Evaluating the Manoeuvrability of Theoretical Tractor-Trailer Combinations and Extended Trailer Configurations on Winnipeg Truck Routes

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Abstract

When transporting low density freight, some trucks “cube out” before reaching their maximum allowable weight. This creates demand for vehicles with higher cubic capacity for certain operations. Evidence of this can be seen in the significant increase in the number of WB-36 trucks (turnpike doubles) on Canadian roads. In recent years some jurisdictions have also begun to permit the use of extended trailers to address this issue, such as the 60’ extended trailers being piloted by the Ontario Ministry of Transportation. Ultimately, this creates a potential safety issue, when trucks larger than the current design vehicles are allowed to operate on existing infrastructure.

As freight movement demands and the use of large trucks increases it is important to ensure that existing infrastructure can accommodate these vehicles. Jurisdictions often attempt to accommodate trucks through geometric design; however, the benefits from these improvements can only be realised on newly constructed or retrofitted roadways. Conversely, modifications to the trucks themselves can improve their manoeuvring capabilities on all existing facilities. The objectives of this paper are to: (1) evaluate truck design modifications with respect to their effect on truck turning characteristics; and (2) investigate the capability of Winnipeg’s existing infrastructure to accommodate new truck and trailer configurations.

This paper was developed based on three key research tasks: (1) an environmental scan, consisting of a literature review and a jurisdictional survey, to determine factors that affect truck manoeuvrability, identify truck design modifications that improve manoeuvrability, and identify locations in Winnipeg that pose operational challenges for trucks; (2) analytical modeling of theoretical tractor-trailer combinations used in Winnipeg using AutoTURN turning simulation software to assess the effect of various design modifications on the vehicles’ turning characteristics; and (3) analytical modeling of truck configurations with extended trailers using AutoTURN turning simulation software to determine if they can be operated safely on Winnipeg’s existing infrastructure from an off-tracking perspective.

Analysis of the vehicle design modifications indicated the need for further analysis to determine if the positive impacts on safety attributable to increased manoeuverability outweigh the negative impacts associated with an increased front and rear swing out. Analysis of the extended trailer configurations indicated a need for field testing to determine if the difference in turning performance output by AutoTURN translates into practical differences for actual trucks on Winnipeg’s truck routes. However, since the extended trailer configuration outperformed the WB-36 with respect to turning performance, it is not hard to imagine a scenario in which extended trailer configurations are allowed to operate in Winnipeg under permit as long as they stay on preapproved routes, much like the WB-36 trucks are today.

1 Introduction

When transporting low density freight, some trucks “cube out” before reaching their maximum allowable weight. This creates demand for vehicles with higher cubic capacity for certain operations. Over the past 40 years the cubic capacity of trucks traveling on Canadian roads has steadily increased due to: (1) the use of longer combination vehicles; and (2) the gradual increase in trailer length. These changes in the Canadian truck fleet were made possible due to the implementation of several policies, including the 1974 Western Canada Highway Strengthening Program (WCHSP), the 1988 Roads and Transportation Association of Canada (RTAC) Memorandum of Understanding (MoU) on Heavy Vehicle Weights and Dimensions, as well as the special permitting of longer combination vehicles (LCVs) [1]. As freight movement demands and the use of large trucks increases it is important to ensure that existing infrastructure can accommodate these vehicles.

The objectives of this paper are to: (1) evaluate truck design modifications with respect to their effect on truck turning characteristics; and (2) investigate the capability of Winnipeg’s existing infrastructure to accommodate truck configurations with extended trailers.

This paper was developed based on three key research components: (1) an environmental scan, (2) analytical modeling of theoretical tractor-trailer configurations; and (3) analytical modeling of truck configurations with extended trailers.

2 Environmental Scan

The environmental scan component of this research consisted of an extensive literature review and jurisdictional survey. The literature review was conducted to identify truck design modifications that improve manoeuvrability and identify truck configurations with extended trailers that could potentially operate on Manitoba’s roads in the future.

The jurisdictional survey portion of the environmental scan was conducted via telephone, targeting the major trucking companies in Manitoba. The intent of the jurisdictional survey was to get a better understanding of the potential for using extended trailer combinations in Manitoba.

2.1 Truck Design Modifications

Jurisdictions often attempt to accommodate trucks through geometric design; however, the benefits from these improvements can only be realised on newly constructed or retrofitted roadways. Conversely, modifications to the trucks themselves can improve their manoeuvring capabilities on all existing facilities.

The manoeuvrability of trucks can be measured in many ways, but for the purpose of this paper it will be discussed in terms of off-tracking, swept-path width, and turning radius. Off-tracking is defined as the distance between the path of the front inside wheel and the rear inside wheel while turning. The magnitude of off-tracking varies based on vehicle configuration and varies in direction based on speed [2]. Off-tracking can be classified as high-speed or low-speed. This paper only addresses low-speed off-tracking because trucks are typically subject to low-speed off-tracking in urban areas. In low-speed off-tracking the rear wheel path deviates towards the inside of turn.

Swept-path is defined as the "widest path swept out by the sides and overhangs of the vehicle" and is designated by the green lines in Figure 1 [3]. The distance between the green lines in Figure 1 is known as the swept-path width. The swept-path width determines how much room a vehicle requires in order to negotiate a turn and limits how sharp of a turn that vehicle can make. Vehicles that are prone to off-tracking tend to have larger swept-path widths, and as a result larger minimum turning radii.

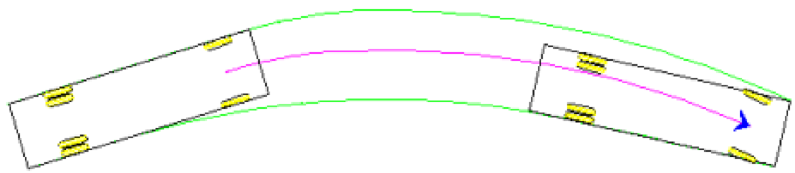


Figure 1: Swept-Path Diagram [3]

Two truck design modifications identified by the literature review that reduce off-tracking, and subsequently also reduce swept-path width are: (1) increasing the kingpin setback (the distance from the center of the kingpin to the point on the front of the trailer directly ahead of the kingpin); and (2) increasing the rear effective overhang (distance from the centre of the rear axle to the back of the trailer). Both of these design modifications reduce off-tracking by reducing the wheelbase of the trailer. It should be noted that this paper does not address the effects that adjusting the kingpin location and adjusting the rear axle location have on axle load distribution.

Although increasing kingpin setback and increasing rear effective overhang are known to improve manoeuvrability, they also are known to have negative safety impacts. From a safety perspective, the main consequence of increasing the kingpin setback is the subsequent increase to the front swing-out of the trailer and the main consequence of increasing rear effective overhang is the subsequent increase to the rear swing-out of the trailer. Trailer swing-out is regulated in order to prevent trailers from encroaching on the edge of the travel way and encroaching on other lanes during turning movements. In the 1986 RTAC Vehicle Weights and Dimensions Study, a truck conducting an 11m turn with a rear effective overhang 50% of the wheelbase resulted in a swing-out of 0.5m. The conclusions of this study indicated that swing-out intrusion values beyond 0.3m should tentatively be considered dangerous and directly contributed to the development of the RTAC vehicle dimension limits, as stated in Table 1 [4].

2.2 Extended Trailers

Over the past few decades North America has experienced an "expansion of the cubic capacity of domestic freight containers and trailers — from 12.2m (40ft.), to 13.7m (45ft.), to 14.6m (48ft.), and to the current widely adopted 16.2m (53 ft.) length" [1]. Further to this trend, in 2012 the Province of Ontario was approached by industry to look into permitting the use of tractor-trailer combinations with trailers greater than 16.2m in length. According to the program's permit conditions with the Ontario Ministry of Transportation, the first configuration features a cab-over tractor and an 18.44m (60.5ft.) drop-deck trailer (Figure 2) and the second configuration has a short-nosed tractor and an 18.44m (60.5ft.) dock height trailer (Figure 3). Both configurations have an overall length of 23m. The drop-deck trailer and dock height trailers have approximately 28% and 14% higher cubic capacity than a standard 16.2m trailer, respectively [5].

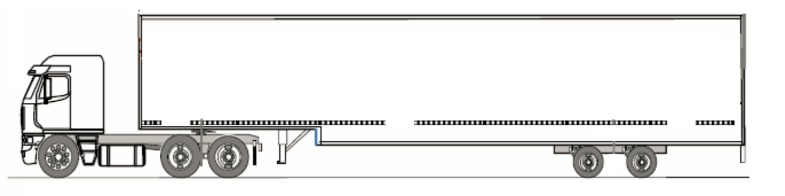


Figure 2: Cab-over Tractor with an 18.44m Drop-Deck Trailer [5]

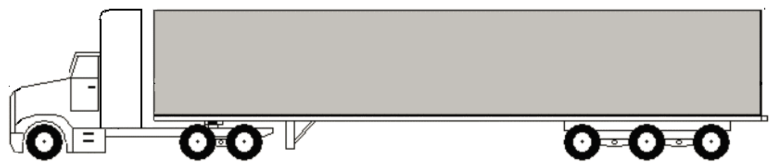


Figure 3: Short-nose Tractor with an 18.44m Dock Height Trailer [5]

Although Ontario is the only province currently piloting these vehicles, it is possible that in the near future other provinces may look into the potential of using trucks with extended trailers. As such, major Manitoban trucking companies were contacted to determine if they had any plans to adopt either of the above configurations or develop their own extended trailer configuration. The following companies were contacted for information:

- Bison Transport
- Big Freight Systems Inc.
- Gardewine Group Inc.
- Kindersley Transport Ltd.
- Kleysen Group LP
- Manitoulin Transport
- Quik X Transportation Inc.
- Transportation Ease and Management Services (T.E.A.M.S.)
- Vitran Express Canada Inc.
- Yanke Group of Companies
- Winnipeg Motor Express Inc.

None of the surveyed companies showed interest in using either of the aforementioned extended trailer truck configurations at this time and stated that they had no intentions of changing any of their current fleet in the foreseeable future. However, a meeting with Manitoba Infrastructure and Transportation (MIT) Motor Carrier Business Division revealed that one anonymous trucking company has requested the use of a tractor having a wheelbase of between 5.5 and 6.2m with an 18.15m (59.5ft) trailer for use in Manitoba. The dimensions of the proposed tractor-trailer configuration are shown in Figure 4 and Table 1. For the remainder of this paper this truck configuration will be referred to as the WB-20 extended trailer.

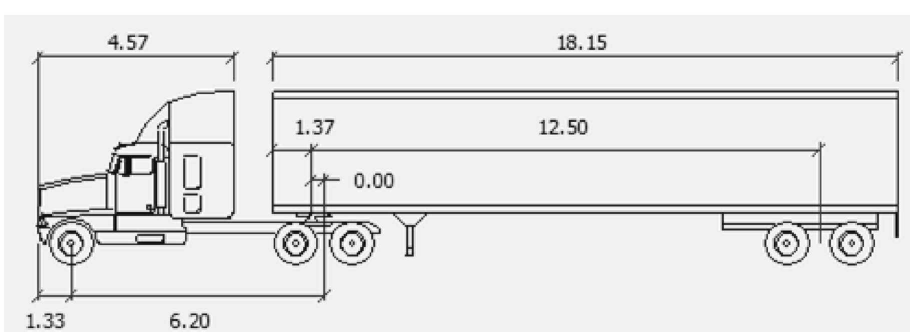


Figure 4: Proposed 24.31m WB-20 Extended Trailer Dimensions (m)

As shown in Table 1, the WB-20 extended trailer exceeds the RTAC limits for trailer length and overall length. Therefore, there is need to model the turning movements of this truck configuration to evaluate its turning performance and determine if it can safely operate on Manitoba's road network, or portions thereof.

Table 1: Vehicle Dimensions for WB-20, WB-20 Extended Trailer, and RTAC Trucks

Dimension	WB-20 [6]	WB-20 Extended Trailer	RTAC Limits [7]
Overall Length (m)	22.7	24.31[1]	23.0
Width (m)	2.6	2.6	2.6
Tractor Wheelbase (m)	6.2	6.2	6.2
Trailer Length (m)	17.0[1]	18.15[1]	16.2
Radial Kingpin Setback (m)	1.84	1.89	2.0
Trailer Wheelbase (m)	12.4	12.5	6.25 – 12.5
Effective Rear Overhang (m)	3.3	4.28	Max 35% of Trailer Wheelbase

[1] This value exceeds the RTAC limit and Ontario HTA limit

3 Analytical Modeling of Theoretical Tractor-trailer Configurations

The purpose of this section of the paper is to assess the effect of various design modifications on the turning characteristics of WB-20 and WB-36 trucks.

3.1 Methodology

The truck configurations selected for analysis were the WB-20 and WB-36. The WB-20 was selected because it is the design vehicle used in Manitoba. The WB-36 was selected because it has the largest design minimum turning radius of a routinely permitted vehicle in Manitoba. The dimensions of the base vehicles used in the study are shown in Figure 5.

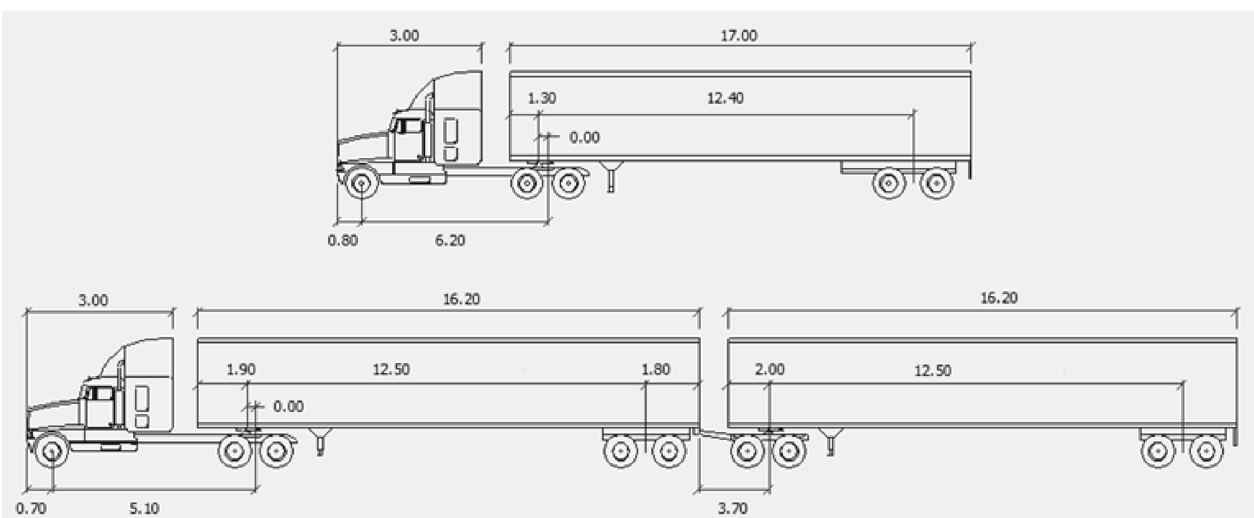


Figure 5: WB-20 (Top) and WB-36 (Bottom) Base Vehicle Dimensions (m)

AutoTURN software was used to model the turning movements for each of the truck configurations. The AASHTO WB-109D truck configuration was modified to match the dimensions and configuration of a WB-36 truck because the WB-36 truck configuration was not included in the software. However, the TAC WB-20 truck configuration was included in the software, so no modifications were required.

In order to study the effects of adjusting the kingpin setback and rear effective overhang a series of theoretical configurations were created by adjusting the kingpin setback and rear effective overhang from the base WB-20 and WB-36 configurations. The trucks were modified in increments of 0.1m for kingpin setback or increments of 0.2m – 1.0m for the rear effective overhang. Due to the nature of AutoTURN, when adjusting the kingpin setback or rear effective overhang, the trailer wheelbase also had to be adjusted in order to keep all other trailer dimensions constant. For example, when creating the WB-20 K0.2 truck configuration (which has a kingpin setback 0.2m greater than the base WB-20 configuration) the trailer wheelbase had to be reduced by 0.2m to ensure the length of the trailer and rear effective overhang remained constant. The theoretical truck configurations can be seen in Table 2. The configurations are named based on their modification from the base vehicles. The letter "K" represents an increase to the kingpin setback and the letter "R" represents an increase to the rear effective overhang. The numerical value beside each letter in the configuration name represents the magnitude of the increase in metres.

Table 2: WB-20 Truck Configuration Dimensions

Theoretical Truck Configuration[1]	Trailer Length (m)	Kingpin Setback[2]		Trailer Wheelbase (m)	Rear Effective Overhang	
		Linear (m)	Radius (m)		Dimension (m)	% of Wheelbase
Base	17.0[3]	1.3	1.84	12.4	3.3	27%
K0.1	17.0[3]	1.4	1.91	12.3	3.3	27%
K0.2	17.0[3]	1.5	1.98	12.2	3.3	27%
K0.3	17.0[3]	1.6	2.06[3]	12.1	3.3	27%
K0.4	17.0[3]	1.7	2.14[3]	12.0	3.3	27%
K0.5	17.0[3]	1.8	2.22[3]	11.9	3.3	27%
R0.2	17.0[3]	1.3	1.84	12.2	3.5	29%
R0.4	17.0[2]	1.3	1.84	12.0	3.7	31%
R0.6	17.0[2]	1.3	1.84	11.8	3.9	33%
R0.8	17.0[2]	1.3	1.84	11.6	4.1	35%

[1] K represents a vehicle with an adjusted kingpin setback; R represents a vehicle with an adjusted rear effective overhang. The numerical value beside each letter in the configuration name represents the magnitude of the increase in metres.
[2] The kingpin setback can be measured linearly as the distance from the center of the kingpin to the front of the trailer, directly ahead of the kingpin or radially as the distance from the center of the kingpin to the furthest point along the front of the trailer.
[3] This value exceeds the RTAC limit.

Table 3: WB-36 Truck Configuration Dimensions

Theoretical Truck Configuration[1]	Trailer Lengths (m)	First Trailer		Second Trailer		
		Kingpin Setback[2]		Trailer Wheelbase (m)	Rear Effective Overhang	
		Linear (m)	Radius (m)		Dimension (m)	% of Wheelbase
Base	16.2	1.9[3]	2.30[3]	12.5	1.7	14%
K0.1	16.2	2.0[3]	2.39[3]	12.5	1.7	14%
K0.2	16.2	2.1[3]	2.47[3]	12.5	1.7	14%
K0.3	16.2	2.2[3]	2.56[3]	12.5	1.7	14%
K0.4	16.2	2.3[3]	2.64[3]	12.5	1.7	14%
K0.5	16.2	2.4[3]	2.73[3]	12.5	1.7	14%
R0.4	16.2	1.9[3]	2.30[3]	12.1	2.1	17%
R0.8	16.2	1.9[3]	2.30[3]	11.7	2.5	21%
R1.2	16.2	1.9[3]	2.30[3]	11.3	2.9	26%
R1.6	16.2	1.9[3]	2.30[3]	10.9	3.3	30%
R2.0	16.2	1.9[3]	2.30[3]	10.5	3.7	35%
R3.0	16.2	1.9[3]	2.30[3]	9.5	4.7[3]	49%[3]

[1] K represents a vehicle with an adjusted kingpin setback; R represents a vehicle with an adjusted rear effective overhang. The numerical value beside each letter in the configuration name represents the magnitude of the increase in metres.
[2] The kingpin setback can be measured linearly as the distance from the center of the kingpin to the front of the trailer, directly ahead of the kingpin or radially as the distance from the center of the kingpin to the furthest point along the front of the trailer.
[3] This value exceeds the RTAC limit.

To model turning performance, the different vehicle configurations were tested using an approximation of the AASHTO (2004) Green Book minimum turning path model shown in Figure 6 [8]. In this model the trucks completed a 180° turn with a radius as small as permitted, as to subject them to low-speed off-tracking. The turning radius of each truck configuration was governed by said configuration’s default steering lock angle. The default steering lock angles provided by AutoTURN were 28.3° for the WB-20 truck configuration and 17.1° for the WB-36 truck configuration. The steering lock angle refers to the maximum angle that the wheels on the steering axle of the tractor can turn.

In each AutoTURN model, the following turning characteristics were recorded for each truck configuration: (1) the vehicle swept-path; (2) the centerline path of the steering axle; and (3) the wheel path of the steering axle.

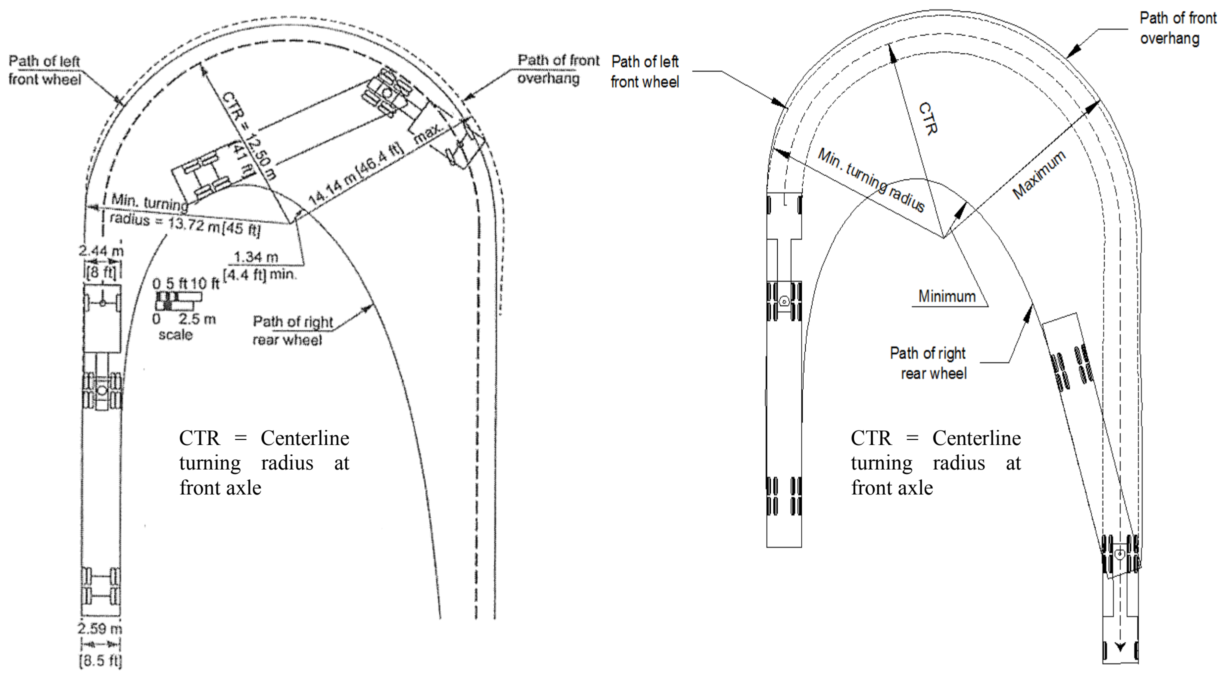


Figure 6: AASHTO Minimum Turning Path Model (left) [8] vs. AutoTURN Minimum Turning Path Model (right)

The minimum inside radius, maximum swept-path width, and maximum front overhang were determined using the swept-path and the steering axle wheel path. In each model, the inside line of the swept path was the path of the right rear wheel and the outside line was the path of the front overhang. The minimum inside radius was determined by calculating the shortest distance between the right rear wheel path and the center point of the turn. Larger minimum inside radii indicate less low-speed off-tracking and the ability to remain clear of larger obstacles in the center of the turn, for a given centerline turning radius. The maximum swept-path width was output by AutoTURN for each turning simulation. The maximum front overhang was determined by calculating the largest distance from the path of the left wheel on the steering axle to the path of the front overhang.

3.2 Analysis

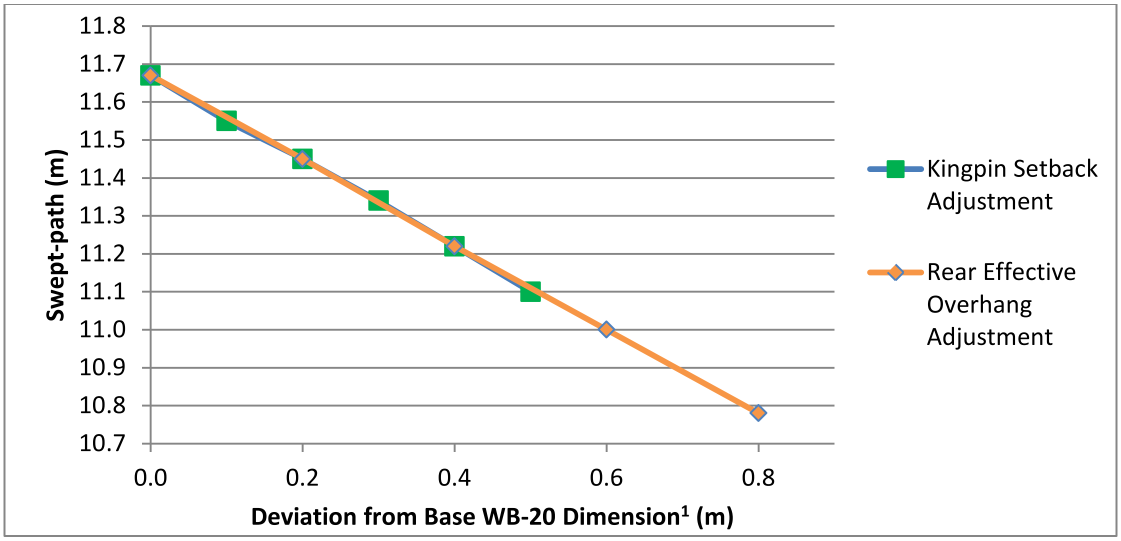
As shown in Table 4, increasing the kingpin setback and rear effective overhang of the trailers reduced the swept-path of the vehicles. However, increasing the kingpin setback in both configurations increased the maximum front overhang. It should be noted the maximum front overhang for WB-20 turning models with a kingpin setback of 1.3m occurred while the vehicle was turning at the maximum steering lock. At greater kingpin setbacks, the maximum overhang occurred after the wheels on the steering axle had returned to a 0° steering angle, near the end of the turning manoeuvre. This difference occurred because in WB-20 turning models with a kingpin setback of 1.3m the path of the front overhang was governed by the front left corner of the tractor, whereas in models with kingpin setbacks greater than 1.3 metres the path of the front overhang was governed by the front swing-out of the trailer. In all WB-36 turning models, the path of the front overhang was governed by the front swing-out

Table 4: Turning Path Dimensions for Models in a 180° turn at 9.66km/h (6mph)

Base Model Configuration	Vehicle Name[1]	Kingpin Setback (m)	Rear Effective Overhang (m)	CTR[2] (m)	Min. Inside Radius (m)	Max. Swept -path (m)	Change in Swept-path Width[3] (%)	Max. Front Overhang (m)
WB-20	Base	1.3	3.3	13.07	2.91	11.68	0.0%	0.34
	K0.1	1.4	3.3	13.07	3.03	11.56	-1.0%	0.35
	K0.2	1.5	3.3	13.07	3.14	11.45	-1.9%	0.40
	K0.3	1.6[4]	3.3	13.07	3.25	11.34	-2.8%	0.45
	K0.4	1.7[4]	3.3	13.07	3.36	11.22	-3.9%	0.48
	K0.5	1.8[4]	3.3	13.07	3.47	11.11	-4.9%	0.53
	R0.2	1.3	3.5	13.07	3.14	11.45	-1.9%	0.34
	R0.4	1.3	3.7	13.07	3.36	11.22	-3.9%	0.34
	R0.6	1.3	3.9	13.07	3.58	11.00	-5.7%	0.34
	R0.8	1.3	4.1	13.07	3.80	10.78	-7.6%	0.34
WB-36	Base	1.9[4]	1.7	17.34	3.65	15.15	-0.0%	0.61
	K0.1	2.0[4]	1.7	17.34	3.74	15.09	-0.3%	0.66
	K0.2	2.1[4]	1.7	17.34	3.82	15.09	-0.3%	0.70
	K0.3	2.2[4]	1.7	17.34	3.93	15.05	-0.6%	0.76
	K0.4	2.3[4]	1.7	17.34	4.02	15.01	-0.9%	0.81
	K0.5	2.4[4]	1.7	17.34	4.12	15.04	-0.9%	0.86
	R0.4	1.9[4]	2.1	17.34	4.01	14.78	-2.4%	0.61
	R0.8	1.9[4]	2.5	17.34	4.36	14.43	-4.8%	0.61
	R1.2	1.9[4]	2.9	17.34	4.71	14.08	-7.0%	0.61
	R1.6	1.9[4]	3.3	17.34	5.04	13.75	-9.2%	0.61
	R2.0	1.9[4]	3.7	17.34	5.36	13.43	-11.4%	0.61
	R3.0	1.9[4]	4.7	17.34	6.12	12.67	-16.3%	0.61

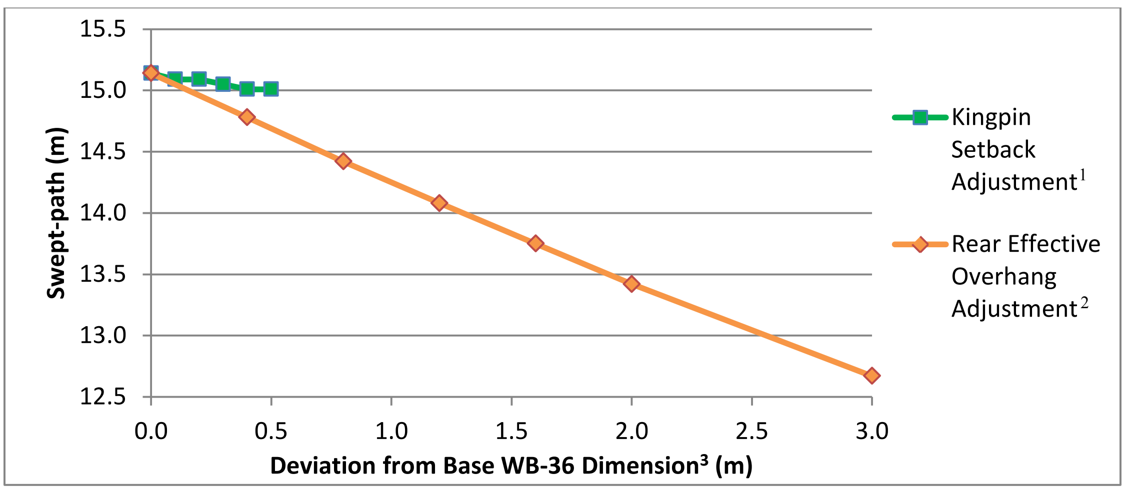
[1] K represents a vehicle with an adjusted kingpin setback; R represents a vehicle with an adjusted rear effective overhang
[2] CTR = Centerline turn radius
[3] The change in swept-path width for each model was measured against the base model for its respective vehicle type (negative % change corresponds to a decrease in swept-path width)
[4] This value exceeds RTAC limit

As it can be seen in Figure 7, for WB-20 truck configurations there is a linear relationship between swept-path width and kingpin setback, as well as between swept-path width and rear effective overhang. It can also be seen that adjustments to kingpin setback and rear effective overhang had similar impacts on swept-path width. However, as it can be seen in Figure 8, the same trend is not evident for WB-36 trucks. For WB-36 trucks rear effective overhang had a greater impact on swept-path width than kingpin setback.



[1] A deviation of 0.0m corresponds to the base vehicle dimension (i.e., 1.3m kingpin setback or 3.3m rear effective overhang)

Figure 7: Effect of Kingpin Setback and Rear Effective Overhang Increases on Swept-path Width for Theoretical WB-20 Truck Configurations



[1] Adjustment to the kingpin setback was applied to the first trailer only
[2] Adjustment to the rear effective overhang was applied to the second trailer only
[3] A deviation of 0.0m corresponds to the base vehicle dimension (i.e., 1.9m kingpin setback or 1.7m rear effective overhang)

Figure 8: Effect of Kingpin Setback and Rear Effective Overhang Increases on Swept-path Width for Theoretical WB-36 (TPD) Truck Configurations

4 Modeling and Analysis of Truck Configurations with Extended Trailers

Based on the result of the environmental scan the WB-20 extended trailer configuration identified by MIT (shown in Figure 4) was selected for modeling, with the goal of evaluating its potential for use in Manitoba. The evaluation of the WB-20 extended trailer configuration was split into two parts: (1) minimum turning path test; and (2) a comparative analysis on intersections found in Winnipeg. AutoTURN was used to complete both evaluations.

4.1 Minimum Turning Path Model Analysis

The minimum turning path model used in this study was based on the AASHTO (2004) Green Book minimum turning path model, as described in Section 3 of this paper. Figure 9 shows the maximum swept-path of the WB-20 extended trailer configuration, the base WB-20 configuration, and the base WB-36 truck configuration. As it can be seen in Figure 9, the WB-20 extended trailer performed worse than the WB-20 and better than the WB-36. The WB-20 extended trailer configuration performed worse than the design vehicle in Manitoba, suggesting that this configuration may be a potential safety risk on Manitoba's roads. However, since the WB-20 extended trailer configuration performed significantly better than the WB-36 truck configuration it is plausible that in the future the WB-20 extended trailer could be operated in Manitoba under special permit on preapproved routes, like WB-36 trucks are today.

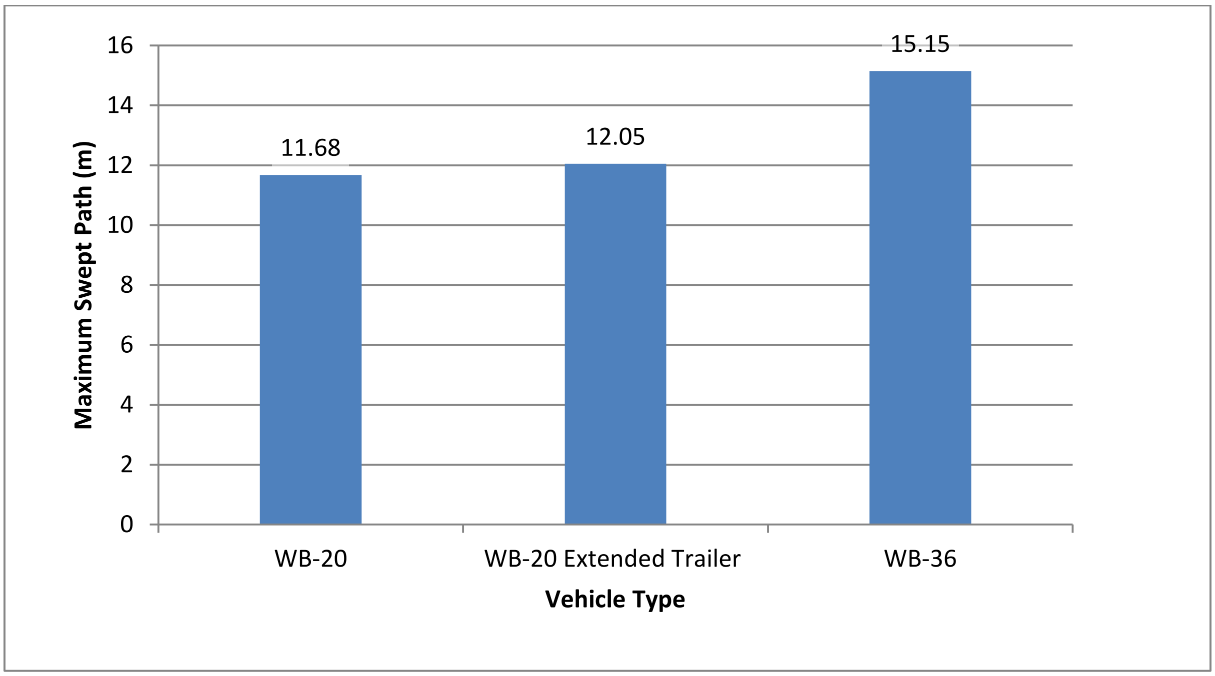


Figure 9: Maximum Swept-path for WB-20, WB-20 Extended Trailers, and WB-36 Trucks in the Minimum Turning Path Model

4.2 Intersection Analysis

Although the results of the minimum turning path test showed that the WB-20 extended trailer configuration performed worse than Manitoba's design vehicle (WB-20), further analyses were conducted to determine whether the difference in turning performance translated into differences for urban operations. Subsequently, the WB-20 extended trailer was evaluated against the Manitoba design vehicle and two other vehicle configurations commonly used in Manitoba, with respect to their ability to complete various turning movements at several Winnipeg intersections. The following intersections were chosen for the analysis:

- Kenaston Blvd. @ McGillivray Blvd.
- King Edward St. @ Saskatchewan Ave.
- Century St. @ Saskatchewan Ave.
- Notre Dame Ave. @ Erin St.
- Smith St. @ Broadway Ave.
- Gunn Rd. @ Day St.

Only intersections located on existing Winnipeg truck routes were selected. Intersections were chosen to get a mixture of the following characteristics:

1. One-way and two-way streets
2. 90° and non- 90° intersection alignments
3. 3-leg and 4-leg intersections
4. Intersections with single cut-off turn lanes, multi-lane cut-off turn lanes, and no cut-off turn lanes

For each intersection, all allowable truck turning movements were modeled. The intersections and modeled turning movements are shown in Figure 11 - Figure 16. The City of Winnipeg provided all intersection layouts in AutoCAD format. The trucks were modeled at a speed of 9.66 km/h (6 mph) and it was assumed that if there was more than one turning lane, the trucks turned from the outside lane. In the event that an intersection model had no clear definition of lanes, Google Earth was used to estimate where the lane lines existed. A summary of the analysis can be found in Table 5.

The turning movements of WB-15 (3-S2 with a 14.63m trailer), B-train double, and WB-20 truck configurations were modeled on the study intersections in order to provide a comparison to the performance of the WB-20 extended trailer. The WB-15 and B-train truck configurations were selected for comparison because they are commonly driven through the studied intersections. The WB-20 truck configuration was selected for comparison because it is the design vehicle in Manitoba. Figure 10 displays a sample comparison of the swept paths for the study vehicles making a 90° right turn. As it can be seen, the turning paths of the study vehicles are all slightly different.

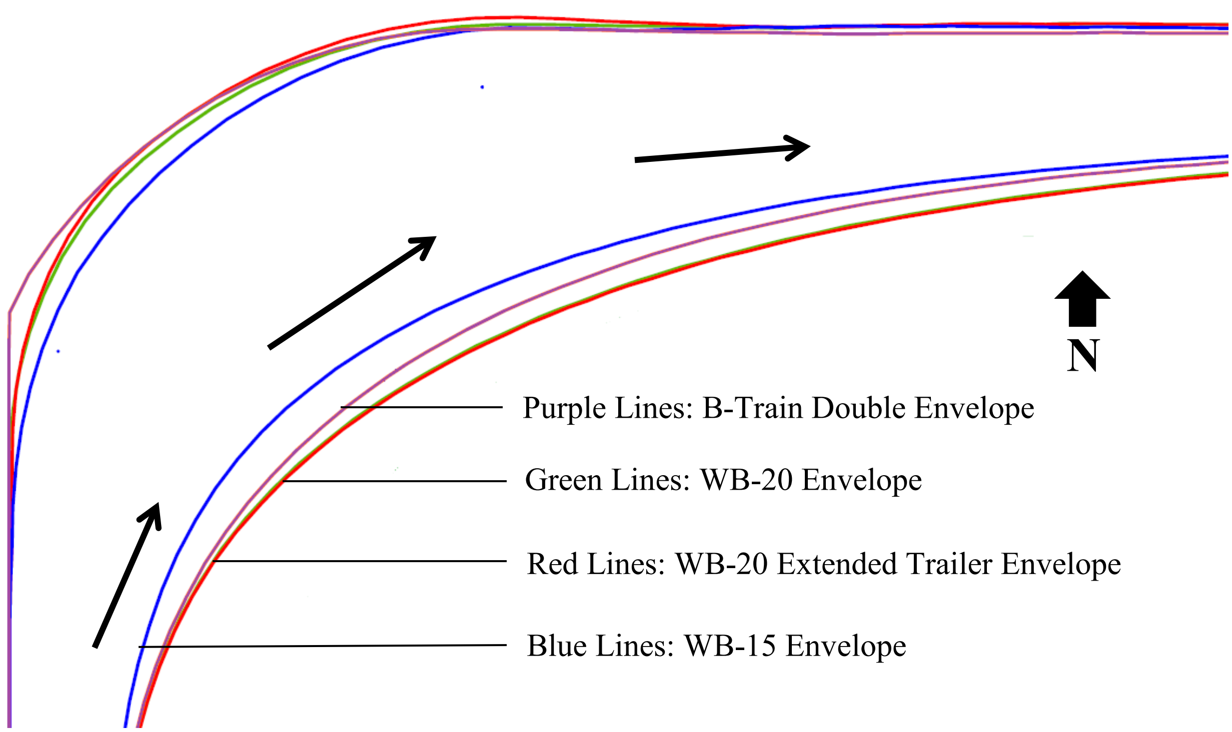


Figure 10: Sample Comparison of the Swept-path of Studied Truck Configurations for a 90° Right Turn from Day Street to Gunn Road

Table 5: Intersection Analysis Summary

Intersection	Minimum Design Radius[1]	Maximum Design Radius[1]	Turning Movement Issues
Kenaston Boulevard @ McGillivray Boulevard	25.0m (All Right Turns)	35.0m (All Left Turns)	There were no identified problems with the left turn movements (movements 5, 6, 7, and 8 in Figure 13) at this intersection. However, all of the studied trucks had to use part of the shoulder to complete the right turn movements (movements 1, 2, 3, and 4 in Figure 13), as well as encroach into the adjacent lane at the end of the turning manoeuvre.
King Edward Street @ Saskatchewan Avenue	7.5m (Turning movement 1)	70.0m (Turning Movement 2)	At this intersection, trucks completing turning movement 2 encroach on the opposing lane when turning right. Aside from this typical manoeuvre, there were no identified problem areas for the WB-20 Extended Trailer.
Century Street @ Saskatchewan Avenue	7.5m (Turning Movement 4)	25.0m (Turning Movement 1)	In order to complete turning movement 4 (Figure 11) all of the studied trucks had to begin their turning manoeuvre from the right lane of Century Street. The WB-20 Extended Trailer did not perform any worse than the typical configurations on this route.
Notre Dame Avenue @ Erin Street	7.00m (Turning Movement 1)	11.0m (Turning Movement 2)	At this intersection there were problems with truck turning movements. Trucks performing both turning movements 1 and 2 used up more than one lane on entry. The trailer also will hit the inside curb when completing the turn. This is more prevalent with turning movement 2 as the intersection opening is very narrow. This movement was typical of all existing configurations using the truck route.
Smith Street @ Broadway Avenue	5.3m (All Right Turns)	14.0m (All Left Turns)	At this intersection, all turning movements were problematic if there were cars parked in the designated parking areas. The WB-20 Extended Trailer and all existing configurations (WB-15, WB-20, and WB-23) would not be able to perform turning movements. It would be recommended to change the truck route restrictions at this location. Typically, large trucks such as noted above, would not use this route to make the allowable turning movements.
Gunn Road @ Day Street	15.5m (All Right Turns)	40.0m (All Left Turns)	At this intersection, trucks turning right are required to over-steer to complete the turn or they will leave the pavement during right-hand turns. This is typical with the WB-20 Extended Trailer as well as the existing configurations (WB-15, WB-20, and WB-23). It is also typical of the LCVs performing turning movement 1 from Day Street to Gunn Road. This is typically not a problem when there are no other vehicles waiting to enter the intersection. It is typical practice in Manitoba to design intersections this way for the WB-20 configuration where there are land constraints.

[1] Minimum and maximum design turning radii were determined from the AutoCAD files provided by the City of Winnipeg. The inside edge of pavement was used to determine the minimum turning radii and the maximum turning radii were estimated based on the existing road configurations that were present at each intersection. Actual City of Winnipeg design radii at these locations may differ from what is recorded in the above table.

5 Conclusion

This research found that the manoeuvrability of trucks can be addressed through adjustments to kingpin setback and rear effective overhang. Increases to the kingpin setback and rear effective overhang reduced the swept-path of the vehicles. However, increases to the kingpin setback also increased the front swing-out. For every 0.1m increase in the kingpin setback for the theoretical WB-20 truck configurations, the front swing out increased approximately 0.044m and the swept-path decreased by 0.11m. For every 0.1m increase in the kingpin setback for the theoretical WB-36 truck configurations, the front swing out increased approximately 0.052m and the swept-path decreased by 0.027m. For every 0.1m increase in the rear effective overhang, the swept-path decreased by 0.11m and 0.08m for the WB-20 and WB-36 theoretical configurations, respectively. These findings show that adjustments kingpin setback and rear effective overhang have approximately equal impacts on manoeuvrability for WB-20 truck configurations. The findings also show that adjusting the rear effective overhang has a greater impact on manoeuvrability than increasing the kingpin setback for WB-36 truck configurations. Further analysis is needed to determine if the positive impacts on safety attributable to increased manoeuverability outweigh the negative impacts associated with an increased front and rear swing out.

Furthermore, the results from this research have shown that many turning movements are difficult for trucks operating on Winnipeg's existing truck route network, especially right turn movements. However, the intersection analysis conducted during the study failed to identify any significant differences between the manoeuvrability of WB-20 extended trailer configuration and truck configurations that commonly operate in Winnipeg today. Each instance where the WB-20 extended trailer could not complete a turning movement without leaving the roadway, or encroaching on other lanes, all other studied vehicles experienced the same issue. With that said, the minimum turning path model proved that the WB-20 extended trailer configuration's turning performance is worse than the design vehicle in Manitoba. The minimum turning path model also proved that the WB-20 extended trailer configuration's turning performance is better than WB-36 trucks (turnpike doubles). Therefore, this research recommends that further analysis be conducted in this field to determine if the difference in turning performance output by AutoTURN translates into practical differences for actual trucks on Winnipeg's truck routes. Currently, WB-36 trucks are allowed to operate in Winnipeg under permit as long as they stay on preapproved routes. It is not hard to imagine a similar scenario in which this new proposed truck configuration could also operate in Winnipeg under permit on preapproved routes.

6 References

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7 Figures

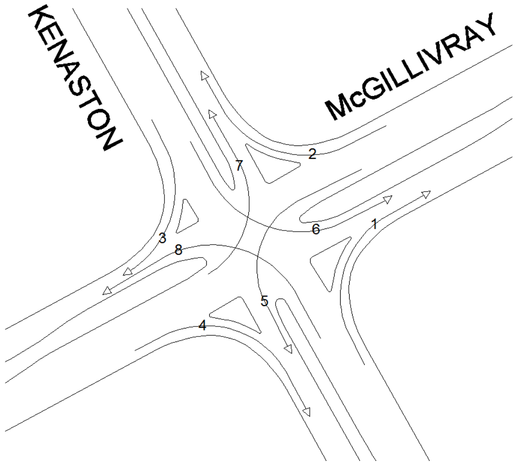

Figure 11: Turning Movements – Kenaston Boulevard at McGillivray Boulevard

Figure 12:Turning Movements – King Edward Street at Saskatchewan Avenue

Figure 13: Turning Movements – Century Street at Saskatchewan

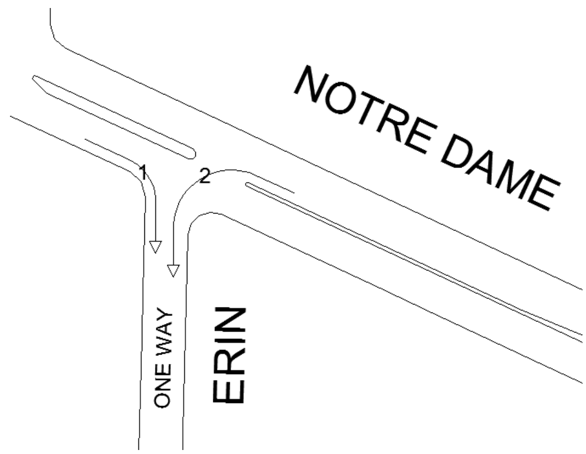

Figure 14: Turning Movements – Notre Dame Avenue at Erin Street

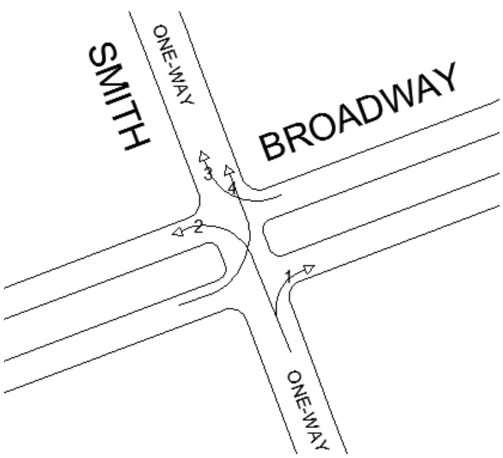

Figure 15: Turning Movements – Smith Street at Broadway Avenue

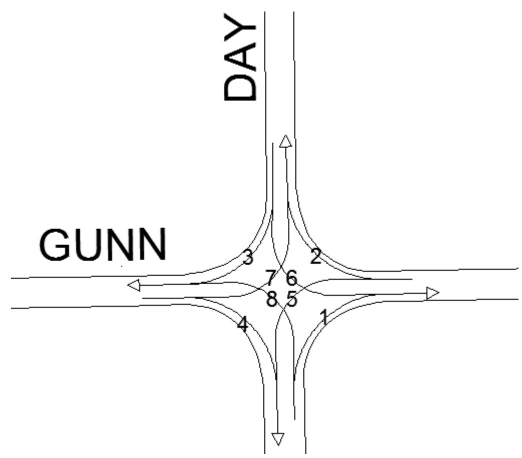

Figure 16: Turning Movements – Gunn Road at Day Street