] “twin trailer” truck has been permitted to operate freely on the NN since 1982 and has become a very common truck on intercity roads. The circumstances in which the WB-20D [WB-67D] would be appropriate as a design vehicle are probably quite limited because it has less offtracking and swept path width than the WB-19 [WB-62] and WB-20 [WB-65 and WB-67] tractor-semitrailers that are more numerous and generally travel the same roads. However, we recommend that the WB-20D [WB-67D] be retained as a design vehicle in the *Green Book* because it represents a maximum vehicle size limit specified in Federal law.

If the current LCV freeze were lifted, one vehicle that might possibly be legalized is a “twin trailer” truck with two 10.1-m [33-ft] trailers. TRB Special Report 267 (TRB, 2002) recommended that Federal law be changed to allow such trucks to operate under state permits. We do not recommend that a design vehicle based with two 10.1-m [33-ft] trailers be included in the *Green Book* at this time, but an appropriate design vehicle has been developed for future consideration should such trucks be permitted and become common in the future. This design vehicle for possible future use is designated the WB-23D [WB-77D] and is illustrated in Figure 4.

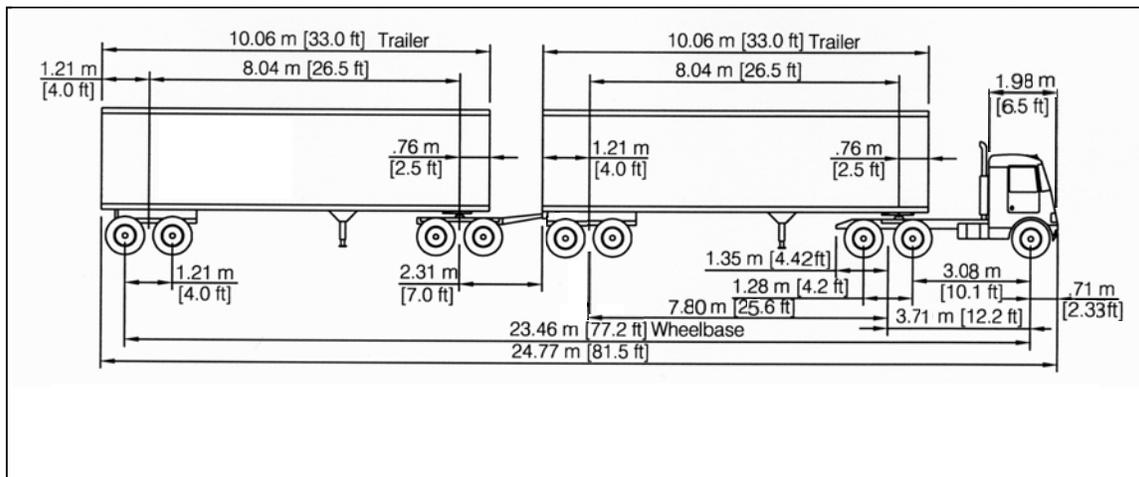


Figure 4. Dimensions of WB-23D [WB-77D] design vehicle for possible future use.

The WB-33D [WB-109D] design vehicle consists of a truck with two 14.6-m [48-ft] trailers. Turnpike doubles generally operate under permit on specific roadways approved for their use. Situations where a turnpike double is the appropriate design vehicle are typically quite limited because turnpike doubles are often made-up and broken-down at staging areas at the entrances or exits of specific highway facilities; they do not typically operate beyond that point onto the local road system. Situations in which a turnpike double might be expected to make a right or left turn at an at-grade intersection are relatively rare. However, for those roadways

where turnpike doubles operate in substantial numbers, they may be an appropriate design vehicle because they will almost certainly be the largest and least maneuverable vehicle on the road.

The dimensions of the turnpike double combination are reasonable except that the *Green Book* uses a cab-over tractor with a 3.7-m [12-ft] wheelbase. A conventional tractor with a larger wheelbase—4.9 m [16 ft] or more—would probably be more realistic. However, the effect of the larger tractor on offtracking would be minimal, and we do not recommend any change in the WB-33D [WB-109D] design vehicle at this time.

If the current LCV freeze were lifted, there might be interest in the trucking industry for use of a “turnpike double” truck with two 16.2-m [53-ft] trailers. The trucking industry might find it economically advantageous to use such trucks to move low density commodities because so many 16.2-m [53-ft] trailers are currently in use in single tractor-semitrailer combinations. However, it is far from certain whether such trucks would be permitted to operate by states, even if allowed by Federal law, because such trucks would offtrack more than even the turnpike double with 14.6-m [48-ft] trailers. The turnpike double with 16.2-m [53-ft] trailers cannot make a 90° right turn with a 22.9-m [75-ft] radius, while a turnpike double with 14.6-m [48-ft] trailers can. We do not recommend that a design vehicle with two 16.2-m [53-ft] trailers be included in the *Green Book* at this time, but an appropriate design vehicle has been developed for future consideration should such trucks be permitted and become common in the future. This design vehicle for possible future use is designated as the WB-37D [WB-120D] (Figure 5).

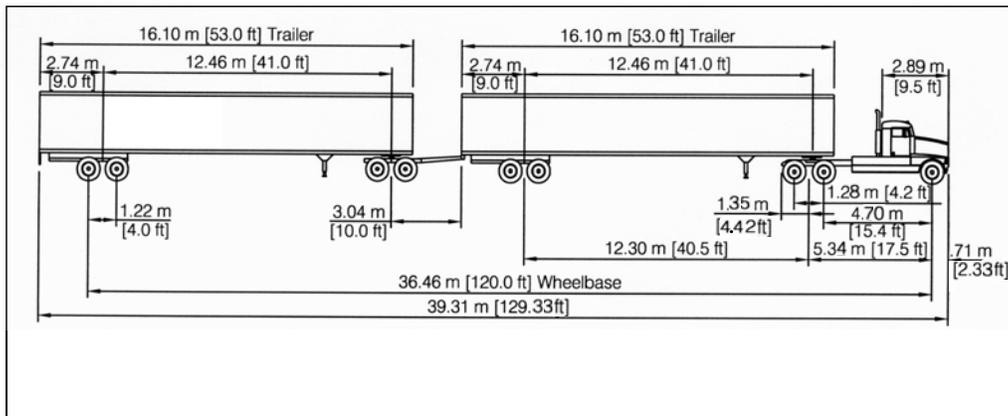


Figure 5. Dimensions of WB-37D [WB-120D] design vehicle for possible future use.

In addition to the WB-20D [WB-67D] and WB-33D [WB-109D], the Rocky Mountain double is also fairly common. It appears as a cross between the twin-trailer and turnpike double trucks, combining a longer semitrailer and a shorter full trailer. A typical Rocky Mountain double combination has a 14.6-m [48-ft] semitrailer followed by an 8.7-m [28.5-ft] full trailer. Rocky Mountain doubles currently operate in twenty states mostly in the western U.S., including three states where turnpike doubles are not permitted, and six states where triples are not permitted. In these states, Rocky Mountain doubles may offtrack more than any other relatively common truck type. Therefore, a Rocky Mountain double design vehicle is recommended for inclusion in the *Green Book* for potential application by state highway agencies that need it. The Rocky Mountain double is designated as the WB-28D [WB-92D] design vehicle. The recommended design vehicle has seven axles and an overall length of 30.0 m [98.3 ft] (Figure 6).

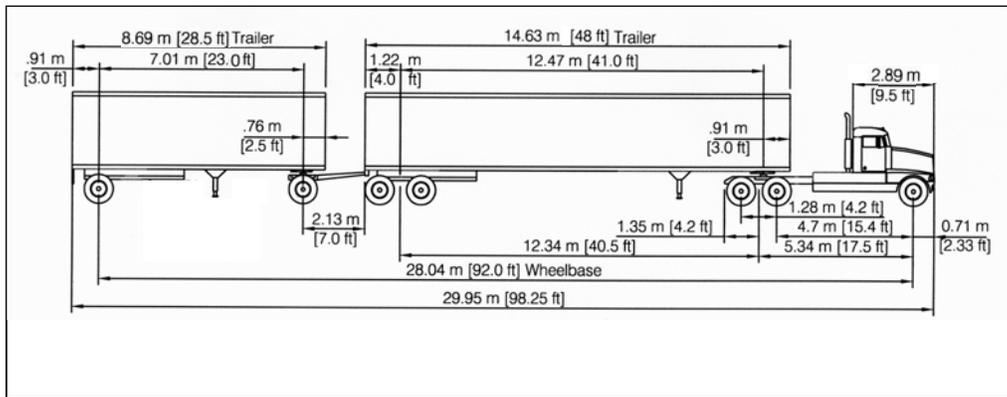


Figure 6. Recommended dimensions of WB-28D [WB-92D] design vehicle.

5.2 Tractor/semitrailer/semitrailer combinations (B-trains)

B-train double-trailer trucks are fairly common in Canada and are used to some extent in some of the northern tier of the United States. B-train doubles are also currently operating under permit between Monterey, Mexico, and Brownsville, Texas. A B-Train has a hitching mechanism that differs from the common double trailers seen in the U.S. The hitch of the U.S. double trailer is typically referred to as an A-hitch. It is essentially a tow bar, fastened at one end to the dolly under the front of the full trailer being towed by the first trailer, and at the other end by an eye which is hooked over a pintle hook attached to the first trailer. The second trailer of a B-Train is connected to the first by a fifth-wheel arrangement mounted on a dolly which protrudes from the rear of the first trailer. Thus, the rear trailer in a B-train double is a semitrailer rather than a full trailer. Having one less articulation point, B-Trains offtrack slightly more than the U.S. twin-trailers, but are more easily backed up. Most importantly, however, they can carry heavier loads (with their extra axles), so they are used for bulk and other types of loads that are particularly heavy. In the U.S., therefore, they are only used in areas where heavier loads are legal.

There is no design vehicle in the *Green Book* corresponding to the B-Train, and due to its limited use in the U.S., there is no compelling reason to add it at this time. However, a potential B-Train design vehicle is presented in Figure 7 should future changes in U.S. truck size and weight laws encourage its use. The B-Train is designated the WB-23BD [WB-75BD] design vehicle. Its dimensions are based on a Canadian design vehicle from the Transportation Association of Canada (TAC) (TAC, 1999), but might need to be adapted for future U.S. application depending upon which configurations become most common in the U.S.

6 TRIPLE-TRAILER TRUCKS

The *Green Book* includes one triple-trailer truck as a design vehicle. This is the WB-30T [WB-100T] with three 8.7-m [28.5-ft] trailers—one semitrailer and two full trailers. The WB-30T [WB-100T] is representative of the most common triple-trailer combination on the road today. Larger triple-trailer combinations are not generally permitted, so the WB-30T [WB-100T] is an appropriate design vehicle. No changes to this design vehicle are recommended.

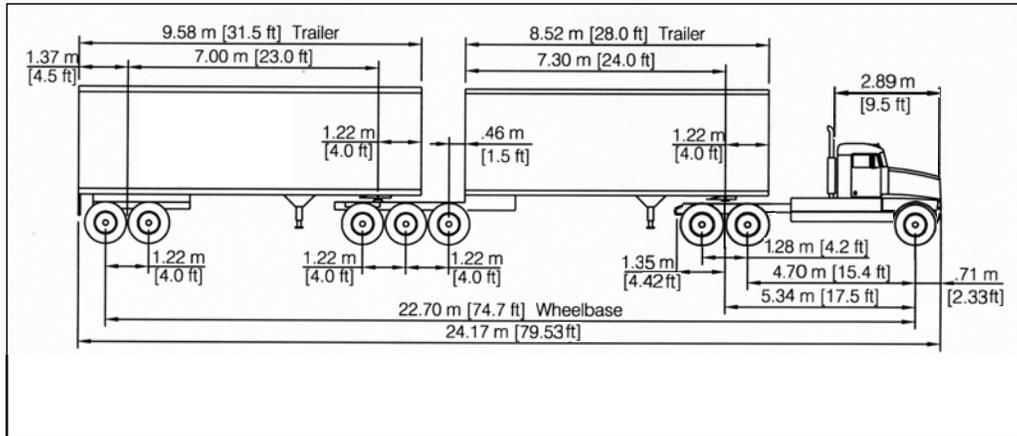


Figure 7. Recommended dimensions of WB-23BD [WB-75BD] for possible future use.

7 SUMMARY OF DESIGN VEHICLE RECOMMENDATIONS

The following changes in, or additions to, the *Green Book* design vehicles are recommended.

7.1 Single-Unit Trucks

- The current 2-axle SU design vehicle should be retained and designated the SU-6 [SU-20] design vehicle.
- A longer 3-axle SU design vehicle should be added and designated the SU-8 [SU-25] design vehicle.

7.2 Single-Trailer Combinations

- The WB-12 [WB-40] should be retained for application to container trucks and local pickup and delivery operations.
- The WB-15 [WB-50] is no longer common and should be dropped.
- The WB-19 [WB-62] design vehicle represents a truck configuration specified in Federal law and should be retained. The KCRT distance for this design vehicle should be increased from 12.3 to 12.5 m [40.5 to 41 ft] to correspond to the maximum limits applicable in 19 states. The WB-19 [WB-62] design vehicle should be used for design of offtracking and swept path width for all longer tractor-semitrailer combinations that are configured with a 12.5 m [41 ft] maximum kingpin-to-center-of-rear-axle-set distance.
- The WB-20 [WB-65] design vehicle represents an “in between” axle placement that is neither a best nor a worst case for design. This design vehicle should be dropped.
- The WB-20 [WB-67] design vehicle should be retained, but the KCRT distance should be increased from 13.3 to 13.9 m [43.5 to 45.5 ft] to represent a “worst case” condition.
- A tractor-semitrailer design vehicle with a trailer length greater than 16.2 m [53 ft] is not needed at this time. However, a WB-22 [WB-71] design vehicle has been developed for future application should such a truck become more common.
- No 6-axle tractor semitrailer design vehicle is needed because such trucks are not common at present and because a 6-axle tractor-semitrailer is not a critical design consideration because it would offtrack less than a comparable 5-axle tractor-semitrailer.

7.3 Double-Trailer Combinations

- The WB-20D [WB-67D] design vehicle with two 8.7-m [28.5-ft] trailers should be retained because it represents a truck configuration specified in Federal law.
- A twin-trailer truck with two 10.1-m [33-ft] trailers is not needed at this time but might become more common if Federal law permitted such a truck to operate at gross vehicle weights over 36,400 kg [80,000 lb]. A WB-23D [WB-77D] design vehicle has been developed for potential future application should such a truck become more common.
- The turnpike double design vehicle with two 14.6-m [48-ft] trailers, known as the WB-33D [WB-109D] design vehicle, should be retained.
- A turnpike double design vehicle with two 16.2-m [53-ft] trailers is not needed at this time. However, a WB-37D [WB-120D] design vehicle has been developed for future application should such a truck become common.
- A Rocky Mountain double design vehicle with a 14.6-m [48-ft] semitrailer and a 8.7-m [28.5-ft] full trailer currently operates under permit in 20 states. The addition of a Rocky Mountain double WB-30D [WB-92D] design vehicle is recommended.
- A B-train double design vehicle is not needed at this time. However, a B-train WB-23BD [WB-75BD] design vehicle has been developed for future application should this truck become more common.

7.4 Triple-Trailer Trucks

- The current triple WB-30T [WB-100T] design vehicle with three 8.7-m [28.5-ft] trailers should be retained.

8 REFERENCES

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