Operational Considerations Relating to Long Trucks in Rural Areas

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Much effort has been devoted to the theoretical aspects of truck turning characteristics, but little has been done to test these theories by observing actual trucks turning. This study focused on the dimensions and turning characteristics of combination tractor-semitrailer vehicles negotiating four rural interchange ramp intersections in Wisconsin. An attempt was made to determine the adequacy of Wisconsin's intersection and ramp terminal design standards and to evaluate the ability of the California Department of Transportation (Caltrans) theoretical turning templates to describe the actual paths of turning trucks. It was found that Wisconsin's intersection design standards are adequate for existing trucks but only marginal for the new, longer trucks (such as Wisconsin's WB-62, which has an overall wheelbase of 61.7 ft). Also, the Caltrans turning templates adequately described the turning path of the most common truck observed operating at low speeds.

It is standard engineering practice to base the design of a proposed highway facility on the needs of a predetermined design vehicle. This is especially critical at intersections where these design vehicles are likely to turn.

Early research on the turning characteristics of various design vehicles was conducted by the Society of Automotive Engineers and the Western Highway Institute (*1*). Later, the University of Michigan Transportation Research Institute (UMTRI) developed a series of equations that became the basis of a computer program designed to describe the paths of turning vehicles. The California Department of Transportation (Caltrans) adapted and enhanced the UMTRI program to develop mainframe computer software that creates theoretical turning templates for a variety of possible design vehicles (*2*). This study was conducted, in part, to field validate the Caltrans model.

Before 1982, rural highways in the United States were designed to accommodate tractor-semitrailer combinations with overall wheelbases of either 40 ft (WB-40) or 50 ft (WB-50). The Surface Transportation Assistance Act (STAA) of 1982 introduced major changes. It authorized even longer tractor-semitrailer combinations to operate on a system of designated truck routes within each state. In Wisconsin this longer vehicle is known as a WB-62. Because the designated routes were for smaller trucks, the Wisconsin Department of Transportation (WisDOT) became concerned that its intersection designs were inadequate for longer trucks.

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This paper documents the efforts that WisDOT made to evaluate rural intersections and ramp terminals in Wisconsin. In this study, rural sites were differentiated from urban sites by their relatively lower traffic volume and their lack of signalized control. These conditions allow many truckers to execute their turns without coming to a complete stop. They also increase the likelihood that trucks will encroach on adjacent lanes.

An evaluation of urban-type intersections was addressed by DeCabooter and Solberg (*3*).

DATA COLLECTION

There were two main objectives in this study:

1. To evaluate the ability of existing rural intersections to accommodate larger trucks, especially at ramp terminals, and
2. To determine how well the Caltrans turning templates describe the low-speed maneuvers of actual trucks.

Because both of these objectives involved actual truck operational characteristics, data collection and analysis were a major part of the study.

Site Selection

This effort began with the review of a previous WisDOT report that identified those interchanges on the state system of designated truck routes that had the highest probability of operational problems. Interchange ramp terminals were selected as the best places to collect truck turning data. Because they are near controlled-access highways, they carry significant amounts of truck traffic. In addition, the geometrics of these sites are deliberately restrictive to discourage wrong-way traffic on ramps.

A multidisciplinary engineering team studied aerial photos of these sites to identify those intersections with the most restrictive geometrics. The team chose small median opening as the key restrictive geometric element. Finally, the most likely sites were inspected for signs of vehicle encroachment in their medians.

Actual volume of truck traffic was not used as a major criterion for site selection. The study team believed truck volume would be adequate for sampling along the entire designated system. Furthermore, the methods of data collection chosen rendered many high-volume traffic sites unsuitable.

The team finally selected four interchanges at which to collect data. They were

1. US-12 with WI-67, Elkhorn;
2. US-51 with I-90/94, Madison;
3. US-14 with I-43, Darien, and
4. US-41 with WI-23, Fond du Lac.

Figure 1 shows their locations, and Figures 2 through 5 show the configurations of the specific sites.

Types of Data

Because the size and location of median openings were considered the controlling geometric elements for truck maneuvers, the team concentrated on collecting data for left turns. Two types of data were collected. The first was dimensions of individual trucks (see Figure 6). The principal dimensions of interest were the effective tractor length (KP-1) and the effective trailer length (KP-2). These were used to classify vehicles and to learn what sizes of trucks are using Wisconsin's roads. To determine these dimensions, the location of the kingpin had to be identified. The location of the fifth wheel was established first. Then, based on previous research, the kingpin location was defined as the center of mass of the fifth wheel. The second type of data collected was the coordinates of key points on trucks as they negotiated through intersections. These were used to define the actual paths of the turning trucks.

Collection Methods

Data were collected by two methods:

1. Photographing trucks from a crane-mounted platform suspended over the intersection and

FIGURE 1 Study of long trucks, rural sites.

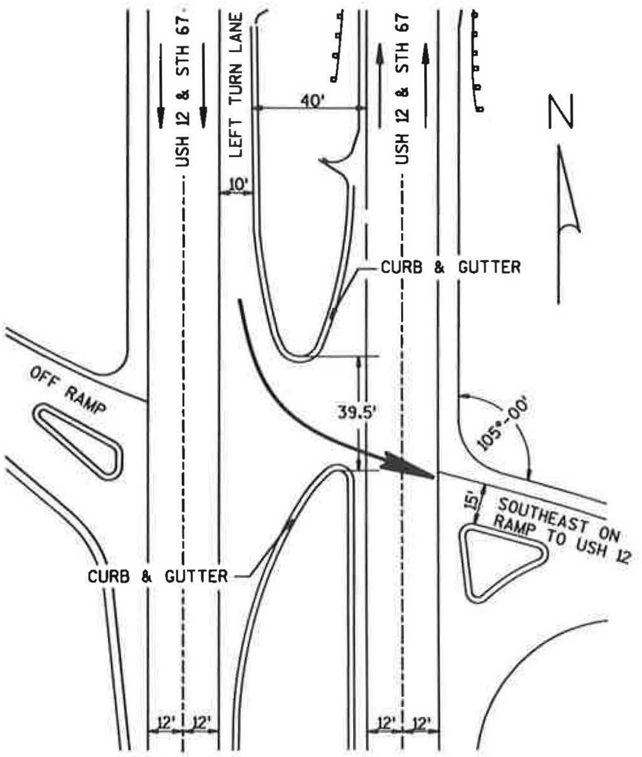


FIGURE 2 US-12 and WI-67, Elkhorn intersection.

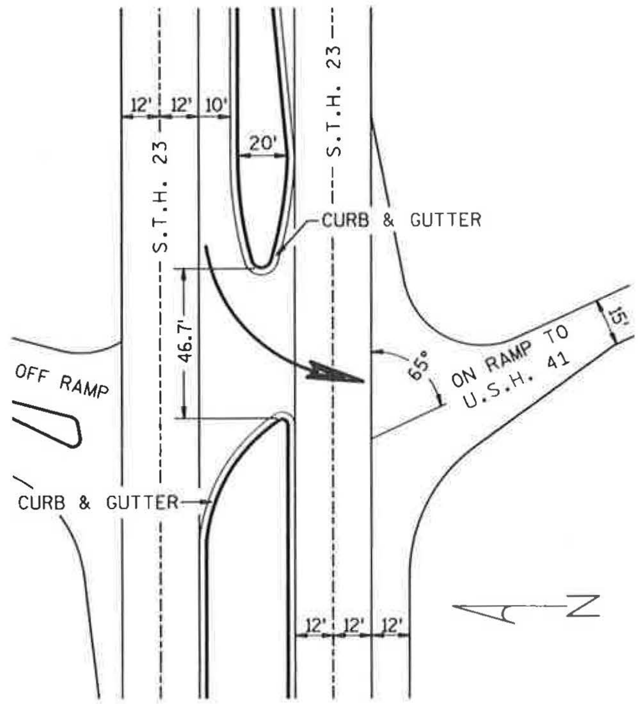


FIGURE 4 WI-23 and US-41, Fond du Lac intersection.

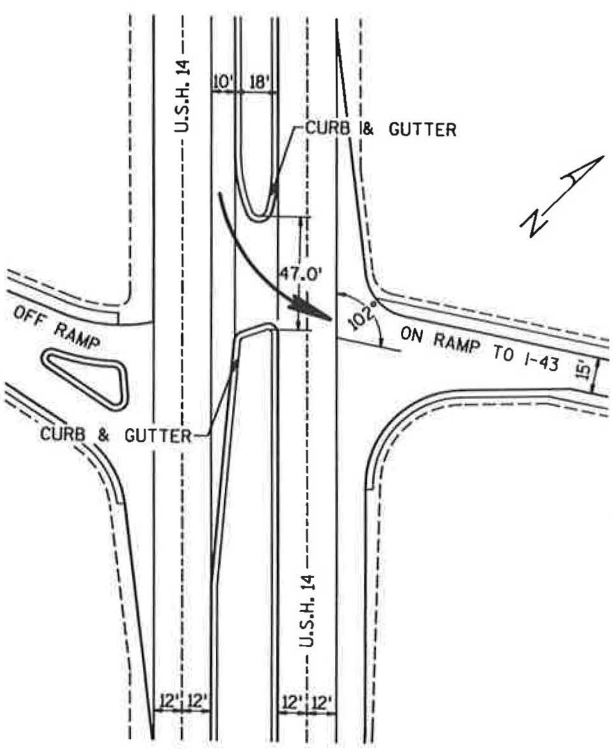


FIGURE 3 US-14 and I-43, Darien intersection.

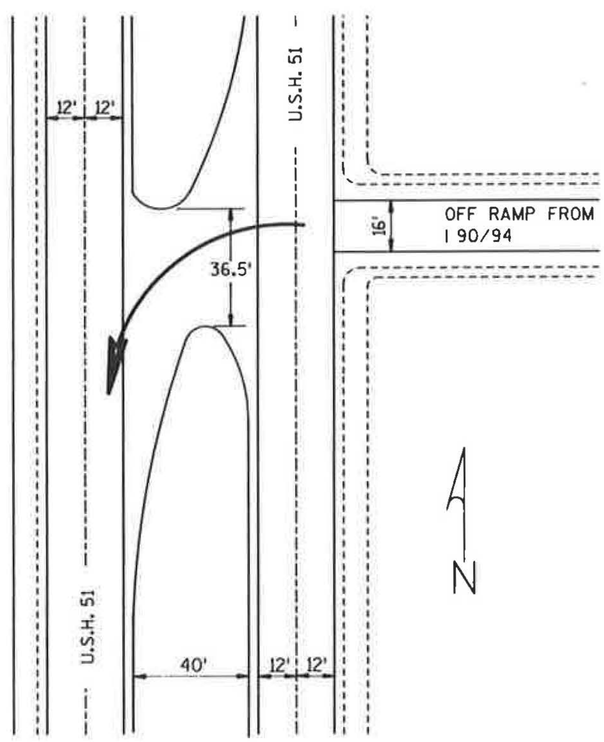


FIGURE 5 US-51 and I-90/94, Madison intersection.

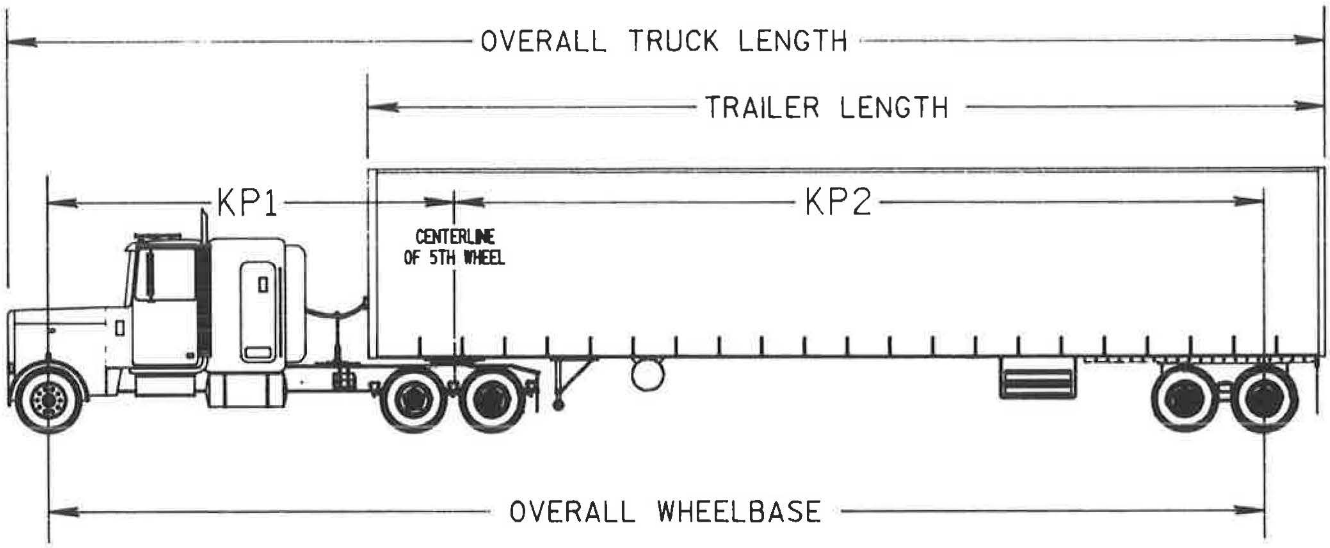


FIGURE 6 Dimensions captured on trucks.

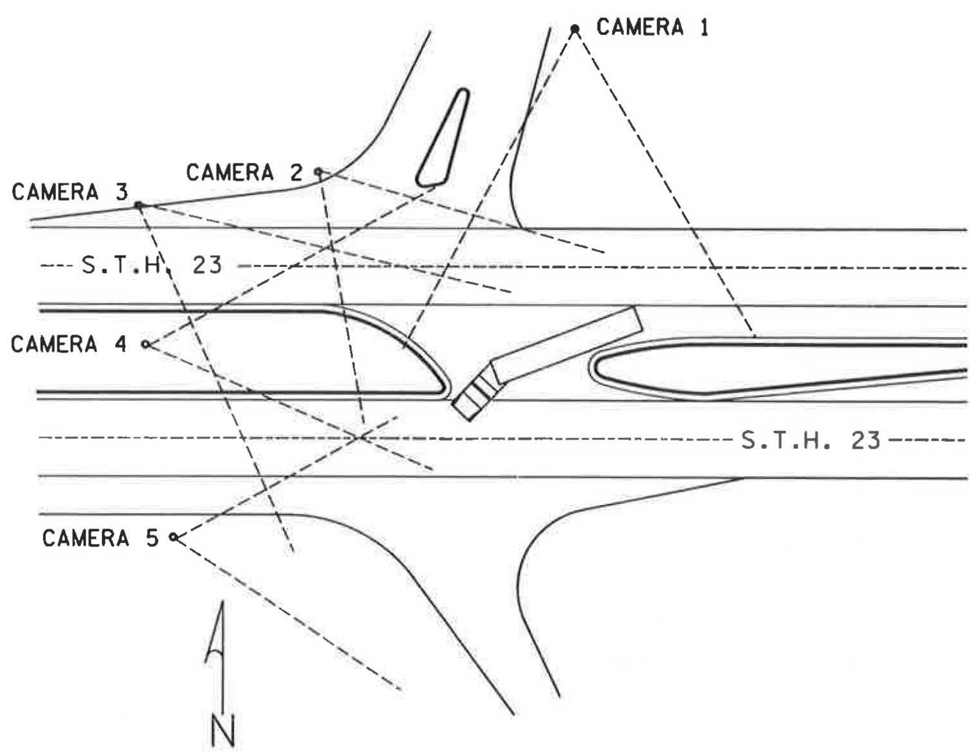


FIGURE 7 Typical camera locations.

2. Phototriangulation of trucks from a series of ground cameras.

The overhead photography method was used successfully at the Elkhorn site. However, this method could not establish the critical KP-1 and KP-2 dimensions by itself, so a second data collection method—phototriangulation—was used in conjunction with overhead photography. Researchers discovered that the overhead photography method was limited by local site conditions. In fact, it could not be used at the other sites due to high fill sections, overhead utility lines, or, in one case, an airport glide path.

The on-ground phototriangulation system developed by University of Wisconsin researchers used a series of nonmetric, single-lens reflex cameras mounted on tripods that were located strategically at the intersections. The cameras were positioned so that turning vehicles were visible within each of their fields of view for the entire turn (see Figure 7). This ensured good geometric strength in the photogrammetric solution obtained.

Simultaneous photographs were taken of each vehicle at five different points within its turning path. Simultaneity was achieved by firing a master switch that was electronically connected to each camera. At the time of photographing, control surveys were performed to support the photogrammetric calculations. Photographic coordinates of vehicle images and control point images were then measured in the University of Wisconsin Photogrammetric Laboratory using a newly developed digital projection system.

Phototriangulation was first tested as a supplement to the overhead photography at Elkhorn. Four cameras were set up, but the control mechanism malfunctioned on one. Therefore, there were problems with the data collected at this site. The fifth wheel location could not be identified for several trucks. Furthermore, three cameras could not provide enough points to define the turning paths adequately. For these reasons, the Elkhorn truck data were not used in this study.

After the Elkhorn experience, the system was redesigned to use five cameras, which all worked at the remaining three sites, significantly increasing the accuracy of the system. The only remaining problem was shadows. The cameras could not identify the fifth wheel location if it was in shadow. This limited the time period during which truck data could be collected. Once the number of cameras was increased and the shadow limitation was recognized, the system collected accurate, useful data.

OBSERVATIONS

Figures 8 through 10 show the truck dimension data for the three remaining sites. These graphs show a broad spectrum of truck sizes on Wisconsin's roads. This diversity is due in part to the number of different sizes that are manufactured, as well as to the variable settings possible for the rear dual axles on a semitrailer. Depending on the situation, the dual axles can be shifted forward or backward over a range of 10 ft. In fact, at the observed sites, none of the trucks fit the AASHTO definitions of a WB-40 or WB-50. Only 19 of the observations were categorized as new, longer trucks allowed by STAA, and these were mostly multiple passes of a special test vehicle at the Elkhorn site.

The wide range of truck sizes observed and the small number of the larger STAA vehicles encountered in this study agree with other data collected at a Wisconsin truck scale in 1985. These findings are also consistent with the data collected in 1987 by DeCabooter and Solberg in their evaluation of long trucks at urban intersections.

The results of the turning maneuver observations are shown in Figures 11 through 13. These figures show a wide variation in the paths taken by individual trucks. The data collection team observed that many truck drivers took advantage of low volumes of opposing traffic to make the most comfortable turn possible. This involved using the farthest possible outside lanes to begin or end their turns. On several occasions, the opportunity to turn without stopping permitted drivers to start or end their turns by encroaching into a lane not intended for that purpose.

Of the four sites observed, the Fond du Lac site offered the most restrictive geometric situation to turning vehicles. In this case, 82 percent of turning trucks started and ended their turns in the proper lanes. For this reason, the following analysis concentrates on that site.

ANALYSIS

Observations of the turning maneuvers at Fond du Lac revealed that most trucks negotiated the intersection without much difficulty. This was true even for the largest trucks. Those

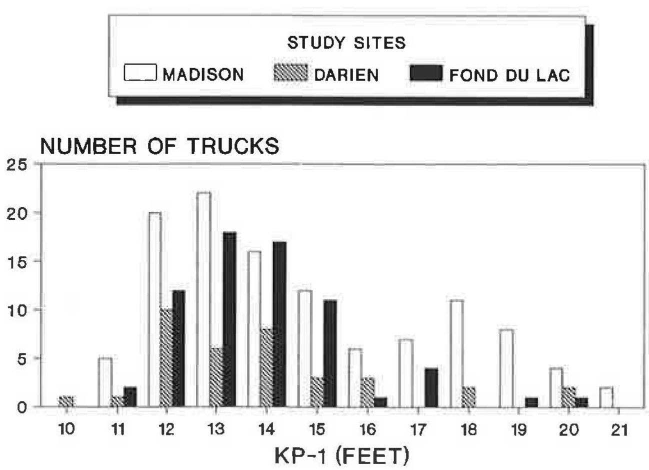
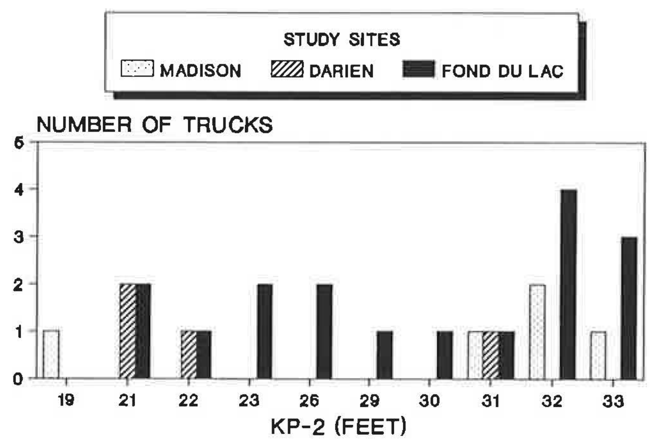


FIGURE 8 Effective tractor lengths (KP-1).



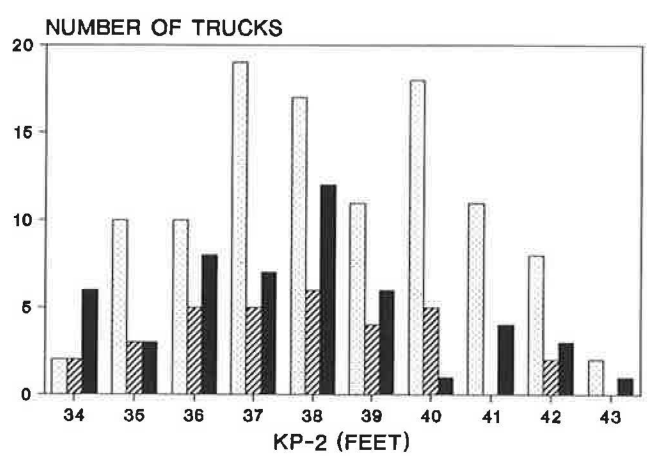


FIGURE 9 Effective trailer lengths (KP-2).

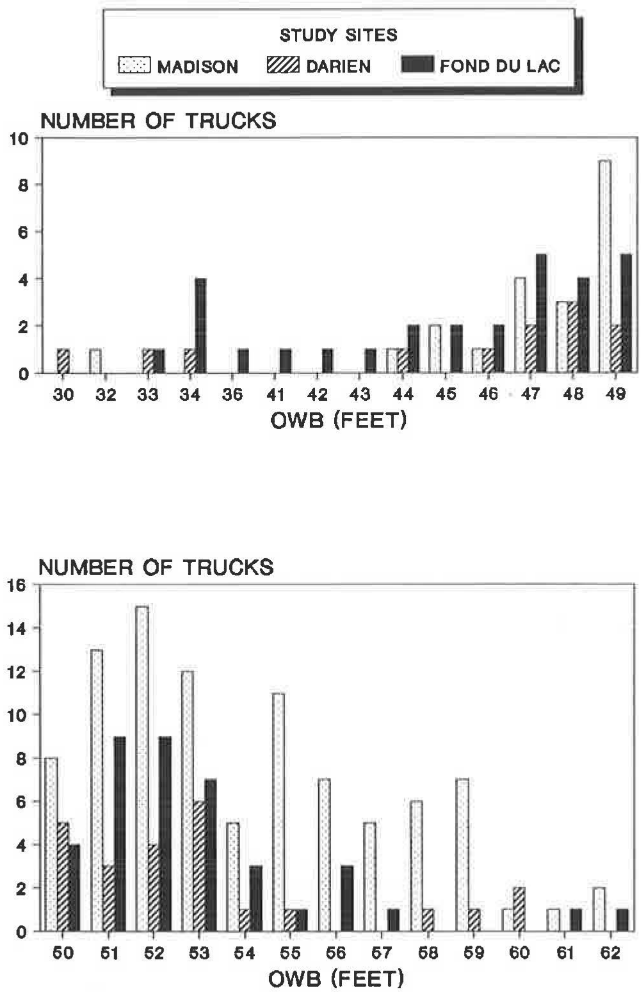


FIGURE 10 Overall wheelbase (OWB).

encroachments that did occur were minimal, and the observers attributed them mainly to driver misjudgment. Unfortunately, only a few of the largest trucks were observed at this site.

Using the Caltrans software, the team generated a hypothetical turning template for one of the larger trucks. The configuration of this vehicle is shown in Figure 14. The vehicle was named WB-62, and its dimensions are those of the largest tractor-semitrailer currently allowed in Wisconsin.

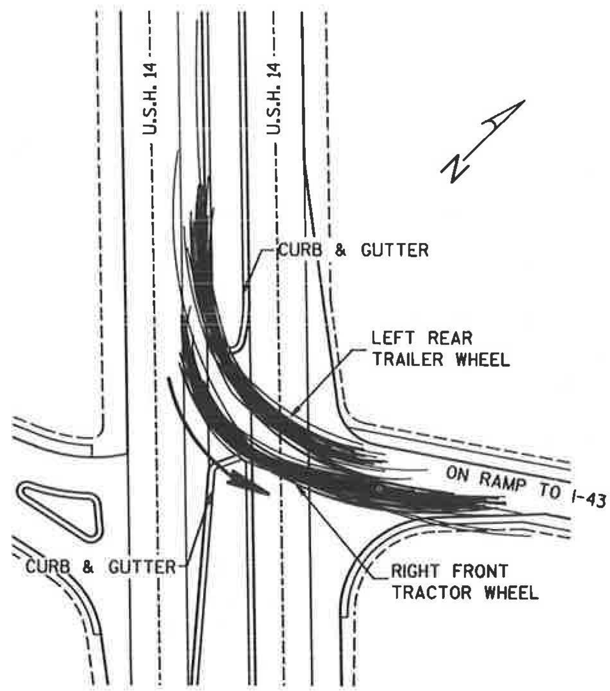


FIGURE 11 Darien intersection, all truck turns.

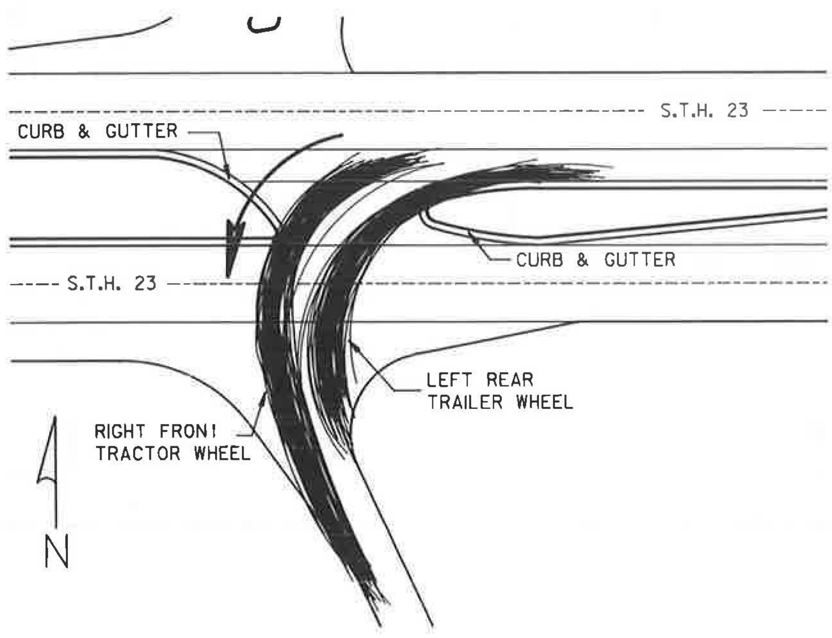


FIGURE 12 Fond du Lac intersection, all truck turns.

When this template is superimposed over the Fond du Lac site (see Figure 15), it appears that a truck of this size could just barely maneuver through the intersection. Even so, there is a high probability that a large truck would either ride over the median curb and encroach onto the shoulder of the on-ramp or initiate the turn from outside the turn lane provided. This agrees with the video evidence and researcher observations at the Elkhorn site. At Elkhorn the WB-62 test truck was only able to turn left if the driver reduced speed significantly.

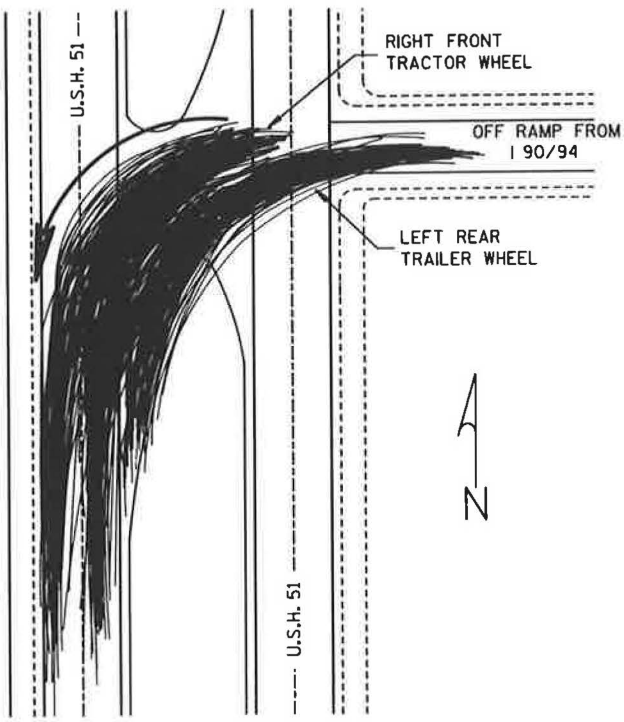


FIGURE 13 Madison intersection, all truck turns.

To evaluate the Caltrans software, the team used it to create a template of the most common truck encountered at the Fond du Lac site. This truck had an effective tractor length (KP-1) of 14 ft and an effective trailer length (KP-2) of 38 ft. The parameters needed by the Caltrans software are given below. It should be noted that the tractor wheelbase is the KP-1 dimension plus the distance from the kingpin to the rear tractor axle (in this case, 3 ft):

Truck Characteristic	*Caltrans Parameter*
Angle of turn	115 degrees
Radius of turn	60 ft
Tractor wheelbase	17 ft
Trailer length (KP-2)	38 ft
Trailer width	8.5 ft
Axle width	8 ft

The template was then compared with a composite of the paths followed by trucks of the same size as they negotiated the intersection. Figure 16 shows that the Caltrans-generated template is reasonably accurate in describing the path of this particular group of trucks.

One of the findings of the Caltrans effort reaffirmed the conclusion of earlier offtracking formulas that the effective trailer length has more of an effect on offtracking than does the effective tractor length. To test this hypothesis, the offtracking of certain vehicles at the Fond du Lac site was plotted against their KP-1 and KP-2 dimensions. Figures 17 and 18 show the results. Figure 17 shows that, for fixed trailer wheelbase, offtracking is stable over a wide range of tractor wheelbases. On the other hand, Figure 18 shows significant variation in offtracking as trailer length changes.

These findings generally agree with the results obtained from the Caltrans modeling.

CONCLUSIONS

- Trucks using Wisconsin's system of routes designated for long trucks vary considerably in size and configuration.

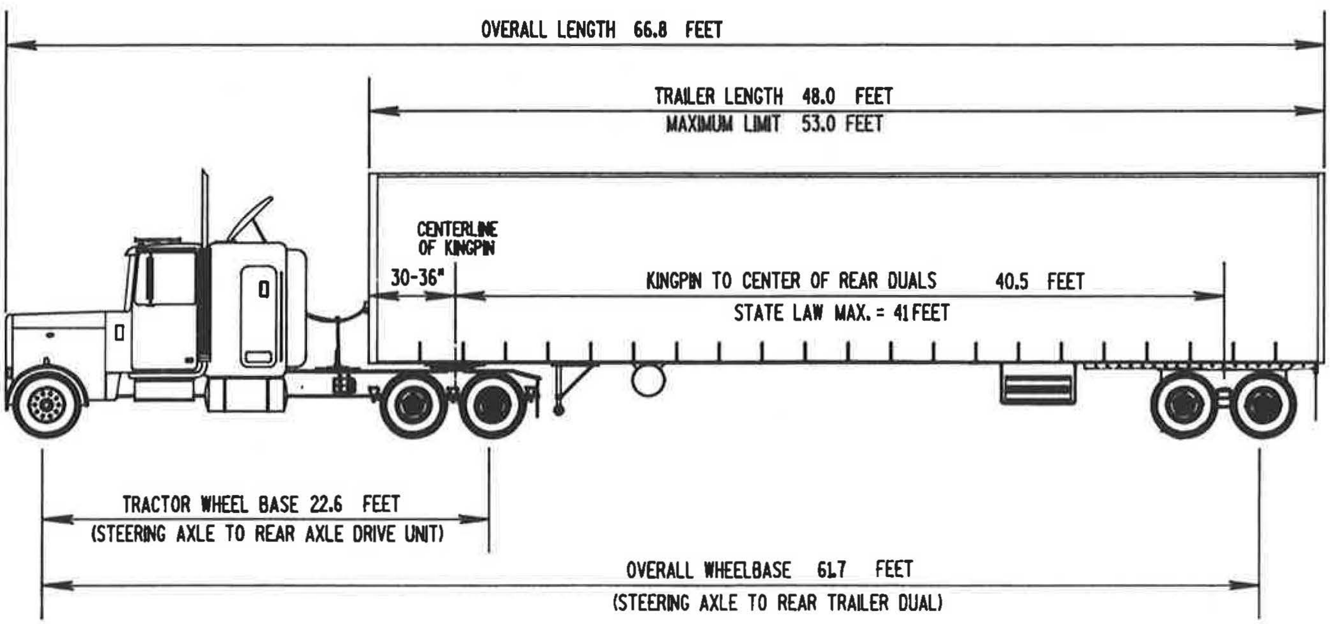


FIGURE 14 Typical Wisconsin WB-62.

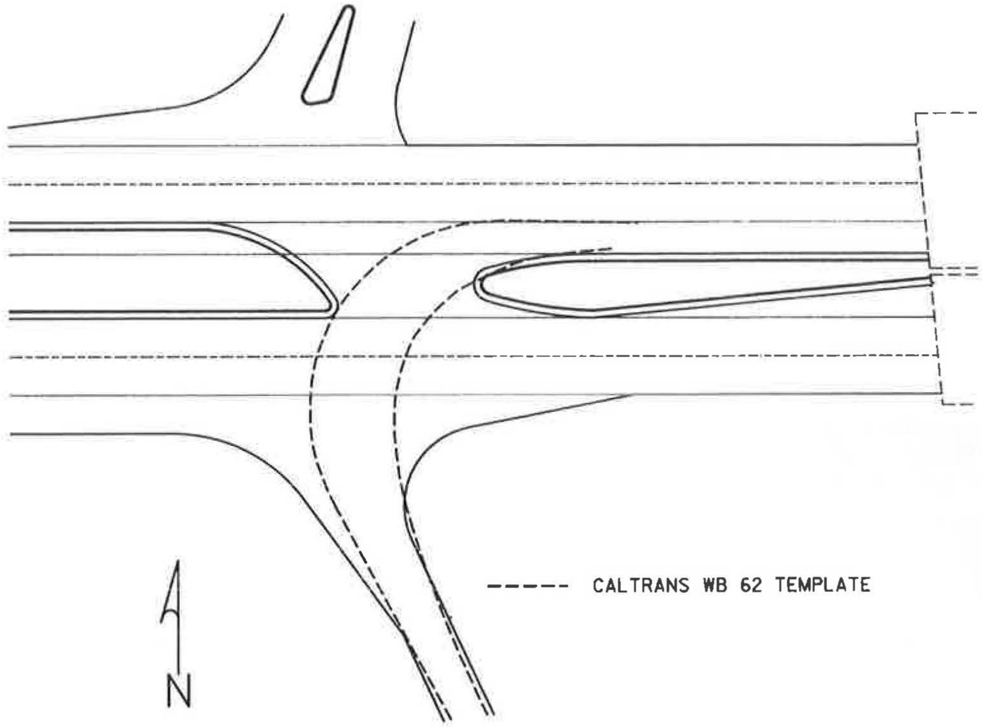


FIGURE 15 WB-62 template comparison.

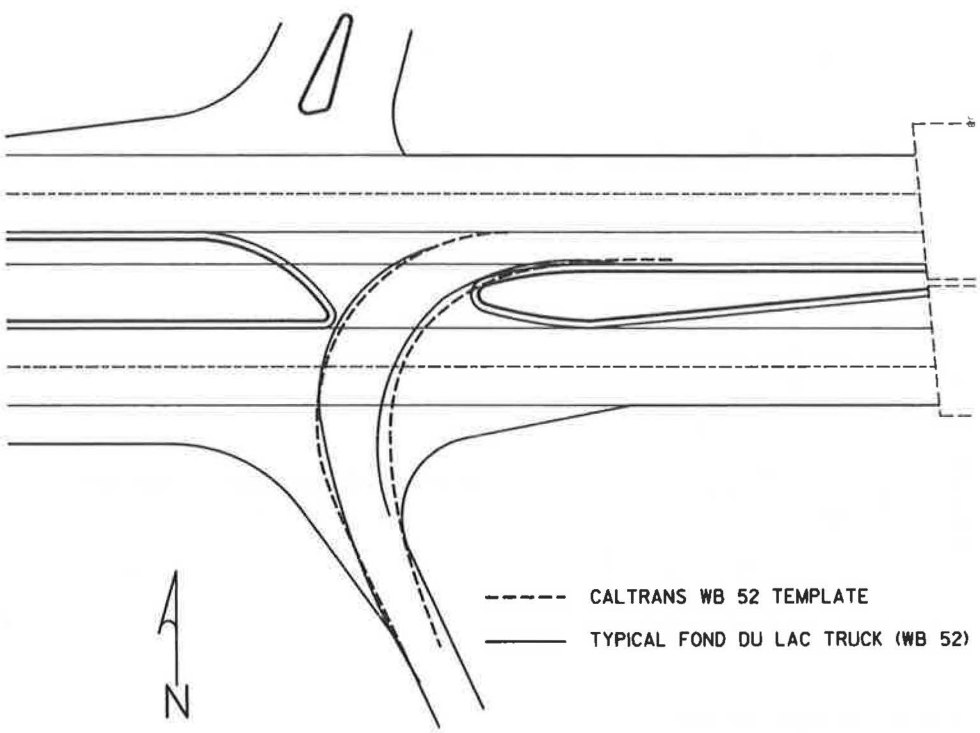


FIGURE 16 Caltrans WB-52 versus actual WB-52.

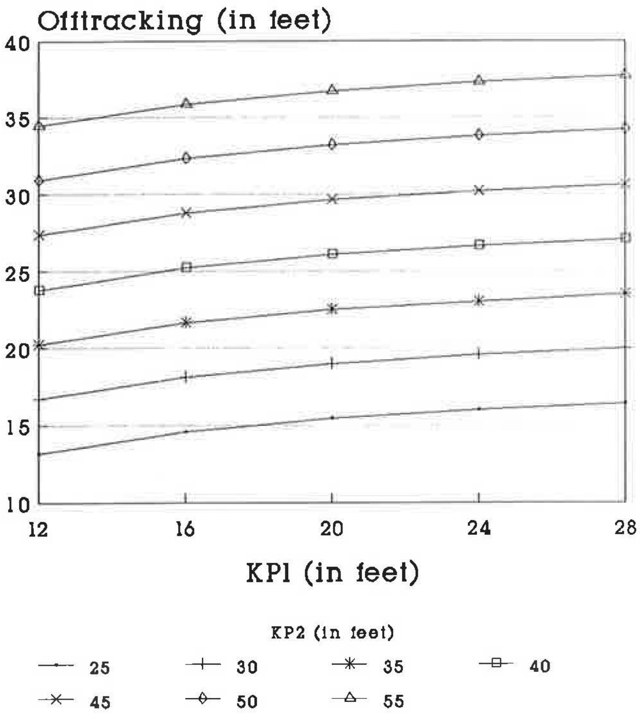


FIGURE 17 KP-1 versus offtracking.

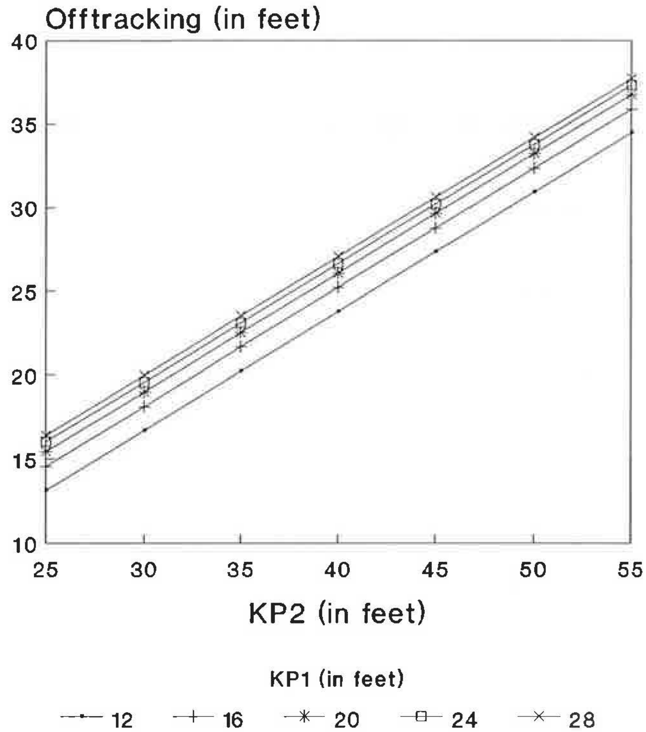


FIGURE 18 KP-2 versus offtracking.

- A significant number of trucks turning at these test sites encroached into lanes not meant for turning traffic. They also avoided coming to a complete stop whenever possible.
- The phototriangulation method of data collection was successful in defining the path of turning trucks.
- In general, intersection design standards in Wisconsin are adequate for the trucks currently using them.
- Theoretically, the new, longer trucks can negotiate intersections designed for smaller vehicles. However, there is little margin for error, and less capable drivers will almost certainly have problems.
- The Caltrans theoretical turning-template software accurately described the low-speed turning characteristics of one type of truck in Wisconsin.

RECOMMENDATIONS

- The Caltrans turning templates should be used when intersections are designed. The software to generate specific templates should be incorporated into the computer-aided design system being used.
- Designers should be more aware of the size of trucks using or likely to use the facility being designed.
- Designers should consider the urban versus rural nature of the intersection location and the volume of traffic to be accommodated. In rural areas, designers should use a turning radius larger than the minimum.
- Further studies should be conducted to determine the actual turning characteristics of the longest legal trucks.

REFERENCES

1. *Observations on the Turning Characteristics of Western Type Trucks and Combinations.* Western Highway Institute, San Bruno, Calif., 1950.
2. *Truck Paths on Short Radius Turns.* Division of Highways, California Department of Public Works, Sacramento, 1972.
3. P. H. DeCabooter and S. E. Solberg. Operational Considerations Relating to Long Trucks in Urban Areas. *In Transportation Research Record 1249,* TRB, National Research Council, Washington, D.C., pp. 5–15.

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