Operational Considerations Relating to Long Trucks in Urban Areas

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The Surface Transportation Assistance Act (STAA) of 1982 mandated the operation of large trucks (generally 102 in. wide and 41 ft from kingpin to rear axle) and twin tractor-trailer combinations on most Interstates and many primary highways, and in 1987 the Surface Transportation and Uniform Relocation Assistance Act reinforced the trend. Many states have rapidly expanded the highway system for longer vehicles by adding secondary highways, many of which involve urban streets and intersections. Many of the intersections are substandard if compared with the ideal 62-ft wheelbase turning template. However, truck operators and automobile drivers take compensatory measures that allow the longest vehicles to successfully negotiate most of these marginal geometric configurations. Demonstrably, full-scale improvements are unnecessary in many instances in which street widths meet or exceed certain minimum tolerances. However, when intersections are so seriously deficient that the operation of long trucks through them endangers public safety, a rational way to identify them should be available to engineers, local officials, and other decision makers. A methodology is presented that allows decision makers to rationalize this process and defend their judgment.

Under the Surface Transportation Assistance Act (STAA) of 1982, and reaffirmed in the Surface Transportation and Uniform Relocation Assistance Act (STURAA) of 1987, numerous highways in the United States were designated by the Federal Highway Administration and the states for use by long semitrailer trucks. Research has been conducted on the theoretical operational and geometric characteristics of these vehicles. However, the way they function in the real-world setting of actual geometric configurations in competition with heavy traffic volumes is a matter for serious engineering consideration. Many intersections on the designated highway system are geometrically inadequate according to current ideal turning templates for long trucks. Reconstructing a substantial number of these to theoretical standards would be cost-prohibitive. Yet traffic engineers and designers know that while most intersections somehow accommodate trucks and will continue to do so as the trucks get longer, a few will lose this capacity at some point. The ability of engineers to differentiate between the intersections that require only minor modification and those that must be rebuilt to provide acceptable levels of service is of critical concern. A second concern is how to decide which modifications, short of complete reconstruction, will be the most effective.

The Wisconsin Truck Study addresses concerns related to the actual operation of long trucks at downtown intersections on the designated highway system. As shown in Table 1, most states allow long trucks on two-lane urban highway sections. Very few of the intersections in these urban sections were designed for 50-ft wheelbase operation, yet 62-ft wheelbases are now permitted. Furthermore, the distance from kingpin to rear trailer axle is usually the critical dimension. Current design criteria are based on overall length.

This research set out to determine the actual operating characteristics of a typical mixture of long vehicles and the impact of various dimensions of these assemblies on

1. Offtracking,
2. Overall swept path,
3. Opposite lane encroachment of the leading edge of the tractor,
4. Intersection traffic operation, and
5. Intersection design and location of traffic appurtenances.

Early assessments of improvement costs for designated highway systems used relatively crude deficiency criteria. Large-scale expenditures based on such tenuous data are difficult to justify. Also, physical improvements in downtown intersections can be very costly in both economic and public relations terms. Therefore, investment in engineering research that examined all aspects of intersection performance (both operational and geometric) could pay dividends. The underlying premise (especially in evaluating truck operations in constricted urban settings) was that immediate and downstream costs of massive reconstruction may be too much to bear, and that simply blending design and traffic engineering expertise in an applications research setting might suggest more cost-effective and publicly palatable solutions than massive reconstruction.

OBJECTIVES

Five primary goals for this study, to be performed in two separate stages, are as follows:

1. Determine real-world operating characteristics of long trucks at intersections in an urban setting.
2. Evaluate the operations of typical medium- to high-volume urban intersections that do not conform to minimal design standards.
3. Establish realistic intersection design and redesign criteria for urban intersections.
4. Establish criteria for location of traffic control devices and other on-street appurtenances where there is a high percentage of truck traffic.
5. Develop engineering analyses based on statistical inference and mathematical models that would enable assessment of the future impacts of longer-wheelbase trucks as their proportion in the vehicle population increases.

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TABLE 1 STATES ALLOWING OPERATION OF LONG TRUCKS IN URBAN AREAS

Name of State	Approximate Percent of State System (Interstate Plus Numbered Highways) Designated for Large Truck Operation)	Do Two Lane Designated Routes or Access Highways Enter or Go Through Cities ?
Alabama	100 %	Yes
Arkansas	100 %	Yes
California	60 %	Yes
Colorado	57 %	Yes
Connecticut (1)	13 %	No
Delaware (2)	4 %	Yes
Florida (3)	100 %	Yes
Idaho	100 %	Yes
Illinois	43 %	Yes
Indiana	100 %	Yes
Kansas	100 %	Yes
Louisiana	100 %	Yes
Maryland	100 %	Yes
Michigan	67 %	Yes
Minnesota	46 %	Yes
Mississippi	100 %	Yes
Missouri (4)	49 %	Yes
Montana	100 %	Yes
Nebraska	100 %	Yes
Nevada	100 %	Yes
New Hampshire	100 %	Yes
New Jersey	55 %	Yes
New Jersey	100 %	Yes
New York	20 %	Yes
North Carolina (5)	4 %	Yes
North Dakota	100 %	Yes
Ohio	100 %	Yes
Oklahoma	100 %	Yes
Pennsylvania (6)	5 %	Yes
Rhode Island	100 %	Yes
South Dakota	100 %	Yes
Tennessee	100 %	Yes
Texas	100 %	Yes
Vermont	100 %	Yes
Washington (3)	100 %	Yes
West Virginia	17 %	Yes
Wisconsin (6)	53 %	Yes
Wyoming	100 %	Yes

1 Multiple trailers (single trailer semi's allowed on entire system)
2 Requires permit
3 All major cities with state highways entering or traversing
4 Interstate and primary sytem
5 Includes 73,221 miles of two-lane system.
6 Anticipates major increase in city two-lane mileage and/or overall system mileage

INVESTIGATIVE METHOD

Although the information desired was easily identified, the question of how to get it was more complex. Initially the researchers thought a straightforward aerial photographic survey could be conducted. A photogrammetric camera was envisioned as the only necessary equipment to capture hours of measurable incremental data from truck wheelpaths. Numerous possibilities were explored. For the first phase it was decided that two separate methods should be tested:

1. Suspending a photographer with his photographic equipment 200 ft above the selected intersections through use of a mobile crane, and
2. Making on-ground phototriangulation photogrammetry.

In the second phase a contract was negotiated with the Department of Civil Engineering Photogrammetry Laboratory at the University of Wisconsin (UW) to perform the trace-plotting of truck wheelpaths.

The on-ground phototriangulation system developed by the university researchers utilized five nonmetric single-lens reflex cameras mounted on tripods 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, and so that good geometric strength in the photogrammetric solution would be obtained. Simultaneous photographs were taken with the cameras for each vehicle at five different points within its turning path. Simultaneity was achieved by electronically firing a master switch connected to each camera. At the time of photographing, control surveys necessary to support the photogrammetric calculations were performed.

Following the photography, photocoordinates of vehicle images and control point images were measured in the UW Photogrammetry Laboratory using a newly developed digital projection system. Initial tests of this device indicated that its accuracy in locating the truck paths was within 3 in.

Four downtown intersections on the Wisconsin Designated Highway System were targeted for intensive field measurements of all long trucks arriving during a standard day-long photographic session at each location. The intersections were selected on the basis of the following criteria:

1. Expected traffic of at least 80 heavy multiunit trucks negotiating both left and right turns during a normal weekday,
2. An intersection angle of at least 90 degrees,
3. Single-lane intersection approaches,
4. Main-approach average daily traffic (ADT) in excess of 4,000, and
5. Enough clear distance to allow all camera setups a sufficiently unobstructed field of view.

The intersections selected were Highway 33 in Horicon, Highway 23 in Montello, Highways 23 and 73 in Princeton, and Highways 44, 49 and 23 in Ripon, Wisconsin. They are shown schematically in Figures 1–4.

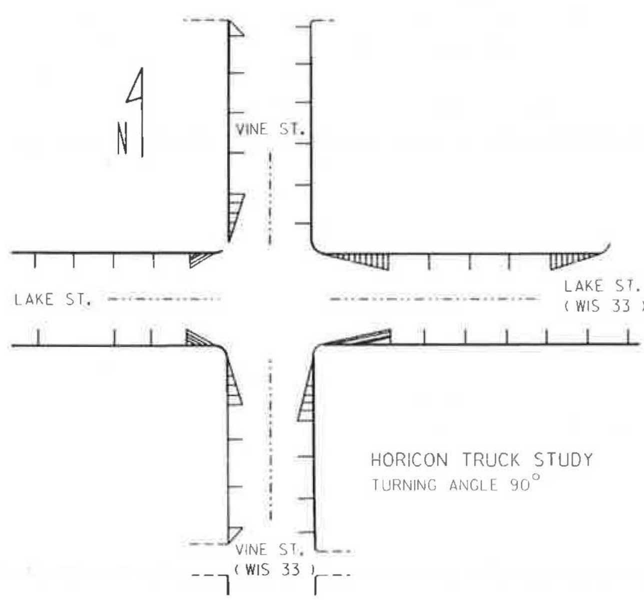

FIGURE 1 Horicon, Wisconsin, intersection layout.

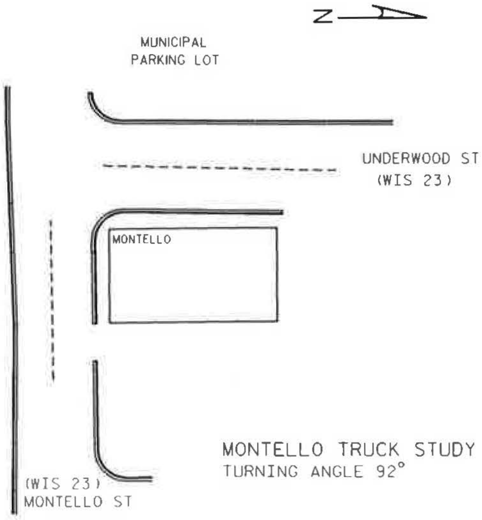

FIGURE 2 Montello, Wisconsin, intersection layout.

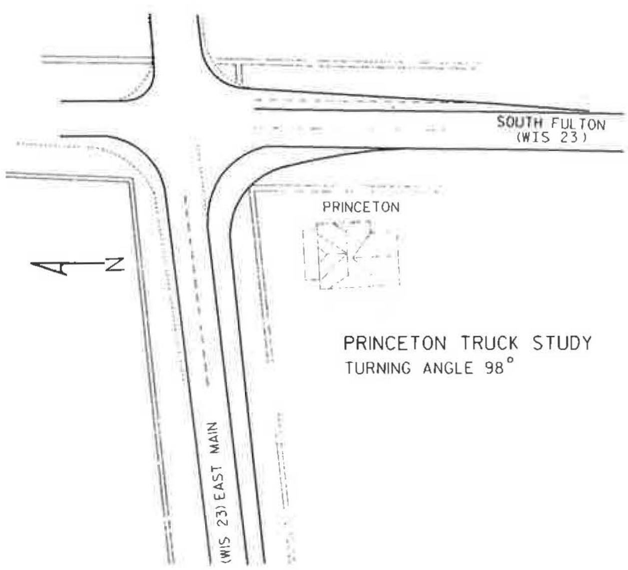

FIGURE 3 Princeton, Wisconsin, intersection layout.

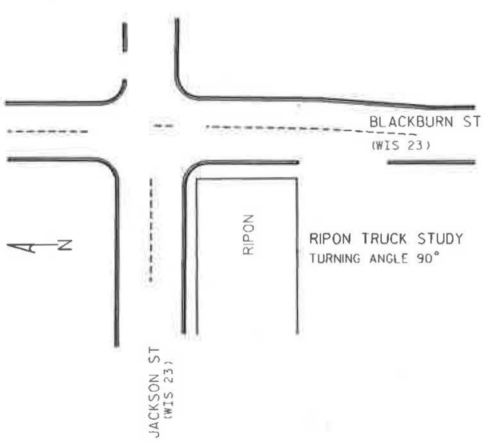

FIGURE 4 Ripon, Wisconsin, intersection layout.

Careful attention was given to working with local officials and law enforcement agencies to make sure that they were fully apprised of the activities of the researchers. Law enforcement personnel were especially helpful in informing property owners adjacent to the study sites and securing permission for the research team to set up photographic equipment, wiring, and other necessary details. In addition, they provided valuable assistance in arranging traffic control, parking prohibitions, and protection for the field personnel.

For the first downtown study session, conducted in Horicon, a driver with a maximum-legal-length control vehicle was hired to circulate through the intersection with the regular traffic stream. This truck is shown in Figure 5. For the second series of urban operational studies, no maximum-length control vehicles were used. Without the control vehicle, few very long-wheelbase trucks (wheelbases approximating 60 ft) appeared in the truck traffic stream. Most were about 57 ft in length or less.

ACTUAL EXPERIMENTAL SESSIONS

Because of weather sensitivity of the photographic work and equipment and the need to avoid traffic disruption of wiring taped across the pavement, all second-phase sessions were conducted during stable summer weather in 1987. This was in contrast to the first-phase sessions, which were conducted in the spring and fall of 1986 and involved overhead photography from a platform 200 ft above. Weather stability during the 1986 sessions was unpredictable and a continual cause for concern.

Intersection selection was governed primarily by entering traffic volumes, numbers of long trucks turning, and the visual field available for the five camera setups. The goal was to photograph a minimum of 80 truck-turning movements per intersection. As each turning truck moved into a minimum of three camera fields, all five cameras were fired simultaneously. This was repeated five times as the truck moved through its complete turning maneuver. The experimental layout allowed five points to be triangulated for each truck turning path, as shown in Figure 6. The result was not as continuous as with the 8 to 10 overhead photographs obtained for individual truck movements in the first phase. However, the turning points established were considered to be sufficient.

OBSERVED RESULTS

The actual wheelpaths of right- and left-turning trucks diverge rather markedly. Truck wheelpaths develop the predictable "humpback" curve for right-turning trucks and the typical crossover encroachment for left-turning trucks (Figures 7 and 8). Indications are that truck operators and other drivers cooperate more or less to compensate for the lack of turning space. As a result, intersection operations are improved in ways not envisioned by theoretical solutions. For example, there were numerous instances in which vehicles would deflect into the parking lanes at the intersection approaches to allow turning trucks sufficient clearance to encroach and complete their maneuvers. It was readily apparent that left-turning trucks consistently use the parking lane as a bypass lane, if it is available.

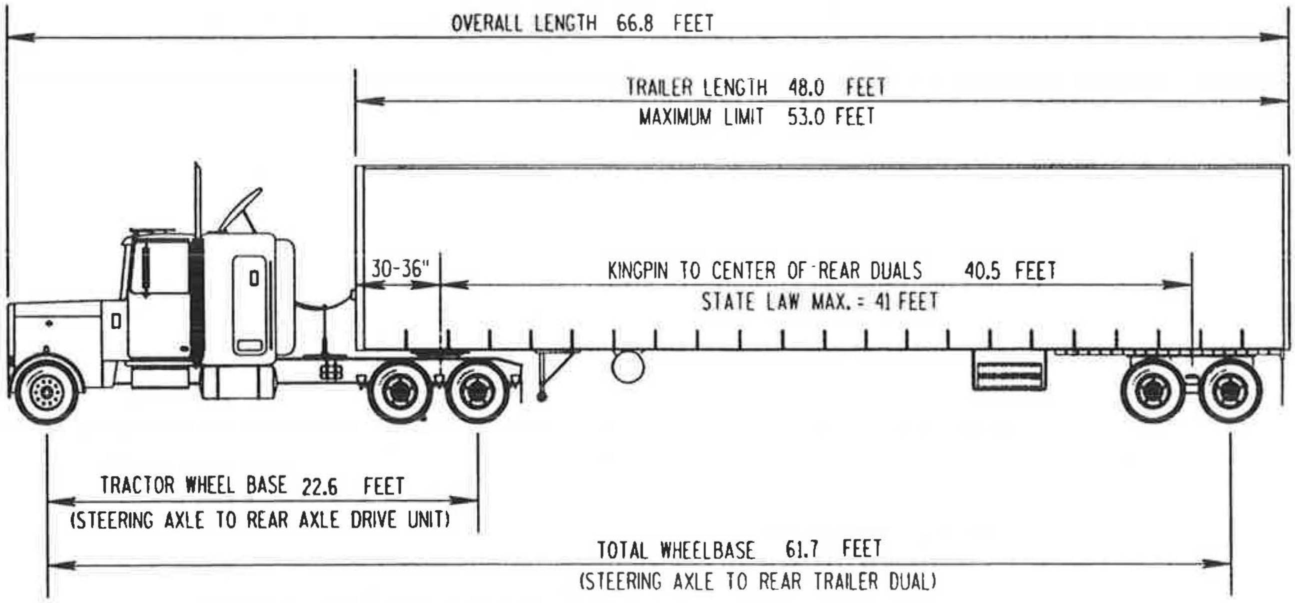

FIGURE 5 Control vehicle dimensions.

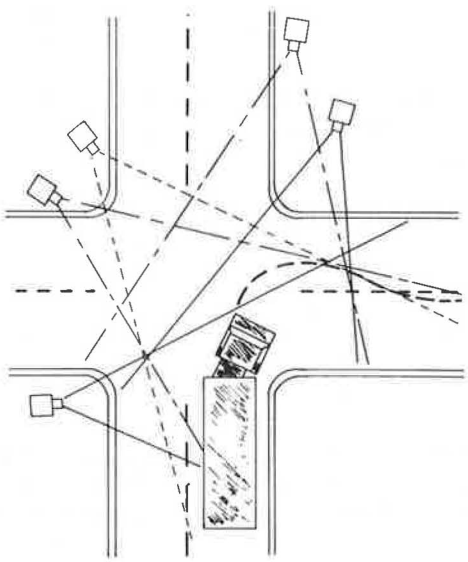

FIGURE 6 Diagram of camera layouts.

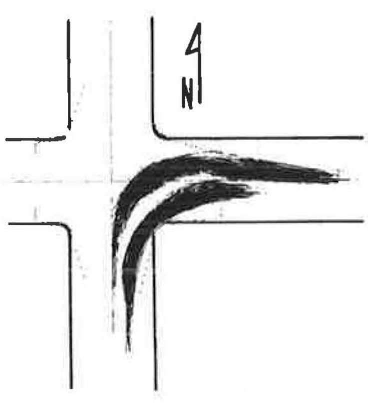

FIGURE 7 Right-turning wheelpaths.

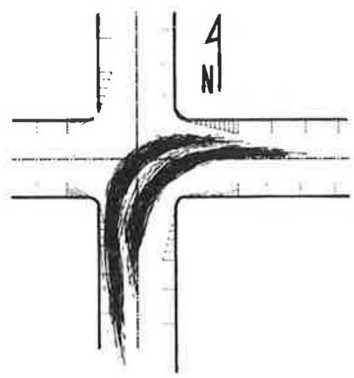

FIGURE 8 Left-turning wheelpaths.

The prevalence of gaps that allowed truckers to complete their right-turning maneuvers was important. Even in relatively high-volume situations (10,000 ADT), enough gaps were available in the traffic stream controlled by a three-way stop to accommodate all arriving trucks with only moderate queueing. Another discovery was the observed relationship between lane width and encroachment distance. For example, if lane widths are reduced from 12 to 10 ft, the minimum encroachment distance for a WB-62 truck only increases roughly 10 percent. Very few trucks ran up on the inside curb in areas where there were sidewalks. The few that did encroach did so minimally. There appeared to be much more concern on the part of truck operators about rear-wheel encroachment on the sidewalk than cross-centerline encroachment by the front of the tractor.

Figures 9 through 12 show the actual wheelpaths of right-turning trucks for the four urban intersections. Figure 13 shows the composite mean, inner, and outer envelopes of truck turning paths for the four intersections superimposed. These dia-

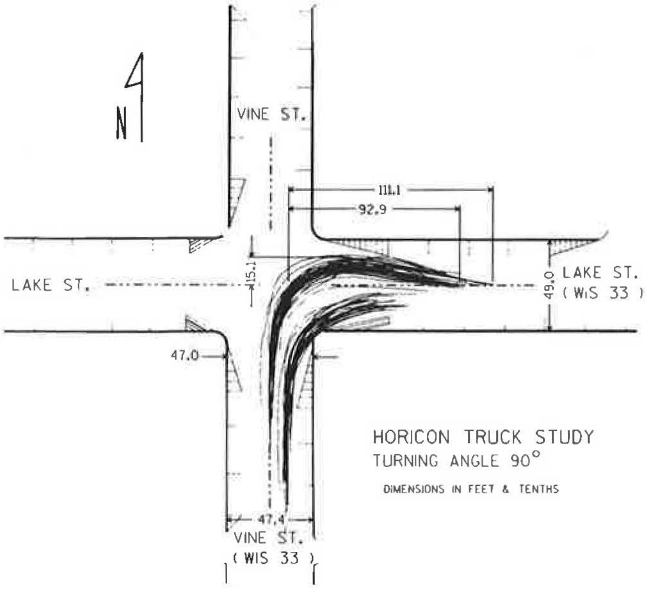

FIGURE 9 Actual wheelpaths, Horicon, Wisconsin.

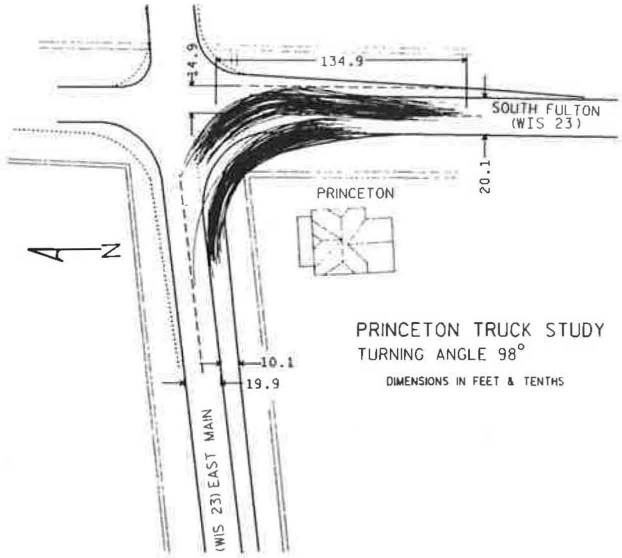

FIGURE 11 Actual wheelpaths, Princeton, Wisconsin.

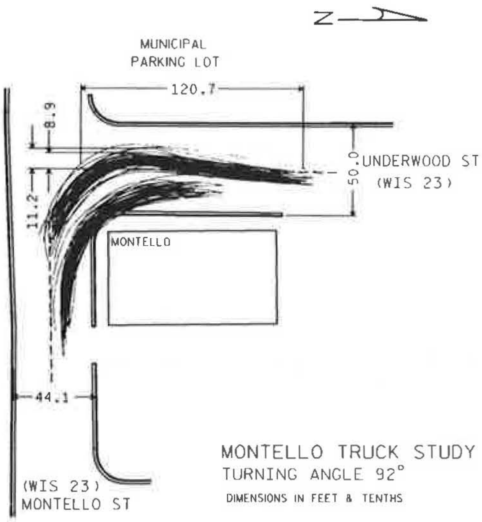

FIGURE 10 Actual wheelpaths, Montello, Wisconsin.

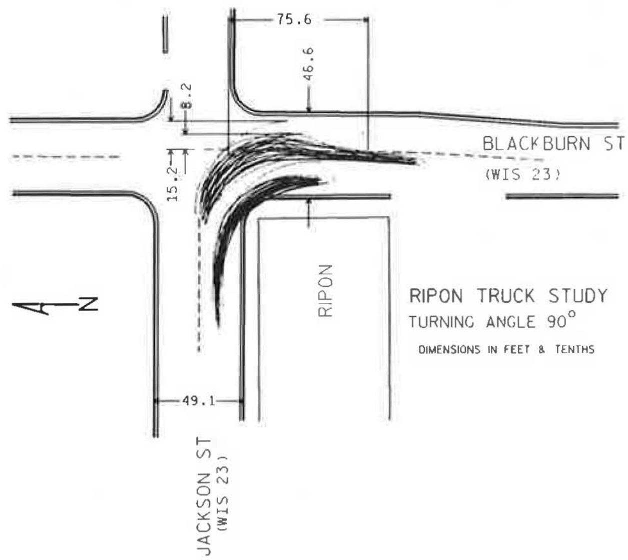

FIGURE 12 Actual wheelpaths, Ripon, Wisconsin.

grams clearly show that right-turning encroachment into lanes with moving traffic is a constant occurrence. However, most moderate-volume intersection approaches will tolerate a reasonable number of such movements because gaps of sufficient length are available.

MATHEMATICAL MODELING METHOD

By utilizing these field observations and integrating them with theoretical mathematical representations derived by the Institute of Transportation Engineers (*1*) and others, the researchers found that they could generalize the results and apply them to the majority of urban settings. Furthermore, graphical templates generated by computer-aided design and drafting (CADD) can be developed with the measurements taken from the precision photographs. A gap acceptance model was

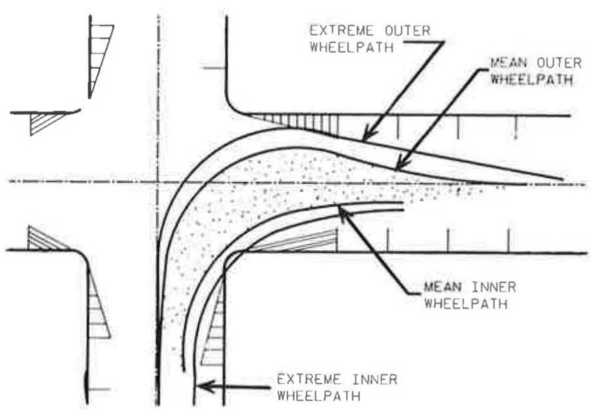

FIGURE 13 Composite mean, inner, and outer wheelpaths, all right-turning trucks.

developed to replicate the cross-traffic stream in five different general stop sign control conditions:

1. Case 1 (three-way stop, right turn no-stop for the truck approach): The observed upper-bound time gap that truck operators accepted in a "roll-through" stop with limited sight distance was 10 sec.

2. Case 2 (three way stop, right turn free flow, all other approaches required to stop): The acceptable gap was increased to 19 sec to account for the additional time for oncoming traffic to decelerate and stop (6 sec average time loss) and clear the stop bar upon reaccelerating (3 sec). This gap time was assumed to be relatively inelastic regardless of approach speed because of the approximate linear relationship between gap time and gap space. The operator must have a minimum time to accomplish the turning maneuver. As approach speeds vary in the most likely operating range of 25 to 55 mph, the space gap to provide acceptable time lengthens in linear fashion.

3. Case 3 (standard two-way stop): The acceptable time gap assumed was 14 sec, the minimum acceptable gap of 10 sec plus an acceleration time gap of 4 sec. The acceleration time to cross the near lane was considered the default value because this is the approximate time (in seconds) that it takes for a normal semitrailer to traverse a 12-ft lane according to the 1984 AASHTO policy (*2*). In addition, during the periods of peak flow it was assumed that a right-turning truck operator would move aggressively to accept a gap in opposing traffic of any reasonable duration, to the point of forcing any gap in traffic from the left that exceeded 4 sec.

4. Case 4 (three-way stop, trucks must stop, free-flow traffic from right): For the same reasons as in Case 3, a 14-sec gap was considered acceptable for a right-turning truck. In this case, traffic from the left would be metered by the stop sign to the trucker's left, thereby creating an acceptable gap from the left after every arrival.

5. Case 5 (four-way stop): Interposing a four-way stop condition was assumed to add all deceleration, acceleration, and reaction times to the observed 10-sec minimum gap. Thus, it would expand the required gap to 23 sec between the arrivals of Car 1 and Car 2 at the stop sign on the right approach. This case was regarded as the most restrictive of all stop-sign controlled configurations.

The graphs in Figures 14 to 17, inclusive, show ranges of ADTs that will provide acceptable gaps for right-turning vehi-

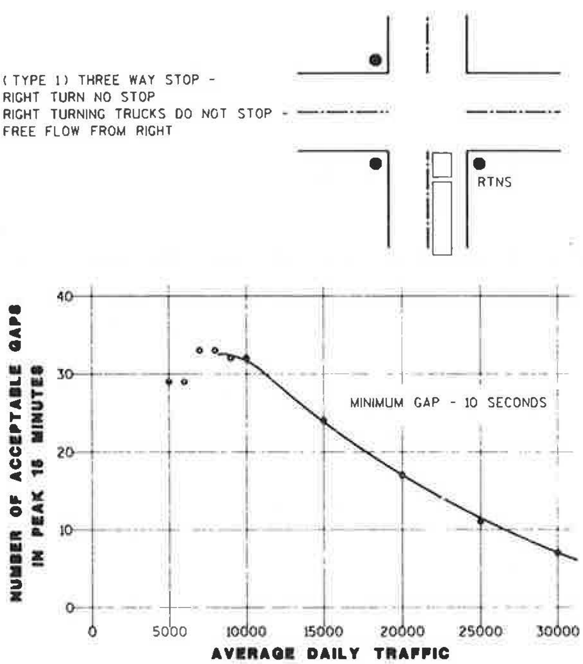

FIGURE 14 Crossroad gap availability curve for peak 15-min flow—Case 1.

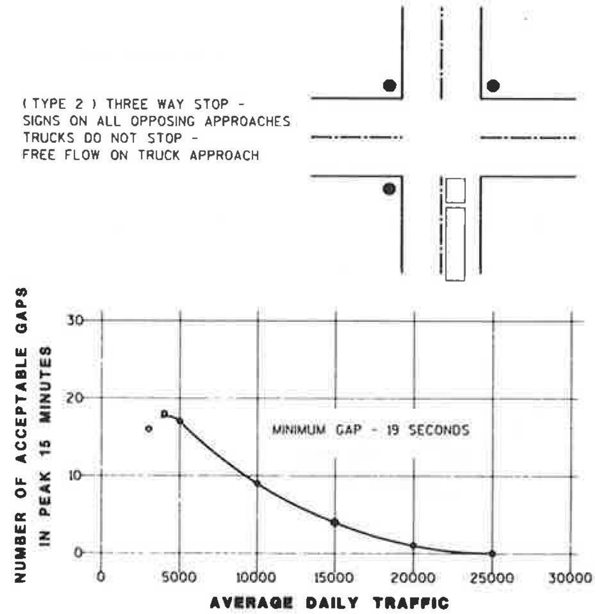

FIGURE 15 Crossroad gap availability curve for peak 15-min flow—Case 2.

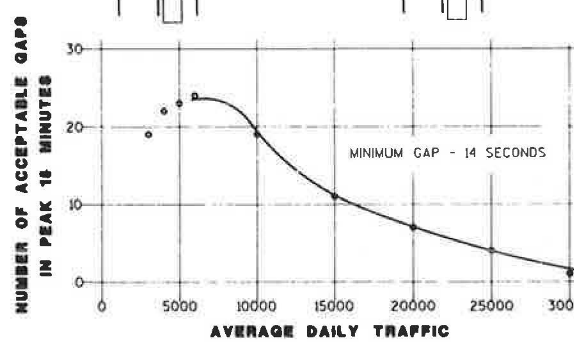

FIGURE 16 Crossroad gap availability curve for peak 15-min flow—Cases 3 and 4.

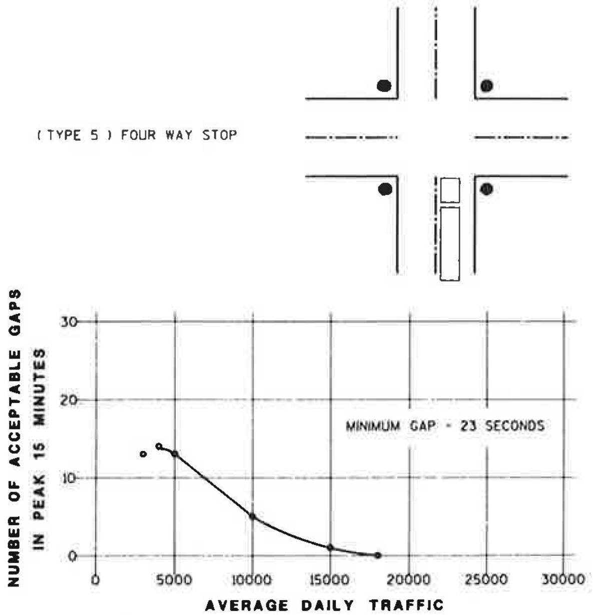

FIGURE 17 Crossroad gap availability curve for peak 15-min flow—Case 5.

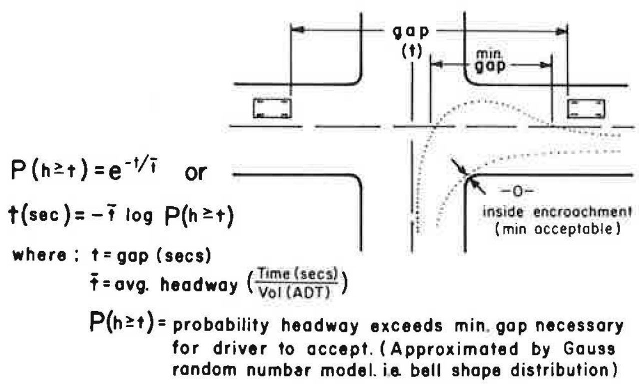

FIGURE 18 Development of negative exponential model.

cles for the time duration noted. The curves shown in these figures utilized the negative exponential distribution function to simulate intervals in the cross-traffic streams from 3,000 ADT to 35,000 ADT. Starting from the assumption that if there is no vehicle arrival in a time interval *t* (*3*), there will be a headway *h* of at least 10 sec between the last previous arrival and the next arrival (Figure 18),

$$P(0) = P(h \geq t) = e^{(-1/\bar{t})t}$$

where $\bar{t}$ is the mean headway and $P(h \geq t)$ is the probability that the headway exceeds the minimum gap necessary for the driver to accept. Then

$$P(h \geq t) = e^{-t/\bar{t}}$$

Transforming the equation,

$$\log P(h \geq t) = -t/\bar{t}$$

$$\bar{t} \log P(h \geq t) = -t$$

$$t = -\bar{t} \log P(h \geq t)$$

Traffic interval distributions were simulated by using a standard Gaussian random number generator to provide normally distributed decimal probabilities between 0.000 and 1.000 to replace $P(h \geq t)$ in the function.

By comparing the calculated or assumed input value for an acceptable gap, the researchers were able to simulate conditions in which truckers would respond to gaps as low as 4 sec. A minimum time study (15 to 30 min) during peak traffic flow could quickly refine the ability to estimate whether an intersection could function (albeit at reduced service levels) or whether arriving volumes were at or above breakdown conditions. These could also be used as design and planning tools to determine whether anticipated volumes and truck percentages would overload an intersection to the point at which it would have to be rebuilt. Another feature of the model is that it provides a method to determine optimal conditions based on assumed or measured gaps in traffic, which relate directly to observed encroachment patterns. Obviously, the longer a truck remains in or across a traffic lane, the greater the duration of the required gap to accommodate that movement. In addition, if sight distances are restricted, required reaction times will increase, causing a consequent reduction in numbers of acceptable gaps.

Figure 19 shows curves for the calculated number of acceptable gaps in the peak 15-min period for time intervals ranging from 4 to 25 sec. The model contrasts crossroad ADT with

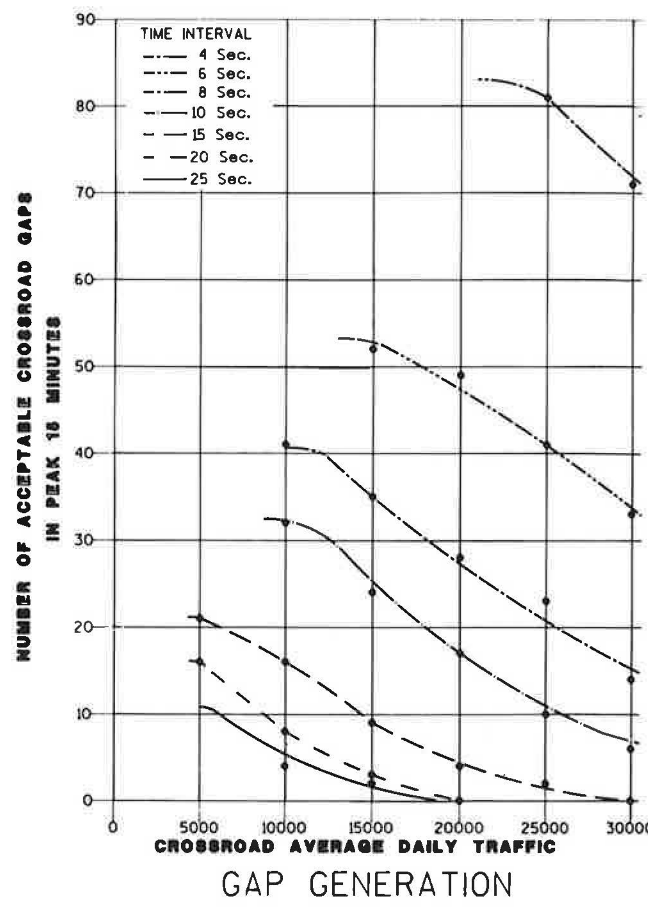

FIGURE 19 Gap availability curves for time intervals ranging from 4 to 25 seconds.

gaps of at least the time intervals specified for the peak 15 min.

PRACTICAL APPLICATIONS

The large number of potentially substandard intersections on the designated system highlights the need for a tool to aid in decision making. A study by the gap acceptance model can now be reviewed in the office. If entering ADTs and truck percentages can be determined, intersections can be evaluated on a standard personal computer or by using the curves in Figure 19. For example, if all trucks arriving on any approach are assumed to turn right (the worst-case condition), a quick assessment can be made as to the maximum crossroad ADT that can accommodate these movements, depending on the type of intersection control. If the number of cross-traffic gaps available substantially exceeds the calculated number of arriving trucks, the analyst can assume that the intersection will function within reasonable tolerances. If the number of available gaps is marginal (that is, at or below the calculated number of truck arrivals), field personnel can be assigned to perform a more in-depth study. This need not be more than a rush-hour study to determine

1. The average number of long-truck arrivals on all approaches;
2. The average number turning right, left, and proceeding straight through;
3. The approximate average time gap required for the right-turning long trucks;
4. The approximate percent of trucks on the critical approach(es);
5. The approximate vehicular counts on the approaches opposing the right-turning trucks;
6. The number of off-pavement encroachments (near-side and opposite side); and
7. The widths of approaches and approximate angles of intersection or right triangle measurement to allow the computation.

Figure 20 shows the optimum number of traffic-stream time gaps of a given duration for the peak 15-min period. Note that the curve drops steeply to a point of flexure as required gap times decrease from 4 to 10 sec. Optimum ADT declines rapidly as required gap times increase above 10 sec. The peak 15-min period was considered as the worst-case condition for cross-traffic flow. An analysis of Wisconsin's automatic traffic recording data showed average peaking characteristics somewhat higher than 9 percent of aggregated ADT. This was the peaking factor used in modeling the traffic stream.

Predictably, signalization of intersections with more than minimal right-turning trucks would create serious operational problems. Normally available gaps would disappear as opposing traffic queued up at the red signal. Trucks waiting to turn at the signal from the right-angle approach would be gridlocked. No possibility for encroachment on the outside of the turning path or offtracking inside would exist because of vehicular and building constrictions. Figure 21 illustrates this problem.

A second conclusion also emerges from the data. Even though sufficient gaps for right-turning trucks exist in the traffic stream, there is a lower-bound street dimension that will foreclose such maneuvers for all practical purposes. It appears from the data that if curb-to-curb street widths on the major approaches are 37 ft or less (including the parking lanes), the route should not be designated for long-truck operation without significant intersection alterations. This is for a current mix of trailer lengths that seldom exceeds 39 ft (overall

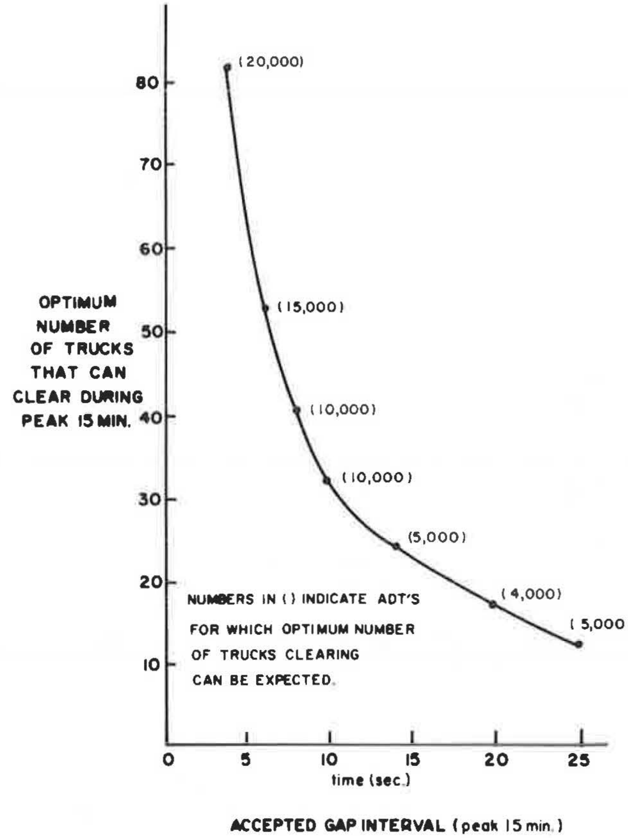

FIGURE 20 Optimum number of trucks that can turn right for a given gap time.

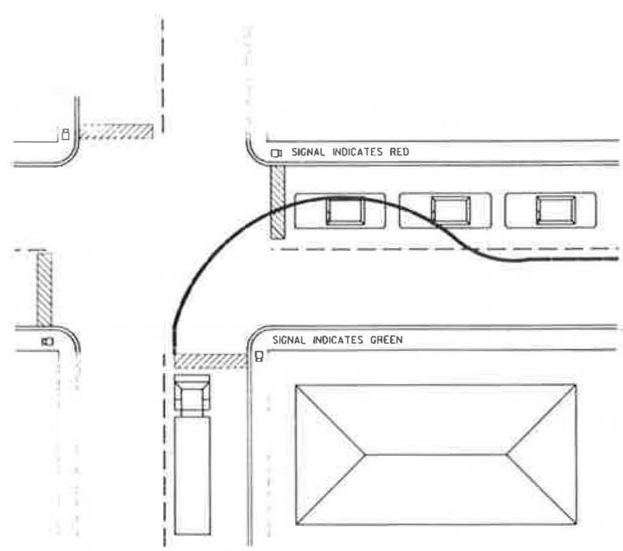

FIGURE 21 Illustration of effect of gap closure at red signal indication on cross street.

semitrailer wheelbases of 57 ft or less). The researchers believe that it will take about 5 years for the shorter trailers to be replaced by longer ones. Observed offtracking increases of 0.75 ft per foot of increased trailer wheelbase length indicate that the lower-bound street width dimension would increase to approximatley 40 ft by the time this turnover has taken place. This would maintain the approximate 9- to 10-ft average opposite-lane encroachment currently being experienced and would allow a bypass lane of similar width. Figures 22 through 25 illustrate the varying degrees of observable offtracking and encroachment severity as intersection approach widths decrease from 50 to 28.5 ft.

Using the nomographs constructed from the observed results and shown in Figures 26 and 27, the planning, design, or traffic engineer can now make several determinations.

1. The approximate average gap lengths in the opposing traffic streams required to accommodate right-turning trucks can be determined. This will also assist in determining how far to restrict parking to allow for a bypass lane.
2. The approximate average lateral encroachment that must be regularly available if a route is to be designated for right-turning trucks can be found. This will help determine whether the street width at the intersection is adequate for turning trucks under any circumstances. (The nomographs assume that the centerline equally divides the curb-to-curb dimension. Appropriate conversions should be made if the centerline is offset.) Using the curves for the gaps versus crossroad ADT (Figures 14–17), the number of gaps of a given time duration that will probably occur in the cross-traffic stream opposing right-turning trucks can be determined. The various traffic control configurations show the gap expectancies.

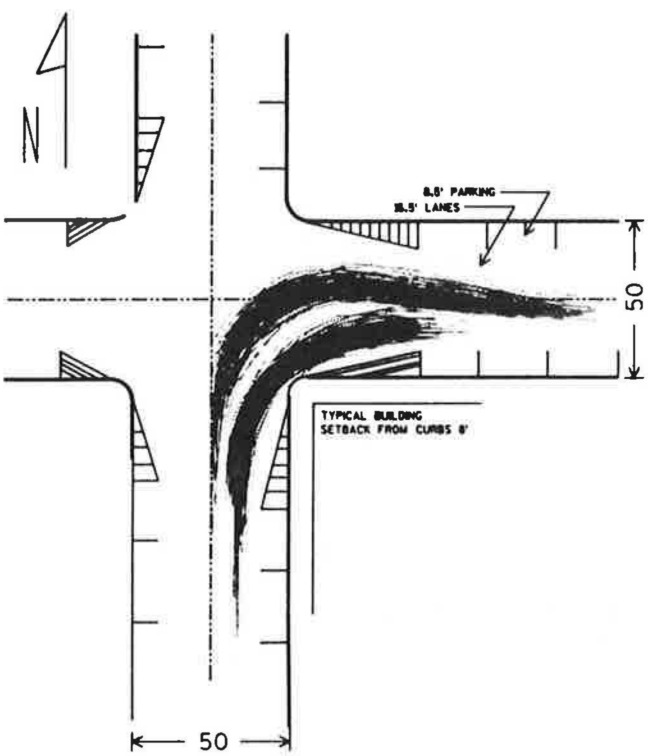

FIGURE 22 Offtracking/encroachment for 50-ft width approaches (note room available for opposing traffic to bypass encroaching trucks).

3. The probability that permitted overwide loads will be accommodated can also be estimated.
4. Finally, Figure 28 and Table 2 show the relationship between street width and stop bar location for left-turning trucks. This graphical solution, based on the actual measured observations of the left-turning truck population, allows the

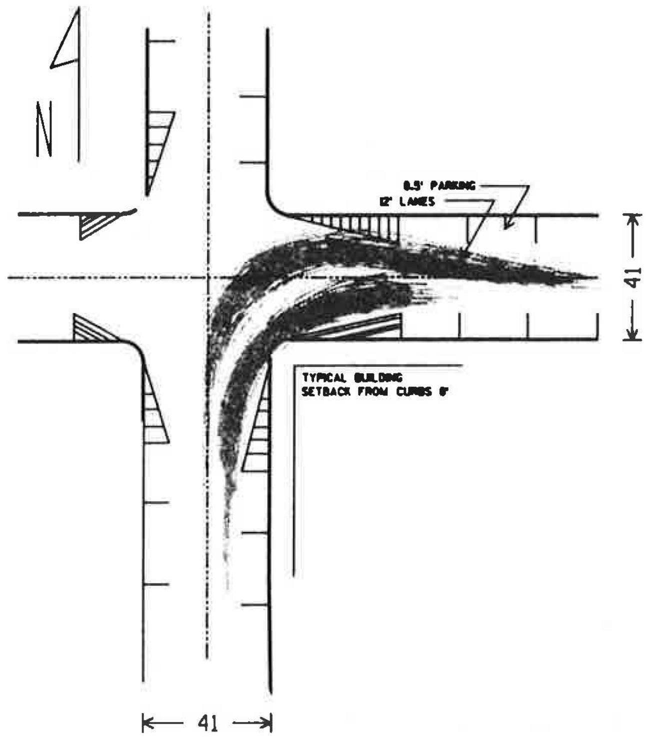

FIGURE 23 Offtracking/encroachment for 41-ft width approaches: trucks must ride up on inside curb or use full approach width to complete turns.

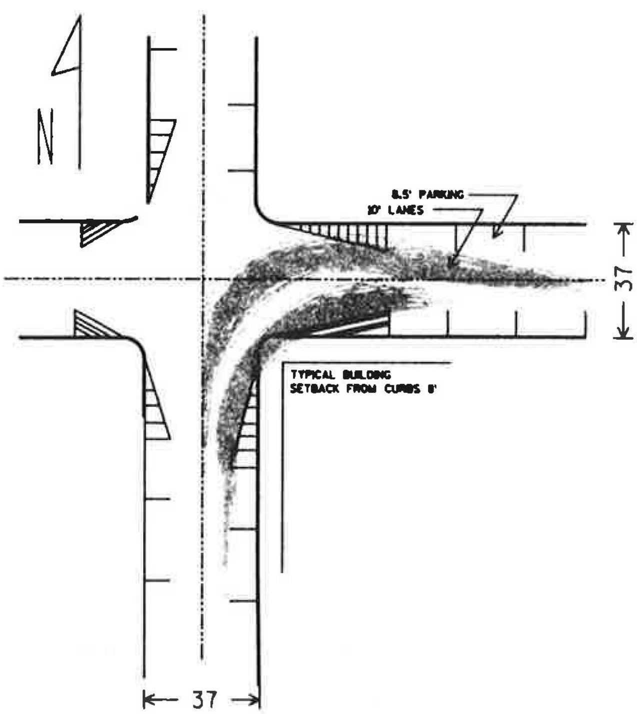

FIGURE 24 Offtracking/encroachment for 37-ft width approaches: entire approach width used; most trucks will ride over inside curb.

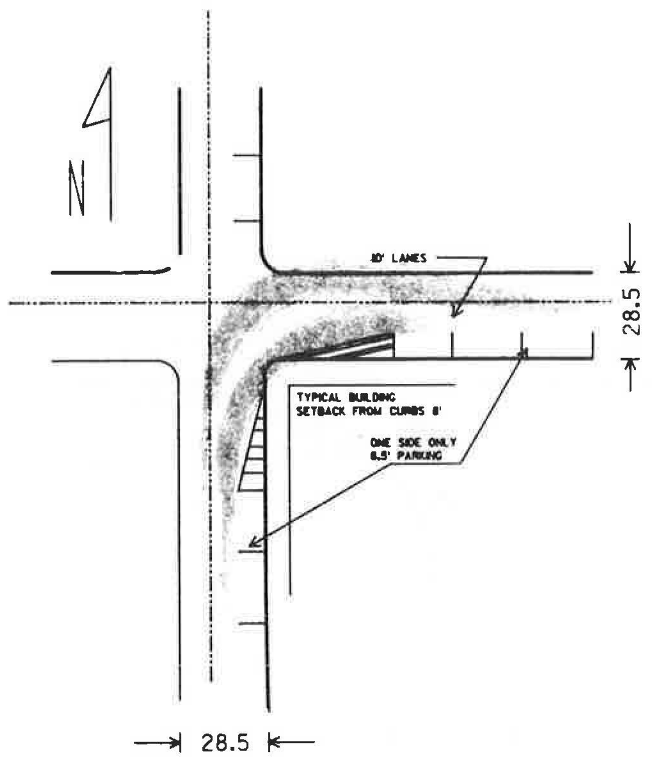

FIGURE 25 Offtracking/encroachment for 28.5-ft width approaches: truck turning movements severely restricted (note distance that trucks traverse behind curbs).

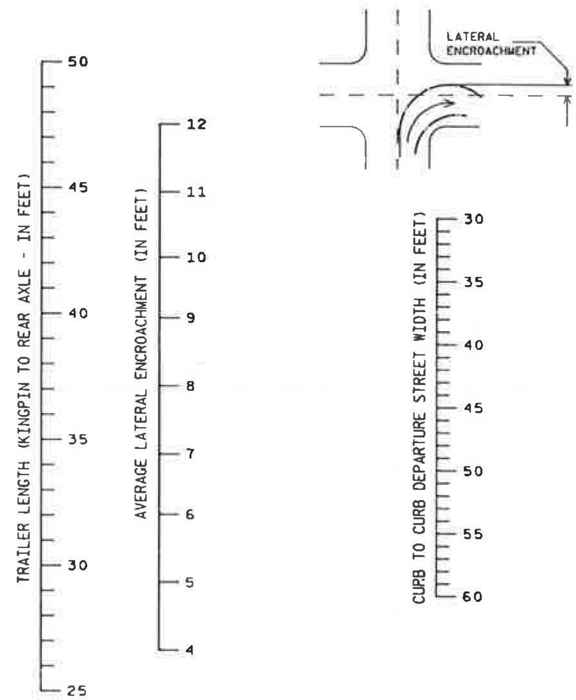

FIGURE 27 Nomograph of lateral encroachment.

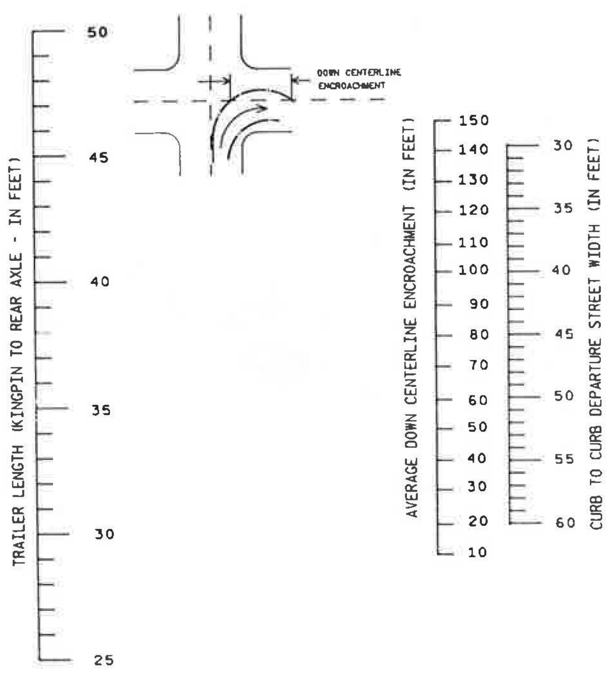

FIGURE 26 Nomograph of sown-centerline encroachment.

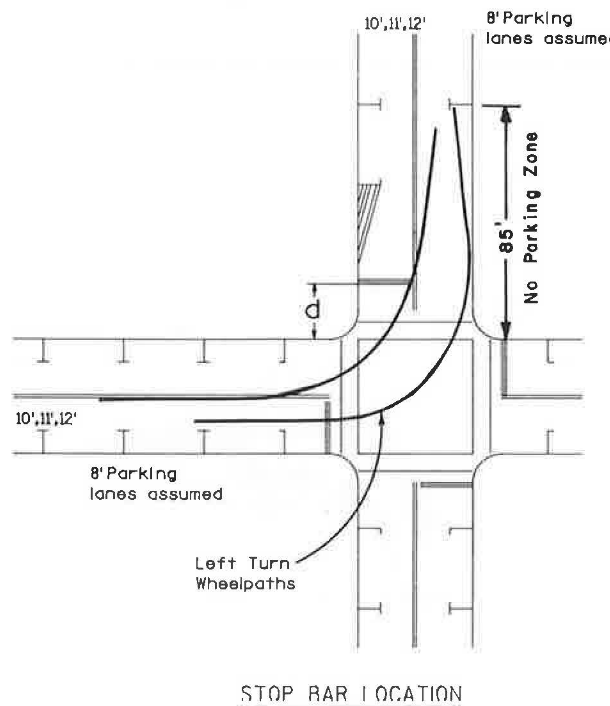

FIGURE 28 Left turn effects on stop bar and parking stall location.

TABLE 2 STOP BAR LOCATION AS A FUNCTION OF STREET WIDTH

Driving Lane Widths (ft)		STOP Bar Distance from back of curb
Turning from	Turning into	d (ft)
10	10	32
11	10	28
12	10	27
10	11	25
11	11	25
12	11	23
10	12	22
11	12	21
12	12	19

engineer to accurately locate signals, signs, parking zones, and other street furniture to help prevent traffic conflicts and accidents. It should be noted, however, that sight distance requirements increase markedly as streets narrow. Therefore engineers should consider removing parking downstream from the stop bar when existing sight restrictions cannot be removed. This would allow the opportunity to shift arriving traffic into the parking lane, reducing the conflict area and allowing stop bar placement much closer to the center of the intersection.

CONCLUSIONS AND RECOMMENDATIONS

1. Critical maneuvers on the designated highway system are right turns in downtown areas.
2. Highways on downtown two-lane streets that are 37 ft wide or less and have right-angle turns at one or more intersections should not be included in a designated highway system if there are large numbers of long trucks in the traffic stream.
3. Installing signals at downtown intersections on the designated highway system can cause serious operational problems for both left- and right-turning long trucks.
4. The best apparent traffic control configuration for downtown intersections is one that maximizes free traffic flow on the heavy-volume approaches and minimizes pedestrian conflicts by placing crosswalks on minor-volume approaches.
5. The optimum traffic volume that will accommodate the largest number of long trucks during rush hours is approximately 10,000 ADT on two-lane cross streets.
6. Parking along the first 100 ft of the critical lanes (the left-turning truck's passenger side and the right-turning truck's driver side) hinders efficient traffic operation if there are high percentages of left- or right-turning trucks during peak hours.
7. Before resorting to full-scale intersection revision or signalization, numerous well-known measures should be tried, namely,

- Removing parking,
- Offsetting (shifting) the location of the centerline,
- Prohibiting rush-hour parking,
- Reducing restrictive traffic control measures,
- Increasing sight distances,
- Minimal widening (if possible),
- Diverting traffic,
- Metering cross-traffic flow through installation of upstream signals,
- Prohibiting long-truck operation during rush hours,
- Restricting right turns, and
- Restricting operation to vehicles with special equipment (such as steerable rear axles).

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