Safety Evaluation of Lane Widths in the City of Edmonton

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Abstract

This paper synthesizes the results of a project completed for the City of Edmonton in 2017 to recommend lane width values for the City's Complete Streets Design and Construction Standards. The project included a literature review to synthesize research on the safety and speed implications of narrowed lane widths in urban areas; a jurisdictional review to document peer practice for lane widths and all-season operation in winter cities; and an in-service evaluation of the safety implications of the City's existing lane widths. A cross-sectional population-segmented study was conducted on the effect of lane widths on safety on 626 Edmonton road segments using five years of data. Regression models were developed to understand the effect of lane width on the proportion of speeding vehicles, the frequency of all severity segment collisions, and the frequency of fatal/injury segment collisions. The main conclusion was that speed should be a primary factor in setting context-sensitive design guidelines for lane widths. The paper concludes with the lane width values incorporated into the City's Complete Streets Design and Construction Standards. Opportunities for future research are discussed.

1 Introduction

1.1 Purpose

This paper synthesizes the results of a project completed for the City of Edmonton in 2017 to recommend lane width values for the City's Complete Streets Design and Construction Standards.

1.2 Background and Need

In late 2015, the City of Edmonton began the process of integrating the Complete Streets Guidelines with the Roadway Design Standards into the Complete Streets Design and Construction Standards. Identification of design lane widths was an important element of the Complete Streets Design Standards as lane widths have an impact on driver behaviour, sidewalk animation, and safety of users of all transportation modes. Lane width considerations must balance the safety, access, and comfort of all users, including people walking and wheeling, cycling, riding transit, driving and delivering goods.

Internal reviews of the existing standards and guidelines, and consultation with internal and external stakeholders to determine the scope of the updates were completed. Feedback from City Administration indicated concern over the reduced recommended lane widths in the 2012 Complete Streets Guidelines which differed from the 1999 TAC Geometric Design Guideline and what had traditionally been provided in Edmonton.

Questions and concerns with narrowing lane widths below 3.50 m fell in to three main categories: (1) safety, (2) operational impacts, and (3) maintenance implications in a winter city. The City felt it was necessary to complete a detailed review on lane widths to address these concerns and continue to recommend narrower lane widths in the Complete Streets Design and Construction Standards.

1.3 Objectives

The project objectives were to:

- Conduct a literature review to synthesize recent research on the safety and speed implications of narrowed lane widths in urban areas.
- Conduct a jurisdictional review to document peer practice for lane widths and all-season operation in winter cities.
- Conduct an in-service evaluation of the safety implications of the City of Edmonton's existing travel lane widths using real data.

This paper synthesizes the methodology and findings of the project and concludes with the lane width values incorporated in the City of Edmonton's Complete Streets Design and Construction Standards. Opportunities for future research are discussed.

2 Literature Review

2.1 Methodology

The literature review synthesized available research on the safety and speed implications of narrowed lane widths in urban areas. It was based on a review of 23 articles published on lane widths ranging between 2.70 m and 4.80 m. Articles were sourced from peer-reviewed journals, conference compendiums, research reports, and technical guidelines.

2.2 Literature Review Results and Discussion

2.2.1 Effect of Lane Width on Collisions

Literature on the safety implications of narrow lane widths in urban contexts reveal mixed results:

- Some studies indicate a decrease in safety performance with narrower lane widths (iRAP, 2013; Heimbach, Cribbins, & Chang, 1983; Gattis & Watts, 1999; Bauer, Harwood, Hughes, & Richard, 2004)
- Other studies indicate negligible or no change in safety performance (Potts, Harwood, & Richard, 2007; Harwood, 1990; Wood, Gooch, & Donnell, 2015; Bellefleur, 2014)
- A few studies indicate improved safety performance with narrower lane widths (Wood, Gooch, & Donnell, 2015; Karim, 2015).

Heimbach, Cribbins and Chang (1983) identified that although the relationship between lane widths and collisions is nonlinear, narrowing lane widths by 0.3 m (1.0 ft) tends to increase collisions by 3% to 5% on four-lane urban highways where the posted speed is 72 km/h (45 mph) or less. iRAP (2013) indicated an increased safety risk of 5% for every 0.5 m decrease in lane widths of 3.3 m and below. Gattis and Watts (1999) found that collision rates were over twice as high on narrower roads than wide roads. Another study found that collisions decrease by 18.7% when lane widths are increased from 3.0 m (10.0 ft) or 3.4 m (11.0 ft) to 3.7 m (12.0 ft) (Ozbay, Yanmaz-Tuzel, Ukkusuri, & Bartin, 2009).

Harwood (1990) found that collision frequency and severity is not influenced by lane width choice in an urban setting on roads with speeds of 72 km/h (45 mph) or less. Potts, Harwood and Richard (2007) found no general indication that collision frequency increases with the use of lanes narrower than 3.6 m (12.0 ft) on urban and suburban arterials. Based on a comparative analysis of collision severity and speed by lane widths common to Toronto and Tokyo, Karim (2015) identified that a safer range of lane widths lies between 3.0 m and 3.5 m, and that collision severity is 10 to 19 times higher on lanes greater than or equal to 4.0 m.

Wood, Gooch and Donnell (2015) found little difference between collision frequency on 3.4 m (11.0 ft) and 3.7 m (12.0 ft) lanes. This study also found that roads with 3.0 m (10.0 ft) lane widths had the highest collision frequency, while roads with 2.7 m (9.0 ft) lane widths had the lowest collision frequency: this was true for all severity levels (Wood, Gooch, & Donnell, 2015). This finding implies an ascending and then descending effect of lane width on collision frequency. The reasoning for this apparent relationship is not completely clear but could be inferred to result from a non-linear sensitivity of driver behaviour to lane width. Initially as lane width is narrowed, drivers do not modify their behaviour at all, but room for error is reduced, resulting in increased collisions. Then, as lane widths are further narrowed, drivers pass a comfort threshold and start to modify their behaviour by reducing speeds and increasing attentiveness, resulting in decreasing collisions. The 2.7 m lanes evaluated in this study were low volume, minor arterials and collectors, with posted speeds ranging from 40 km/h (25 mph) to 56 km/h (35 mph).

The relationship between lane width and safety is complex as many factors contribute to safety performance, such as traffic volume, speed, and lane configuration, as illustrated in the following studies:

- A cross-sectional analysis of oversized (11.6 m and above) and standard-sized (11.5 m and below) two-lane urban residential-collector roads in the City of Edmonton found the interaction of traffic volume and roadway width to be positively related to collisions: for every 10% increase in volume, predicted collisions increase by 1.68% and 4.85% on standard-sized and oversized collectors, respectively (Manuel, El-Basyouny, & Islam, 2014). This study also found that oversized collector roads have better safety performance than standard-sized collector roads when traffic volumes are below 4000 Average Daily Traffic (ADT), and that the opposite is true when traffic volumes are above 4000 ADT (Manuel, El-Basyouny, & Islam, 2014).
- Collision Modification Factors (CMFs) developed by Wood, Gooch and Donnell (2015) for various lane widths and collision types reveal a complex relationship between lane width and collision frequency, severity, and configuration: some CMFs were point estimates, while others varied with traffic volume (Wood, Gooch, & Donnell, 2015).

- Sando and Moses (2011) identified a relationship between lane width and safety when asymmetrical lane widths are used and the outside lane is wider than the inside lane. Outside lane widths in this study ranged from 3.8 m (12.5 ft) to 4.8 m (16.0 ft) and inside lane widths ranged from 3.3 m (10.8 ft) to 3.7 m (12.0 ft). The asymmetric lane configuration with wider outside lanes was associated with a 4% to 30% reduction in severe collisions compared to a typical lane configuration, where both lanes are the same 3.7 m (12.0 ft) width (Sando & Moses, 2011).

Overall, the literature review did not reveal a clear relationship between lane width and collision frequency or severity. Although one study indicated that lane widths of 2.7 m yield the lowest collision frequency and severity, others make similar conclusions for wider lanes, or find no relationship between lane width and safety. A general consensus is that the relationship between lane width and safety is complex and difficult to isolate as there are many factors which contribute to safety performance. Lack of consistency in the literature on this topic may lead to the conclusion that a design domain concept for lane width decisions is appropriate, where context sensitive solutions are necessary based on a site-specific evaluation. The literature reveals some justification for using 2.7 m as the lower bound of a lane width design domain applied to some urban roads, where the posted speed is 50 km/h or less and other factors of the built environment are employed as speed reduction measures. A lower bound of 3.0 m or 3.3 m may be appropriate for other urban roads where the posted speed is greater than 50 km/h.

2.2.2 Effect of Lane Width on Speed

The relationship between speed and collision severity is well documented: higher-speed impacts result in higher applications of force and more severe collisions. For this reason, reducing speeds is a key element of the Safe System and Vision Zero road safety approaches. The literature review found either no change in speed or reduced speeds with narrowing lane widths, which supports the use of narrower lane widths.

Several studies confirm that narrower lane widths are associated with reduced vehicle speeds (Karim, 2015; Fitzpatrick K., Carlson, Wooldridge, & Brewer, 2000; Parsons Transportation Group, 2003; Gattis & Watts, 1999; Martens, 1997; Heimbach, Cribbins, & Chang, 1983; Bellefleur, 2014). Speed tends to reduce by 1 km/h to 2 km/h for each 0.3 m reduction in lane width (Fitzpatrick K., Carlson, Wooldridge, & Brewer, 2000; Martens, 1997; Heimbach, Cribbins, & Chang, 1983). Other studies, however, have found no relationship between lane width and speed (Fitzpatrick K., Carlson, Brewer, & Wooldridge, 2003; Lee, Abdel-Aty, Park, & Wang, 2015; Gattis J., 2000). Similar to safety performance, the relationship between lane width and speed is complex, difficult to isolate, and tied to may other factors associated with the given road facility (Martens, 1997; Gattis & Watts, 1999).

Fitzpatrick (2000) indicated that speed reductions of as much as 5 km/h (3 mph) can be achieved per 0.3 m (1.0 ft) of lane width narrowing. A case study in Victoria, B.C., found average speeds dropped from 48 km/h (30 mph) to 40 km/h (25 mph) when lane widths were reduced from 3.7 m (12.0 ft) or 3.4 m (11.0 ft) to 2.7 m (9.0 ft) (Parsons Transportation Group, 2003). New landscaping and revitalization of commercial developments along the corridor were thought to contribute to this reduction in speed. A literature review by Martens et al (1997) concluded that decreasing lane width shows improved lane keeping, steering behaviour, and reduced speeds. The literature review by Martens et al (1997) references a 1983 paper by Yagar and Van Aerde, which found that speed can be reduced by 1.8 km/h (1.1 mph) for every 0.3 m (1.0 ft) reduction in lane width below 4.0 m (13.0 ft). A final study found that speeds could be reduced in the off-peak hours by 1.0 km/h (0.6 mph) and in the peak hours by 1.6 km/h (1.0 mph) per 0.3 m (1.0 ft) of lane width narrowing (Heimbach, Cribbins, & Chang, 1983).

Bellefleur (2014) reviewed policies and previous studies conducted in North American jurisdictions regarding the use of 3.0 m lane widths in urban areas. The report suggests that, “it may be beneficial to reduce traffic lane widths to 3.0 m in order to help reduce motorized traffic speeds,” and acknowledges that “even narrower traffic lanes (2.7 m) are frequently used in combination with other measures to calm vehicle traffic on local residential streets and to ensure compliance with relatively low traffic speed limits (often 30 km/h)” (Bellefleur, 2014). Findings from the report state that, “reducing lane widths to 3.0 m in urban environments does not lead to congestion and does not increase collisions, contrary to traditional thinking”. The report recommends that jurisdictions consider adopting a contextually appropriate default 3.0 m lane width for urban arterial roads.

3 Jurisdictional Review

3.1 Methodology

The jurisdictional review documented peer practice for lane widths and all-season operation in eight winter cities (listed below). These cities were selected based on their documented Complete Streets policies, road safety policies, experience with implementing narrower lane widths, and winter climate. The jurisdictional review had two components: (1) a desk-review of transportation design standards and Complete Streets documents for all eight jurisdictions; and (2) a survey on the safety and operational implications of narrower lane widths with five of the eight jurisdictions. Operational implications of interest in the survey were winter maintenance, emergency services, waste management services, and transit accommodation. The lane width component of the 2017 TAC GDG was also synthesized during this phase of the project.

- Calgary, Canada
- Toronto, Canada[1]
- Ottawa, Canada
- Cincinnati, United States
- Rotterdam, the Netherlands
- Edmonton, Canada[2]
- Boston, United States[2]
- Chicago, United States[2]

[1] Policy was recently released, however, not in time to be included in this study
[2] Policy review only; jurisdiction did not participate in survey

3.2 Jurisdictional Review Results and Discussion

Table 1 summarizes ranges of lane widths and target values by lane type from each jurisdiction's Complete Streets guideline and/or transportation design standards. Lane width policy is reflected by lane type and road classification. Several jurisdictions present lane width policy as a design domain and specify a target value within that domain. Design exceptions have been made in the surveyed jurisdictions to allow for the use of lane widths which are narrower than the minimums included in design standards and guidelines. Unless otherwise stated, lane widths are measured from face of curb. The following findings are drawn regarding minimum lane width standards in winter cities:

- Minimum values for curbside through / travel lanes range from 2.70 m (Chicago) to 3.55 m (Calgary), while minimum values for non-curbside travel lanes range from and 2.70 m (TAC, Chicago) to 3.50 m (Ottawa). A commonly used minimum for both curbside and non-curbside travel lanes is 3.00 m.
- Minimum values for curbside bus lanes range from 3.25 m (Rotterdam) to 3.55 m (TAC, Calgary), while minimum values for non-curbside bus lanes range from 3.20 m (Edmonton) to 3.50 m (Ottawa). Commonly used minimums for curbside bus lanes are 3.40 m or 3.50 m, while a narrower 3.30 m is often allowable for non-curbside bus lanes.
- Minimum values for curbside travel lanes accommodating trucks range from 2.90 m (Rotterdam) to 3.65 m (Edmonton), while minimum values for non-curbside lanes accommodating trucks range from 2.90 m (Rotterdam) to 3.50 m (Ottawa). Common minimums for truck lanes are between 3.40 m and 3.65 m.
- Minimum values for bike lanes range from 1.20 m (Chicago, Boston) to 1.50 m (Edmonton, Calgary, Ottawa, Rotterdam, Cincinnati). A buffer zone is commonly used when bike lanes are below 1.50 m.
- Minimum values for parking lanes range from 1.80 m (Rotterdam) to 2.50 m (Ottawa); 2.10 m is a commonly used minimum.
- Minimum values for shared use curb lanes range from 2.80 m (Toronto) to 4.40 m (Rotterdam). Widths vary depending on the modes intended to use the lane, with wider requirements for lanes shared by transit, parking and cyclists.

All five surveyed jurisdictions reported a context-sensitive approach to lane width design. The City of Toronto's guideline and complementary lane width design tool quantifies appropriate deviations from target lane width values and within design domains based on the presence of various influential site factors (e.g., transit, cycling facilities, pedestrian activity, posted speed, etc.). Developing a similar tool for the City of Edmonton could provide guidance for designers on when and by how much to deviate within or outside lane width design domains.

Based on the survey with the five jurisdictions, the following findings were drawn regarding the implications of installing narrower lane widths in winter cities:

- In general, jurisdictions did not highlight any priority safety issues resulting from narrowing lane widths within the values included in their design guidelines. Vision Zero is focused on the elimination of road fatalities and injuries. The jurisdictional survey did not raise any concerns regarding an increased risk of fatal or injury-causing collisions with the installation of narrower lane widths. Because installations of narrower lanes are relatively new or have been unstudied, there were also no accounts of reductions in severe collisions due to lane narrowing.
- More frequent snow clearing, additional off-site hauling, and increased allowance for on-site storage in the boulevard or median may be required when lane widths are narrowed in cities with heavy snow falls. The increased requirement to haul snow away as opposed to store on-site can increase maintenance budgets.
- Emergency services accommodation is governed by total roadway width as opposed to lane width, since these users are not restricted to operate within a lane and can instead use the full roadway.
- The implications of narrower lane widths on waste management services generated fewer survey responses. Space requirements dictated by emergency services are often sufficient to accommodate waste management services. Waste management operations have been altered and parking restrictions have been implemented when access required for individual property collection is a concern.
- Common minimum travel lane widths for transit ranged from 3.25 m to 3.55 m from face of curb. The constrained bus lane width in the City of Edmonton’s current Complete Streets Guideline is within these minimums at 3.45 m measured from face of curb (3.20 m from gutter).

Table 1: Lane Widths Jurisdictional Review Summary

Jurisdiction	Lane Type								
	Through / Travel Lane		**Travel Lane (Bus)**		**Travel Lane (Trucks)**		**Bicycle Lane**	**Parking Lane**	**Shared-use Curb Lane**
	Curbside	*Centre*	*Curbside*	*Centre*	*Curbside*	*Centre*			
TAC GDG 2017 Update[1]	2.95 – 4.25 *[3.25 – 3.95]*	2.7 – 4.0 *[3.0 – 3.7]*	3.55	3.3	3.55	3.30	N/A	N/A	N/A
Edmonton, Alberta	3.25 – 3.75 *[3.45]*[2]	3.0 – 3.5 *[3.2]*[2]	3.45	3.2	3.65 – 3.75	3.4 – 3.5	1.5 – 2.1	2.2 – 2.5	4.0 – 4.2
Calgary, Alberta	3.55 – 4.75	3.3 – 4.5	3.55 – 3.75 *[3.75]*[4]	3.3 – 3.5 *[3.5]*[4]	N/A		1.5[5]	2.1[7] – 2.5	-[8]
Toronto, Ontario	2.8 – 3.6 *[3.0, 3.2]*[3]		N/A		N/A		N/A	N/A	2.8 – 4.3 *[3.2, 4.3]*[9]
Ottawa, Ontario	3.5 – 4.5		3.5		3.5		1.5 – 2.0	2.5	4.0 +
Rotterdam, the Netherlands	2.9 – 3.25		3.25 – 3.5		2.9 – 3.25		1.5 – 2.0	1.8 – 2.5	4.4 – 4.5
Cincinnati, Ohio	3.0		N/A		N/A		1.5	2.4	N/A
Boston, Massachusetts	3.0 – 3.7 *[3.0]*		3.4		3.4 – 3.7		1.2 – 1.8 *[1.5]*	2.1	3.7 – 5.8[10]
Chicago, Illinois	2.7 – 4.3		3.4		3.4		1.2 – 3.7[6]	2.1 – 3.0	*[4.3 – 5.5]*
Range of Minimums	**2.7 – 3.55**	**2.7 – 3.5**	**3.25 – 3.55**	**3.2 – 3.5**	**2.9 – 3.65**	**2.9 – 3.5**	**1.2 – 1.5**	**1.8 – 2.4**	**2.8 – 4.4**

Dimensions are expressed in metres from face of curb. Italicized text in square brackets express target lane width values. Non-italicized text express range of lane width values allowable by guideline/standard. Policies may have provided guidance on lane width values marked as N/A, however, it may not have been amenable to reporting in the format of this table. TAC, Edmonton, and Calgary measure the width of curbside motor vehicle travel lanes from the lip of gutter, while the remaining jurisdictions measure from the face of curb. For curbside motor vehicle travel lanes, an additional 0.25 m was added to the widths presented above for TAC, Edmonton and Calgary to account for the additional gutter space and allow for a consistent comparison across all jurisdictions.

[1] Lane widths apply to urban streets with design speeds of 60 km/h or less.

[2] Standard lane width for non-high truck volume routes, general purpose travel lanes.

[3] Target lane width varies by road classification.

[4] Target applies to travel lanes on Calgary's Primary Transit Network.

[5] May include an additional 1.0 m buffer, depending on other cross-sectional elements and road type.

[6] Dimensions presented for bikeways, which is a category inclusive of bike lanes and other types of bike facilities.

[7] May include 0.6 – 0.8 m dooring buffer zone when bike lane present.

[8] Dimensions for shared-use curb lanes not exclusively given in Calgary design guidelines. Rather, dimensions for various combinations of parking, bike lanes, and travel lanes are provided by road classification.

[9] Target varies by road classification and presence of adjacent bike lanes.

[10] Largest dimension used when on-street parking is adjacent to travel lanes.

4 In-Service Evaluation

4.1 Methodology

The in-service evaluation informs policy by providing an understanding of the impacts of lane widths on speeds and collisions using real City of Edmonton data. The evaluation examines how these relationships vary among facility types and contexts, relying on statistical techniques to control for other contributing factors. A cross-sectional population-segmented study on the effects of lane widths on collisions and speeds on 626 Edmonton road segments for the five-year period (2011-2015) was conducted, resulting in the development of 40 statistical models which passed goodness-of-fit tests.

Policy can be informed by detecting a strong link between variables or by finding that there is no significant relationship between variables. In contexts where the effect of lane width is not found to be significant, it means that the lane width can be reduced without undue safety concerns. However, in contexts where the effect of lane width on collisions is significant and negative, it means that a lane width reduction would be associated with an increase in collisions. By using population segmentation, context-sensitive design can be supported because the analysis investigates if the relationship between variables changes depending on the facility type. The study interprets results from a Vision Zero road safety framework, which means that an emphasis is placed on collision severity and results that pertain to injuries over results that pertain to property damage only collisions. Table 3 defines the relevant variables used in the regression analysis.

Table 2: Variables used in Regression Analysis

Type	Variable	Definition
Outcome	N_a	Number of segment collisions, all severities
	N_{fi}	Number of segment collisions, fatal or injury only
	P	Proportion of vehicles exceeding the speed limit
Explanatory	l	Length of road segment
	$AADT$	Annual Average Daily Traffic
	LW	Width of the narrowest general purpose travel lane on the segment
	SL	Speed limit

The following regression model forms were selected using theoretical assumptions combined with exploratory data analysis, with ε as the negative binomial model error.

$$N_a = l * e^{\beta_1} AADT^{\beta_2} LW^{\beta_3} + \varepsilon \qquad [1]$$

$$N_{fi} = l * e^{\beta_1} AADT^{\beta_2} LW^{\beta_3} + \varepsilon \qquad [2]$$

$$P = \beta_1 AADT^{\beta_2} LW^{\beta_3} SL^{\beta_4} + \varepsilon \qquad [3]$$

For models analyzing the effect of lane width on *P* (the proportion of vehicles speeding), the following population segments were analyzed separately to determine how the effect of *LW* on *P* may vary among population segments:

- All facilities
- High speed facilities (V_{85} ≥ 60 km/hr), where V_{85} is the 85th percentile speed measured in a speed survey
- Low speed facilities (V_{85} < 60 km/hr)
- Facilities with bicycle lanes
- Facilities with wide curb lanes
- Facilities with full-time parking lane
- Facilities with mono-walk sidewalks
- Facilities that are Complete Streets or Main Streets
- Facilities using combined minimums, that is where multiple cross-section elements were designed to the minimum width standards
- Facilities with transit routes

For models analyzing the effect of lane width on N_a *and* N_{fi} (total collisions and fatal/injury collisions) population segments analyzed include:

- Each facility group noted above for the speeding proportion models
- Facilities with off-peak parking lanes
- Facilities with BOTH combined minimums AND mono-walks
- Facilities with BOTH combined minimums AND full-time parking
- Facilities with BOTH transit routes AND mono-walks
- Facilities with BOTH transit routes AND full-time parking

4.2 In-Service Review Results and Discussion

Table 3 to Table 5 show the impact of lane width on the proportion of vehicles speeding, on fatal and injury collisions, and on all collisions across various contexts. In these tables, when the p-value for a relationship is less than 0.05, the relationship is considered significant. If the p-value is more than 0.05, the relationship is considered non-significant. In both cases, the results are useful. In contexts where the effect of lane width is not found to be significant, it means that the lane width can be reduced without undue safety concerns. However, in contexts where the effect of lane width on collisions is significant and negative, it means that a lane width reduction would be associated with an increase in collisions.

The main conclusion from the in-service evaluation is that speed should be a primary factor in setting context-sensitive design guidelines for lane widths. For high speed roads, narrow lanes should be avoided. For low speed roads, narrow lanes should be allowed, except in cases of full-time parking lanes or wide curb lanes. These conclusions should be applied within the specified lane widths of 2.85 m and 4.25 m and in consideration of the limitations noted in Section 6 of this paper.

Table 3: Models of the relationship between lane width and the proportion of vehicles exceeding the speed limit

Model ID	Population Segment	Model (P, proportion of vehicles exceeding speed limit)	n	Estimate of Effect % change in P for 10% increase in LW (p-value)	Quality
P-4	All Facilities All Speeds	$P = 18.698 \times AADT^{0.228} \times LW^{0.694} \times SL^{-1.673}$	203	6.8% (0.011)*	1
P-6	All Facilities V85 ≥ 60 km/hr	$P = 418.877 \times AADT^{0.069} \times LW^{0.282} \times SL^{-1.890}$	91	2.7% (0.277)	1
P-5	All Facilities V85 < 60 km/hr	$P = 654.749 \times AADT^{0.203} \times LW^{0.283} \times SL^{-2.476}$	112	2.7% (0.428)	1
P-7	With Bicycle Lanes	$P = 88.961 \times AADT^{0.261} \times LW^{1.157} \times SL^{-2.275}$	27	11.7% (0.286)	1
P-8	With Wide Curb Lanes	$P = 0.048 \times AADT^{0.052} \times LW^{0.846} \times SL^{0.176}$	41	8.4% (0.238)	1
P-9	With Full-Time Parking Lanes	$P = 0.041 \times AADT^{0.235} \times LW^{0.300}$	37	2.9% (0.700)	1
P-10	With Monowalks	$P = 29.559 \times AADT^{0.243} \times LW^{0.527} \times SL^{-1.785}$	48	5.2% (0.509)	1
P-11	Complete / Main Streets	$P = 5.928 \times AADT^{0.188} \times LW^{0.700} \times SL^{-1.269}$	47	6.9% (0.208)	1
P-12	With Combined Minimums	$P = 201.450 \times AADT^{0.250} \times LW^{-0.200} \times SL^{-2.056}$	56	-1.9% (0.700)	1
P-13	With Transit Routes	$P = 70.129 \times AADT^{0.236} \times LW^{1.673} \times SL^{-2.345}$	62	17.3% (0.003)*	1

* = statistically significant
Model quality: 1 (excellent goodness of fit); 2 (goodness of fit is acceptable); 3 (goodness of fit is problematic)

Note: A goodness-of-fit assessment procedure was applied that includes a review of model explanatory power, significance levels for the estimates of effect for each explanatory variable (in particular lane width), and cumulative residuals (CURE) plot analysis with respect to each explanatory variable for each model. Based on this analysis, a professional statistician assigned a model quality ranking to each model estimated, ranging from 1 (excellent goodness of fit) to 2 (goodness of fit is acceptable) to 3 (goodness of fit is problematic). Only models with quality rank 1 and 2 are reported in Tables 3 - 5.

Table 4: Models of relationship between lane width and the fatal and injury collision count

Model ID	Population Segment	Model (N_{fi}, Fatal and Injury Collisions)	n	Estimate of Effect % change in N for 10% increase in LW (p-value)	Quality
FI-2	All Facilities All Speeds	$N = \exp(-10.158) \times AADT^{0.876} \times LW^{-3.361} \times l$	588	-27.4% (3.16e-06)*	2
FI-S4	All Facilities V85 ≥ 60 km/hr	$N = \exp(-4.951) \times AADT^{0.615} \times LW^{-5.785} \times l$	64	-42.4% (0.021)*	1
FI-S1	All Facilities V85 < 60 km/hr	$N = \exp(-11.545) \times AADT^{0.778} \times LW^{-1.250} \times l$	117	-11.2% (0.467)	1
FI-4	With Bicycle Lanes	$N = \exp(-14.216) \times AADT^{0.851} \times LW^{0.212} \times l$	50	2.0% (0.928)	1
FI-5	With Wide Curb Lanes	$N = \exp(-8.898) \times AADT^{1.097} \times LW^{-5.911} \times l$	89	-43.1% (0.002)**	1
FI-6	With Full-Time Parking Lanes	$N = \exp(-16.609) \times AADT^{1.131} \times LW^{0.211} \times l$	121	2.0% (0.887)	1
FI-7	With Off-Peak Parking Lanes	$N = \exp(-6.297) \times AADT^{0.928} \times LW^{-6.983} \times l$	43	-48.6% (0.021)*	1
FI-8	With Monowalks	$N = \exp(-15.150) \times AADT^{1.103} \times LW^{-1.007} \times l$	134	-9.2% (0.606)	1
FI-9	Complete / Main Streets	$N = \exp(-10.258) \times AADT^{0.697} \times LW^{-1.676} \times l$	147	-14.8% (0.284)	1
FI-10	With Combined Minimums	$N = \exp(-13.382) \times AADT^{1.079} \times LW^{-2.448} \times l$	145	-20.8% (0.107)	1
FI-11	With Transit Routes	$N = \exp(-15.309) \times AADT^{1.160} \times LW^{-1.183} \times l$	141	-10.7% (0.391)	1
FI-12	Combined Minimums AND Monowalks	$N = \exp(-6.808) \times AADT^{0.780} \times LW^{-5.799} \times l$	39	-42.4% (0.130)	1
FI-13	Combined Minimums AND Full-Time Parking	$N = \exp(-14.249) \times AADT^{1.311} \times LW^{-3.257} \times l$	37	-26.7% (0.374)	1
FI-14	Transit Routes AND Monowalks	$N = \exp(-16.366) \times AADT^{1.316} \times LW^{-1.607} \times l$	38	-14.2% (0.626)	1
FI-15	Transit Routes AND Full-time Parking	$N = \exp(-11.754) \times AADT^{1.128} \times LW^{-3.871} \times l$	37	-30.9% (0.311)	1
* = statistically significant Model quality: 1 (excellent goodness of fit); 2 (goodness of fit is acceptable); 3 (goodness of fit is problematic)					

Table 5: Models of the relationship between lane width and all-severity collision counts

Model ID	Population Segment	Model (N_a, All Collisions)	n	Estimate of Effect % change in N for 10% increase in LW (p-value)	Quality
A-4	All Facilities All Speeds	$N = \exp(-5.941) \times AADT^{0.368} \times LW^{-1.242} \times l$	118	-11.2% (0.149)	1
AS-4	All Facilities V85 ≥ 60 km/hr	$N = \exp(-6.363) \times AADT^{0.532} \times LW^{-2.148} \times l$	73	-18.5% (0.045)*	2
AS-1	All Facilities V85 < 60 km/hr	$N = \exp(-8.789) \times AADT^{0.479} \times LW^{0.577} \times l$	117	5.7% (0.457)	1
A-5	With Bicycle Lanes	$N = \exp(-11.168) \times AADT^{0.551} \times LW^{1.664} \times l$	49	17.2% (0.233)	1
A-6	With Wide Curb Lanes	$N = \exp(-6.844) \times AADT^{0.729} \times LW^{-3.145} \times l$	84	-25.9% (0.003)*	1
A-7	With Full-Time Parking Lanes	$N = \exp(-9.227) \times AADT^{0.541} \times LW^{0.439} \times l$	113	4.3% (0.612)	1
A-8	With Off-Peak Parking Lanes	$N = \exp(-5.269) \times AADT^{0.624} \times LW^{-3.373} \times l$	41	-27.5% (0.032)*	1
A-9	With Monowalks	$N = \exp(-8.262) \times AADT^{0.536} \times LW^{-0.284} \times l$	124	-2.7% (0.795)	1
A-10ii	Complete / Main Streets	$N = \exp(-11.962) \times AADT^{0.764} \times LW^{1.168} \times l$	72	11.8% (0.284)	1
A-11	With Combined Minimums	$N = \exp(-7.836) \times AADT^{0.520} \times LW^{-0.606} \times l$	138	-5.6% (0.436)	1
A-12	With Transit Routes	$N = \exp(-9.633) \times AADT^{0.544} \times LW^{0.691} \times l$	134	6.8% (0.484)	1
A-13	Combined Minimums AND Monowalks	$N = \exp(-4.327) \times AADT^{0.528} \times LW^{-3.518} \times l$	37	-28.5% (0.058)*	2
A-14	Combined Minimums AND Full-Time Parking	$N = \exp(-9.182) \times AADT^{0.565} \times LW^{0.353} \times l$	35	3.4% (0.830)	1
A-15	Transit Routes AND Monowalks	$N = \exp(-11.757) \times AADT^{0.609} \times LW^{2.112} \times l$	36	22.3% (0.361)	1
A-16	Transit Routes AND Full-time Parking	$N = \exp(-8.114) \times AADT^{0.466} \times LW^{-0.005} \times l$	35	-0.05% (0.998)	2

* = statistically significant
Model quality: 1 (excellent goodness of fit); 2 (goodness of fit is acceptable); 3 (goodness of fit is problematic)

Key conclusions from the in-service evaluation are:

Conclusion 1: For high-speed roads, where the 85th percentile speed (as measured in a speed survey) is at least 60 km/hr, the data show that all collision types decrease significantly as lane widths increase. Fatal and injury collisions decrease by 42.4% for every 10.0% increase in lane width, while all-severity collisions decrease by 18.5%. The design implication of this conclusion is that narrower lane widths should be avoided on high-speed roads. A higher target lane width value is recommended for high-speed roads compared to low-speed roads. Comprehensive evaluation and caution should be exercised when deviating toward lower bounds of the lane width design domain on high-speed roads.

Conclusion 2: For low-speed roads in general, where the 85th percentile speed is less than 60 km/hr, the data show that lane width does not have a statistically significant effect on collision count. The p-value indicates the significance of a model. A p-value of 0.05 or less is considered significant and indicates that it is unlikely that the observed influence of lane width on collisions is due to chance. Large p-values for the lane width parameter of 0.467 (fatal and injury collisions, model FI-S1) and 0.457 (all severity collisions, model AS-1) mean that lane width has no significant impact on collision count on low speed roads. Lane width is not associated with an increase or a decrease in collision count on lower speed roads. The design implication of this conclusion is that for lower speed roads, narrower lane widths do not present a safety concern, subject to conclusion 3, and a designer should feel free to select from anywhere in the design domain based on other design objectives.

Conclusion 3: The use of narrow lanes adjacent to a wide curb lane or adjacent to an off-peak parking lane are associated with statistically significant increases in total and fatal/injury collisions.

- Adjacent to wide curb lanes, a 10.0% increase in lane width yields a 41.0% reduction in fatal and injury collisions (model FI-5).
- Adjacent to an off-peak parking lane, a 10.0% increase in lane width yields a 48.6% reduction in fatal and injury collisions (model FI-7).
    - The design implication of Conclusion 3 is that narrow lane widths in these contexts present some safety risks. Designers should target a lane width at the upper end of the design domain.

Conclusion 4: The in-service evaluation also investigated the impact of lane widths on speed. In general, wider lanes were found to be associated with a higher proportion of speeding vehicles. This effect was found to be strongly significant when the whole population was considered and when facilities with transit routes were exclusively considered. The effect was not significant when other sub-populations with smaller sample sizes were considered. The speeding proportion models do not provide any direct design implications, except that lane width alone cannot be used to control speeds; speed management must be attained using a suite of measures.

5 Conclusions and Recommendations

This paper synthesized a project completed for the City of Edmonton to recommend lane width values for the Complete Streets Design and Construction Standards based on an improved understanding of the safety and operational impacts of narrower lane widths on urban streets. Findings from the research support the use of a design domain concept for lane width decisions, where context sensitive solutions are generated based on an evaluation of factors like available right of way, land use, topography, alignment, parking, loading, and transit operations, among others.

A main conclusion from the research is that speed should be a primary factor in setting design guidelines for lane widths. Design domains were developed by design speed instead of posted speed. The in-service evaluation models were developed using the 85th percentile speed, which proved to be closer to the design speed than the posted speed. On 85% of segments analyzed, the 85th percentile speed exceeded the posted speed by an average of 7 km/h. These results indicate that drivers tend to travel closer to the design speed, which is 10 km/h above the posted speed in the City of Edmonton.

The City of Edmonton modified the recommended lane widths after additional stakeholder consultation within the City, development industry, engineering consultants, and advocacy groups. Significant changes included: (1) reducing the threshold for recommended lane widths for design speed from above or below 60 km/hr to above or below 50 km/hr; and (2) reducing the practical range to the recommended range to align with the balance of the new standards document. Engineers who were consulted were concerned about liability, reducing the factor of safety and margin of error for drivers who exceed the speed limit for high speed arterials (over 50 km/hr) with the application of narrower lane widths. To manage this concern, lane widths are differentiated at design speeds of above or below 50 km/hr. In the future, the City will consider reverting back to differentiating widths above or below 60 km/hr as a better understanding of the implications of lane widths on higher speed roads emerges.

The Complete Streets Design and Construction Standards provide a range of acceptable values for many street elements. Stakeholders indicated a desire to only include the recommended range rather than the entire practical range, as in the TAC GDG, throughout the document to ensure that if minimums were applied, the resulting overall design would be acceptable. As a result, it was determined that the range of lane widths should reflect the recommended range rather than the practical range to be consistent with the remainder of the standards document.

Other modifications included removing the 4.45 m curb lanes that were provided in the former Edmonton standards and widening the parking lane. The width of the existing standard road right-of-way will be maintained, and a maximum 3.95 m curb lane will be utilized, with additional width provided as wider boulevards to store snow. Elimination of the wide curb lanes will be complimented with provision of shared use paths on both sides of arterials to improve cyclist accommodation. Parking lane widths were increased as it was felt that drivers would not typically park on the gutter and to account for the width of vehicles typical to Alberta (i.e. pickup trucks and SUVs).

Table 6: Design Domain for Lane Widths (in m): Design Speed 50 km/h or Less

Parameter: Lane Widths[1,2]	Design Domain Recommended Range Recommended Lower Limit	 Recommended Upper Limit	City of Edmonton Design Target Value
Standard Travel Curbside Lane (non-transit, non-truck route)[3]	3.25	3.75	3.25
Standard Travel Lane (non-transit, non-truck route)	3.00	3.50	3.00
Transit Route Curbside Lane	3.55	3.75	3.55
Transit Route Lane	3.30	3.50	3.30
Truck Route Curbside Lane	3.55	3.95	3.65
Truck Route Lane	3.30	3.70	3.40
Parking Lane	2.35	2.65	2.45[4]

Notes
1) Dimensions are for through and turning lanes. Turning lanes are typically at the lower end of the recommended ranges as these movements are completed at lower operating speeds.
2) Dimensions are measured to face of curb for curbside and parking lanes.
3) For local streets, alleys, shared streets, and pedestrian only streets, a combined single drive lane with yield operation for both directions can be provided. This shared lane must be a minimum of 4.1 metres wide. For local streets, the minimum Travelled Way width shall be 8.0 m to accommodate required offsets for underground utilities and emergency response access, which may require parking restrictions. Service roads have a minimum Travelled Way width of 6.0 m due to the presence of an adjacent street. The designer must also consider the impacts of underground utilities, as well as winter design and operations when selecting Travelled Way widths.
4) Parking lanes for large trucks in industrial areas shall be 3.10 m to face of curb for collector and local roadways.

Table 7: Design Domain for Lane Widths (in m): Design Speed Over 50 km/h

Parameter: Lane Widths[1,2]	Design Domain Recommended Range Recommended Lower Limit	 Recommended Upper Limit	City of Edmonton Design Target Value
Standard Travel Curbside Lane (non - transit, non -truck route)	3.55	3.95	3.75
Standard Travel Lane (non-transit, non-truck route)	3.30	3.70	3.50
Transit Route Curbside Lane	3.65	3.95	3.75
Transit Route Lane	3.40	3.70	3.50
Truck Route Curbside Lane	3.65	3.95	3.95
Truck Route Lane	3.40	3.70	3.70

Notes:
1) Dimensions are for through and turning lanes. Turning lanes are typically at the lower end of the recommended ranges as these movements are completed at lower Operating Speeds.
2) Dimensions are measured to face of curb for curbside lanes.

6 Opportunities for Future Research

The City of Edmonton has an interest in expanding this lane width research with respect to: (1) the impact of lane widths on the safety of vulnerable users; (2) the relationship between lane widths, collisions and seasonality; and (3) the impact of lane widths when considering other contextual elements such as land use type, built form and street trees. Vulnerable road user collisions were not analyzed in this project due to sample size issues, but the lane width impacts on these users could be different. Edmonton is a winter city and many decisions related to street design are guided by a winter design lens such as space for snow storage. It is important to understand the trade-offs related to public realm and safety of vulnerable users in pedestrian oriented areas. This is particularly important when considerations are placed towards expanding the travelled way to manage winter operations and driver safety. Further research will inform evidence-based decision making in these circumstances.

The in-service evaluation methodology was sound and robust from a statistical perspective. However, some limitations should be noted for future analysis:

- When possible, before-after studies are preferable to cross-sectional studies for estimating the effects of road design changes on safety outcomes. This is because before-after studies are less susceptible to bias and confounding effects from omitted or non-observed variables. All results from cross-sectional studies should be taken with the understanding that non-observed factors may have contributed to the measured effects from the explanatory variables instead of the explanatory variables themselves. We offset this limitation through sample size, parameter significance analysis, and controlling for some of the other variables known to impact the outcomes, most notably volume, speed, and segment length.
- A greater database size could allow further population segmentation. Our database size of 626 segments, with 3166 collisions, allowed for breakout analysis of up to 15 population segments for collision counts and 10 population segments for speeding proportions. As the population is segmented, the sub-population sample size decreases. Some sub-populations of interest do not have a sufficient sample size and cannot be modelled. For example, combinations of speed and facility type features such as a model for 'low speed streets with transit and bike lanes' did not have sufficient sample size to be modelled. The lowest sample size for which we generated acceptable models had 35 segments, so any extension of this study to analyze additional road types could aim to have at least 35 segments per road category.
- Resource constraints limited the number of model forms that could be investigated. In the future, additional model forms such as quadratics could yield interesting results.

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