

1 **Large-Scale Microscopic Traffic Behaviour and** 2 **Safety Analysis of Québec Roundabout Design**

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23 **ABSTRACT**

24 Roundabouts are a staple of European road design with many international studies demonstrating
25 important reductions in collision severity and, to a lesser extent, frequency, among other bene-
26 fits. With the promise of better safety, roundabouts have recently proliferated across across North
27 America as well. However, regional adoption has not been smooth and questions still remain
28 regarding roundabout design and suitability in the context of North American driving culture. In-
29 deed, driving behaviour is a vital component of a well functioning roundabout as all movements
30 within are managed entirely by driving etiquette.

31 To obtain a better understanding of how roundabout design affects driving behaviour at
32 Québec roundabouts, a study of 37 instrumented weaving zones across 20 roundabouts throughout
33 the province of Québec was conducted. The instrumentation captured continuous, high-resolution,
34 microscopic movements and speeds fifteen times per second (trajectories) of over 80,000 individual
35 vehicles over a combined 9,500 veh-km, one of the largest studies of its kind to date. This study
36 looks at the effects of several geometric design and built-environment factors on the indicators of
37 behaviour of speed and time-to-collision.

38 Among the major findings, roundabout conversions from traffic circles consistently scored
39 the highest speeds and lowest (most dangerous) time-to-collisions, the number of roundabout lanes
40 was negatively correlated with speed in the weaving zone, and mixed flow ratios between the
41 roundabout lanes and the approach lanes produced the lowest time-to-collisions.

42 INTRODUCTION

43 Roundabouts are a relatively new design for intersection traffic management in North America.
44 With great promises from abroad in terms of safety, as well as capacity—roundabouts are a staple
45 of European road design—roundabouts have only recently proliferated in parts of North Amer-
46 ica, including the province of Québec. However, questions still remain regarding the feasibility
47 of introducing the roundabout to regions where driving culture and road design philosophy differ
48 and where drivers are not habituated to their use. This aspect of road user behaviour integration
49 is crucial for their implementation, for roundabouts manage traffic conflicts passively. In round-
50 abouts, road user interactions and driving conflicts are handled entirely by way of driving etiquette
51 between road users: lane merging, right-of-way, yielding behaviour, and eye contact in the case of
52 vulnerable road users are all at play for successful passage negotiation at a roundabout. This is in
53 contrast with typical North American intersections managed by computer-controlled traffic-light
54 controllers (or on occasion police officers) and traffic circles (1) of all kinds which are also signal-
55 ized. And while roundabouts share much in common with 4 and 2-way stops, they are frequently
56 used for high-capacity, even high-speed, intersections where 4 and 2-way stops would normally
57 not be justified. Resistance to adoption in some areas is still important, notably on the part of
58 vulnerable road users such as pedestrians and cyclists (2, 3, 4, 5) but also by some drivers too.

59 While a number of European studies cite reductions in accident probability and accident
60 severity, particularly for the Netherlands (6), Denmark (7), and Sweden (2, 8), research on round-
61 abouts in North America is still limited, and even fewer attempts at microscopic behaviour analy-
62 sis exist anywhere in the world. The latter is important because it provides insight over the inner
63 mechanics of driving behaviour which might be key to tailoring roundabout design for regional
64 adoption and implementation efforts.

65 Fortunately, more systematic and data-rich analysis techniques are being made available
66 today. This paper proposes the application of a novel, video-based, semi-automated trajectory
67 analysis approach for large-scale microscopic behavioural analysis of 20 of 100 available round-
68 abouts in Québec, investigating 37 different roundabout weaving zones. The objectives of this pa-
69 per are to explore the impact of Québec roundabout design characteristics, their geometry and built
70 environment on driver behaviour and safety through microscopic, video-based trajectory analysis.
71 Driver behaviour is characterized by merging speed and time-to-collision (9), a maturing indicator
72 of surrogate safety and behaviour analysis in the field of transportation safety. In addition, this
73 work represents one of the largest applications of surrogate safety analysis to date.

74 LITERATURE REVIEW

75 Roundabout Safety Studies in Europe

76 A number of roundabout safety studies have been performed throughout Europe. In the Nether-
77 lands, for example, one study found a decrease in casualty rate across 46 roundabout conversions
78 of up to 74% (6) (though admittedly the rates were small to begin with). A more recent example
79 in Denmark shows important reductions in accident rates and accident severity across a large data
80 set, though it also suggests that roundabouts have the least effect on mitigating property-damage-
81 only (PDO) collisions (7). This study also looked at contributing factors and recommends tapered
82 central islands above installations with islands which are not elevated or that have elevations with
83 cylindrical shape (obstruction of visibility). Finally, it notes that cyclist collisions increased over
84 the same period.

85 Similar results have been shown in Sweden (2, 8) and in 28 other studies (10). Overall,

86 there is clear evidence of roundabouts reducing accident severity.

87 **Roundabout Safety Studies in North America**

88 Experience and research in North America are still lacking, though some efforts have nevertheless
89 been made. One study found a decrease in collision severity, particularly for fatal collisions, using
90 an empirical Bayes model on 24 stop-controlled intersection conversions into roundabouts (11, 12).
91 A more recent, but similar, study found essentially the same result across 28 sites in the same region
92 (13). Meanwhile, closer to Québec, Burns found that large passenger vehicles, multiple vehicles,
93 and night time were associated with increased accident severity (14).

94 **Behavioural and Surrogate Safety Studies**

95 Surrogate safety analysis is a pro-active road safety diagnosis methodology which aims to improve
96 road safety analysis methods by complementing historical accident data (or supplanting it alto-
97 gether when it is not available) with cheap and short observations of ordinary traffic behaviour
98 (15). Speed is a classic surrogate safety measure, though this designation is rather new: many
99 studies in the literature infer from or target speed directly for purposes of road safety. Its effects
100 on collision severity are well known, though its effects on collision probability are less sure (16).

101 Roundabout speed is consistently measured around 30 km/h in the literature (17). In fact,
102 it has been observed that, while high-speed areas typically have their speed decrease to 30 km/h
103 after implementation of a roundabout, areas with lower speeds (e.g. 20 km/h) can have their speed
104 increased to 30 km/h as well (2). This effect has been also observed at the microscopic level in
105 Québec (18).

106 There are many other surrogate safety measures, but time-to-collision (TTC) is the surro-
107 gate measure of safety of choice for its relative maturity, simplicity, and transferability properties.
108 TTC measures the time remaining, at any instant in time, before two road users on a potential colli-
109 sion course collide: higher values are better for safety. It does not have the same level of validation
110 in the literature as speed, but while speed is a good predictor of collision severity, TTC promises to
111 be a good predictor of collision probability, a property which is arguably lacking with speed (16).
112 Therefore, modelling both speed and time-to-collision should give a good overall representation of
113 collision risk associated with road user behaviour.

114 Several collision-course modelling techniques are used in the literature, chief amongst them
115 in terms of ubiquity is constant velocity (9). However, the constant velocity motion-prediction
116 model is deemed inadequate for TTC measurement in roundabouts, as road users in roundabouts
117 rarely follow straight trajectories, both inside the roundabout and on a significant portion of the
118 approach. Fortunately, some more sophisticated naturalistic motion-prediction models have been
119 developed to overcome this shortcoming: motion patterns are used for their ability to learn normal
120 movement within a traffic scene. A discretized motion-pattern matrix method has been developed
121 specifically for roundabouts (19).

122 **METHODOLOGY**

123 **Scope**

124 Early in the research project, a decision was made to decompose roundabouts into symmetrical
125 and repeating sections for use as units of analysis. There are several reasons for this:

- 126 • Roundabout **branches vary in number** (between two and six, with a median of four
127 branches) and branches can vary greatly in geometry even among branches of the same

128 roundabout, which makes detailed description of the entire roundabout as a whole very
129 complex. Instead, a smaller number of measures are chosen to describe a larger number
130 of repeating design elements found at each branch, for example: number of approach
131 lanes.

- 132 • There are **practical limitations** to performing video-data collection which covers the
133 entire roundabout *and* a sufficient distance upstream of the approaches.
- 134 • Roundabouts are large enough that they can and often do contain **multiple independent**
135 **road user interactions simultaneously**. For example, a motorist approaching a four-
136 legged roundabout from one section (e.g. north-west) can do so independently of any
137 movement occurring on the opposite section (e.g south-east). This is not strictly true
138 for all interactions, however; particular care should be taken at the transitional zone
139 between sections.

140 These sections are termed *quadrants* as they cut the most common roundabout configura-
141 tion, a four-way roundabout, into four sections using two axes of symmetry. Though other config-
142 urations do exist and roundabouts are rarely perfectly symmetrical in reality, the general principle
143 still applies: a quadrant is defined as the section of a roundabout delimited by an approach and the
144 next immediate exit, bounding a central weaving zone (depicted in Figure 1, first presented and
145 discussed in (18)) where the approach and exit lanes overlap with the lanes of the central ring. In
146 this zone, road users experience weaving conflicts in addition to all others.

147 These weaving conflicts are virtually unique to roundabouts and are the key aspect of the
148 yielding mechanisms that govern right-of-way behaviour at the roundabout as a whole. These
149 weaving zones are also of particular interest because they contain the most complex driving situa-
150 tions: single-lane corridors generate rear-end conflicts, multi-lane corridors generate rear-end and
151 lane-change conflicts, while weaving zones generate rear-end, lane-change, and weaving/merging
152 conflicts. This is still a smaller theoretical conflict diversity than at signalized intersections, a point
153 commonly brought up in the literature as justification for roundabout safety (1, 20), yet it does not
154 account for conflict frequency.

155 Pedestrian-motorist conflicts normally do not overlap with the weaving zone as the cross-
156 walks are normally set back from the roundabout by a couple of car-lengths. Interactions between
157 users, motorists, and pedestrians alike, located on an approach and an adjacent exit, and vice
158 versa, can be considered independent from one another as they are normally always separated by
159 a median.

160 While factors are mostly recorded per quadrant, some factors, particularly factors related
161 to the built environment, affect the roundabout as a whole so are thus measured site-wide.

162 **Factors**

163 Each quadrant has 60 recorded factors. These factors include geometric design, signalization, and
164 built environment factors. The most interesting and least covariant of these factors are retained for
165 this study and are presented in the following sections.

166 *Geometric Design Factors*

167 Table 1 lists the most important and least collinear geometric factors under study. This includes
168 lane number and arrangement at the start and end of the roundabout, lane number and arrangement

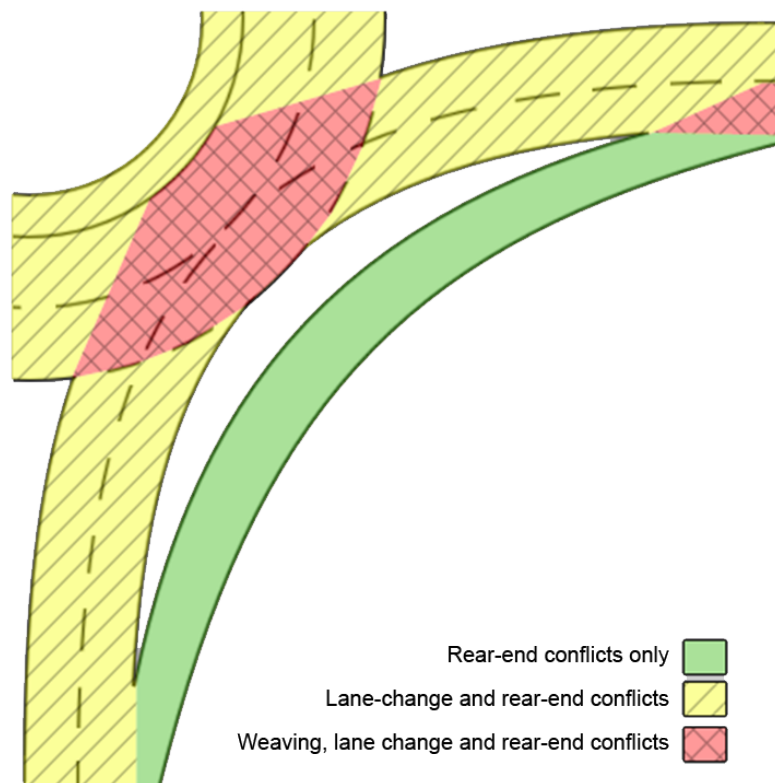


FIGURE 1 A quadrant with highlighted conflict zone complexity.

169 at the approach and exit, inside and outside radii, size of the quadrant measured as an angle (typi-
 170 cally affected by the number of branches), and upstream intersection distance. Note that the posted
 171 speed limit is the legal speed limit, not the recommended roundabout speed. The measurement
 172 criteria can be seen in Figure 2.

173 *Built Environment Factors*

174 Table 2 lists the built environment factors under study. These are descriptive observations of net-
 175 work topology and land use—zoning and road classification. Private roads and commercial land
 176 use are rather under-represented, as these produce very low traffic volumes. Mixed land-use is used
 177 in situations where multiple types of land-use occur near a roundabout. This is typically the case
 178 where commercial rows intersect a residential neighbourhood. The effect may not be comparable
 179 to the sum of its parts, however, so is treated separately.

180 **Traffic Data**

181 Traffic-flow data is obtained from the automated analysis video data: vehicle trajectories extracted
 182 from video data using computer vision techniques built for traffic analysis applications. In this
 183 case, the computer vision tool used is the Traffic-Intelligence project, an open-source traffic-
 184 analysis software (21). See section 5.1 for more details on the source and size of the data.

TABLE 1 Important Geometric Design Factors and Descriptive Statistics from the Dataset

Variable	Description	Type	Min	Mean	Max	Units
n_start_lanes	Number of lanes in roundabout	Integer	1	1.29	2	-
n_app_lanes	Number of approach lanes	Integer	0	1.31	2	-
n_exit_lanes	Number of exit lanes	Integer	1	1.21	2	-
n_slip_lane	Number of slip lanes	Integer	0	.024	1	-
a_quad_size	Angular size of quadrant	Continuous	45	91.07	145	Degrees
r_out_start	Outside roundabout radius	Continuous	13.5	24.90	54	metres
r_in_start	Inside roundabout radius	Continuous	6.5	13.36	41	metres
w_apron	Width of truck apron	Continuous	0	2.98	7.75	metres
d_app_inter	Upstream dist. to nearest intersection	Continuous	36	381.35	2924	metres
app_speed_limit	Upstream posted speed limit	Continuous	30	59.02	90	km/h

TABLE 2 Built Environment Factors: Network Class & Land Use

Variable	Description	Count
Network Topology		
_constant	Private Road	0
nc1	Collector	6
nc2	Arterial	20
nc3	Regional Highway	10
nc4	Access Ramp	5
Land Use		
_constant	None	8
lu1	Residential	16
lu2	Commercial	1
lu3	Industrial	7
lu4	Mixed	5
lu5	School	0
lu6	Institutional	4

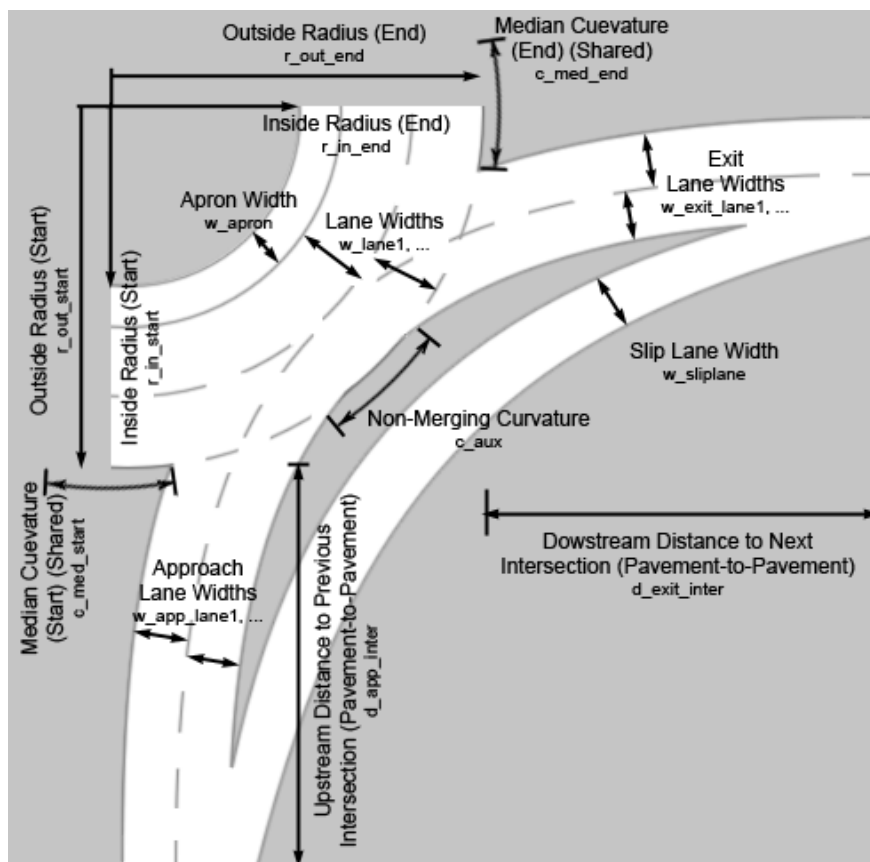


FIGURE 2 17 different geometric design factors can describe the physical design of any roundabout quadrant.

185 Trajectory data is obtained from the tracking of moving features within camera space.
 186 These feature tracks are a series of continuously measured positions mapped to real coordinates
 187 using a scene projection transformation by way of a homography matrix. These features are con-
 188 tinuous, forming a path (trajectory) moving through space and time representing a road user's
 189 movement through the scene. Features are grouped together into objects using specifically cali-
 190 brated algorithms for the task of identifying individual road users in the a scene (though context-
 191 insensitive classification is still a work in progress). Some secondary filtering techniques were
 192 developed to automate validation and error correction (19, 21).

193 Traffic flow and flow ratios can be obtained by performing counts on these objects accord-
 194 ing to the context of the specific metric. In this case we collect per-lane per-hour counts over the
 195 time of the study. Flow ratio is calculated as follows:

$$Q_r = Q_{approach} / (Q_{roundabout} + Q_{approach}) \quad (1)$$

196 where $Q_{roundabout}$ is the count of vehicles entering the weaving zone from within the round-
 197 about and $Q_{approach}$ is the count of vehicles entering the weaving zone from the approach. A low
 198 $Q_r < 0.33$ indicates a large traffic flow arriving from a different section of the roundabout (users
 199 who have priority) with little mixing. A high $Q_r > 0.66$ indicates a large traffic flow arriving from

200 the approach (users who do not have priority) with little mixing. A Q_r between 0.33 and 0.66 in-
201 dicates an even balance of traffic flow between the approach and inside the roundabout with good
202 mixing. This is more common with low flows, as priority rules tip the balance of flow in favour of
203 those already in the roundabout at flow saturation. A polarized flow ratio is a flow ratio less than
204 0.33 or greater than 0.66.

205 *Speed*

206 Speed is similarly obtained from trajectory data. It is derived from position observations between
207 successive frames. It should be noted that a moving average filter with a half window of 5 frames
208 is applied to this data to reduce tracking noise, but this still corresponds to speed measurements
209 performed several times per second per object.

210 *Time-to-collision*

211 A discretized motion pattern matrix method developed specifically for roundabouts (19) is used
212 for this study. We also elect to model all traffic events, using a conservative minimum probability
213 of collision detection of 0.001, and using the indicator aggregation by the 15th percentile unique
214 per user pair as described in (22).

215 **Site Selection**

216 Site selection was performed according to a number of criteria including practical constraints and
217 statistical representation. Data collection feasibility was scored on a five-point scale measuring
218 data collection cost and quality and sorted to generate a feasibility rank. Among a population
219 of nearly one hundred candidate roundabouts in the province of Québec, starting from the most
220 feasible, thirty sites were chosen to provide a good representation of design and land-use charac-
221 teristics, knowing that a fraction of these sites would have to be rejected due to logistical issues
222 (e.g. adverse weather, road closures, or equipment failure hampering data collection efforts). In
223 particular:

- 224 • An adequate geographical coverage of the province of Québec and land-use types was
225 desired. Sites were selected throughout all but one of the the major populated regions
226 of Québec, as well as some of the more rural areas to provide regional representation.
227 As listed in Table 2, representation of the built environment factors is adequate, although
228 with a few exceptions. Notably, roundabouts on private roads are difficult to access for
229 data collection and, in any case, provide little safety information as traffic flows are too
230 small. Also, while roundabouts can often be found in school or commercial zones, these
231 roundabouts did not serve through-traffic, serving instead as limited access points for
232 parking lots or campus roads. These sites were rejected.
- 233 • Roundabouts located on the territory of the provincial transportation agency are all built
234 to very similar specifications and are significantly more consistent in design than munic-
235 ipal roundabouts. However, provincial roundabouts tend to serve more network classes
236 than municipal roundabouts, which serve collector roads for the most part. Forty percent
237 of the sites were located on provincial territory, while the remainder were strewn across
238 seven different municipalities.

TABLE 3 Data details

Roundabouts	20
Analysis Areas	37
Hours of Video Data	473.9 hours
Total Traffic Volume Observed	79,432 veh
Veh-km Traveled	9505.97 veh-km

239 Modelling

240 Speed can be nicely averaged as it is generally normally distributed. However, TTC is not always
 241 so nicely distributed. Therefore different aggregation methods should be used. So instead of using
 242 aggregation, this data will be analysed in a disaggregated manner. The data is thus effectively
 243 unbalanced panel data, where sites are the panels containing individual observations of behaviour
 244 (speed, TTC indicators, gap acceptance). Random effects modelling is chosen for the analysis
 245 using the formula

$$\ln(Y_{ij}) = \mu + \sum_{k=1}^n \beta_k X_{kij} + u_{ij} + \epsilon_{ij} \quad (2)$$

246 where Y_{ij} is the safety indicator of the j th road user at the i th site, β_k is the coefficient of
 247 factor X_{kij} from $k = 1..n$ factors and μ is the average safety indicator (base case). u_{ij} and ϵ_{ij} are
 248 the between-entity error and within-entity error respectively. Regressing for the natural logarithm
 249 instead of the dependant variable directly mitigates issues with non-normal distributions, which
 250 is particularly the case with TTC. A useful model for evaluating the effects of sites has a large
 251 between- R^2 and minimises within- R^2 effects.

252 EXPERIMENTAL RESULTS

253 Data Size

254 Video data was collected at 20 different roundabouts of varying geometrical configuration and
 255 land-use across the province of Québec. Video was shot using a purpose-built mobile video-data
 256 collection system designed for temporary, high-angle video data collection, with tamper-proof,
 257 weather-proof, self-contained cameras mounted on a 7.5 to 10.5-metre pole (21).

258 At these 20 roundabouts, video data was recorded for 39 merging zones (the study sites)
 259 of varying lane configuration, geometry, land use, and traffic volumes. The merging zone of the
 260 roundabout is defined as the portion of the ring intersected by an approach and the next exit, and the
 261 area proper is the area where the approach and exit lanes overlap with the ring. There is generally
 262 one merging zone between every pair of adjacent branches, unless one of these branches does not
 263 have an approach (these are rare and not included in the study). Video data at each site was taken
 264 during one mild summer workday from 6 AM to 7 PM or 10 PM and captures both peak traffic
 265 hours (18). See Table 3 for details.

266 Dependent Variables

267 The dependent variables being modelled are speed and time-to-collision (TTC). A quick correla-
 268 tion test between TTC values and speed values at the time of TTC capture for each observation
 269 returns a Pearson correlation of -0.2150, signifying that the two are mostly independent. This is
 270 further illustrated in a scatter of each individual observation in Figure 3. After instantaneous in-
 271 dicator aggregation by 15th percentile, there are a total of 61,089 TTC observations and 58,379

272 associated speed observations (the difference being rejected on the grounds of quality).

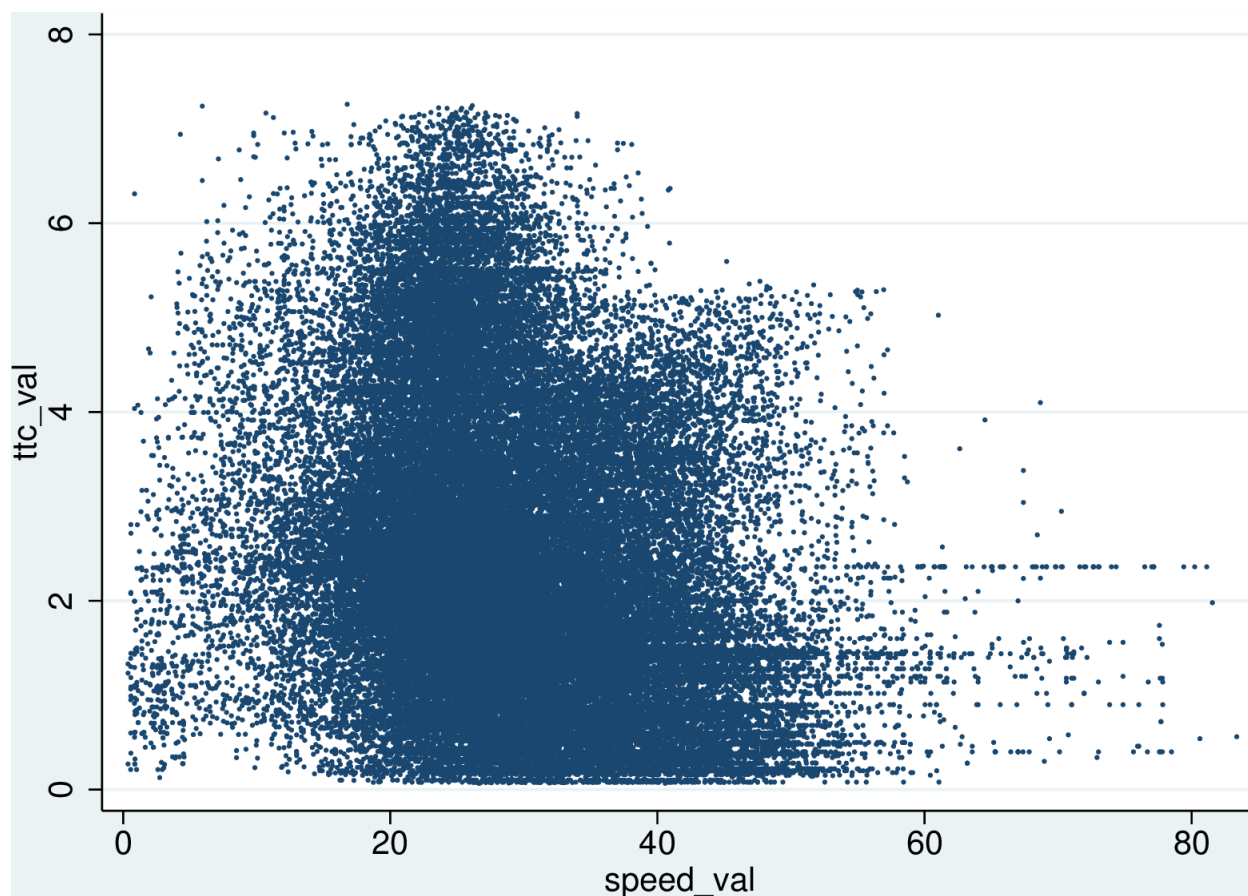


FIGURE 3 Scatter of individual speed versus TTC observations.

273 *Mean Speed Aggregated*

274 A simple linear regression for aggregated mean speed across the 37 sites is explored first. Including
 275 dummy variables from land use categories, over 20 variables are available for modelling. With only
 276 37 sites, this leaves very little room for degrees of freedom. While a handful of factors individually
 277 contribute significantly to explaining mean speed, only two to three can be used simultaneously
 278 before the model significance starts to erode.

279 Table 4 lists the coefficients and p-values for three factors which stand out: commercial
 280 and institutional land-uses as well as number of exit lanes off the roundabout are found to have a
 281 traffic calming effect on an average speed of 42 km/h for vehicles travelling through the weaving
 282 zone by 5 to 10 km/h. Number of exit lanes having a negative effect on speed is unexpected, may
 283 be explained by more regular arrivals of inside of the roundabout providing fewer opportunities
 284 for vehicles on the approach to enter the roundabout without stopping. Regardless, in a future
 285 study, it should be interesting to compare this effect with yielding behaviour and gap times. Un-
 286 surprisingly, speed limits are also correlated with speed, though they are covariant with many built
 287 environment factors, so are ignored. The R-squared for this first model is 0.2766, which offers

TABLE 4 Linear regression for aggregated mean speed (p-values and significance in parenthesis)

Factor	Coefficients	Coefficients	Coefficients
Constant	42.01 (0.000 ***)	4.74 (0.002 ***)	26.91 (0.000 ***)
Commercial land-use	-5.51 (0.053 *)		
Institutional land-use	-9.41 (0.050 **)		
Number of exit lanes	-6.80 (0.041 **)		
Approach speed limit		0.32 (0.001 ***)	
Apron width		-1.51 (0.056 *)	
Inflow per hour per lane			0.02 (0.081 *)
R-squared	0.277	0.2446	0.0760
No. observations	41	41	41

288 modest explanatory power. To improve results, site clustering and random effects regression is
 289 performed next.

290 **Disaggregated Speed Regression**

291 To better manage results due to the number of variables, k-means clustering is employed on all of
 292 the variables. Several clusters were performed using between three and six centroids to find a suit-
 293 able model that i) produces the most meaningful and interpretable clusters, ii) produces a random
 294 effects regression model with explanatory power, and iii) where p-values still remain relatively
 295 significant. However, because we know the different indicators are statistically independent for
 296 the most part, we find that different clusters offer different explanatory power for each dependant
 297 variable. Table 5 lists the distribution of observations (at the site level and at the disaggregated
 298 level) for the clusters used to model speed and offers a short profile for each.

299 This regression model offers relatively good explanatory power. The coefficients and statis-
 300 tical test results are provided in Table 6 All but cluster c6_s (2-lane arterials) provides moderate to
 301 very strong statistical significance. Cluster c1_s (single-lane residential arterial) is associated with
 302 the lowest speeds. From the cluster characteristics, we gather that high and moderate flow ratios
 303 have an important effect of increasing speed. Unsurprisingly, the highest speeds attributed to re-
 304 gional highway roundabouts. Large-diameter, 2-lane, roundabout-converted traffic circles had the
 305 poorest speed results, probably because the approach angle remained tangential to the circle instead
 306 of the usual mostly orthogonal approach of smaller roundabouts. Interestingly, roundabouts situ-
 307 ated in residential neighbourhoods on collector streets (cluster c4_s) were associated with higher
 308 speeds than highway ramps (cluster c3_s), despite the smaller size. This may be attributed to
 309 significantly lower flows and thus fewer conflicts.

310 **Disaggregated TTC Regression**

311 Table 7 lists the distribution of observations (at the site level and at the disaggregated level) for the
 312 clusters used to model TTC and provides a short profile for each. Weaving zones are slightly less
 313 well balanced across groupings, though individual observations are better distributed. Also of note
 314 is that clusters c5_s and c5_t are identical.

315 This regression model offers moderately good explanatory power. The coefficients and sta-
 316 tistical test results are provided in Table 8. Clusters c5_s and c6_s are not statistically significant.

TABLE 5 K-means cluster profile for speed regression

Cluster	Description	Group size	Observations
c1_s	Arterial with wide lanes, far distance to upstream intersections, and very low flow ratios, mixed land-use	6	5,232
c2_s	Regional, single lane highways in industrial complex with mixed flow ratios	6	13,267
c3_s	A mix of highway ramps and arterials with extremely polarized flow ratios	13	17,130
c4_s	Residential collectors with reasonably well mixed flow ratios and short upstream distance to nearest intersection	6	325
c5_s	Traffic circle converted to roundabout (2 lanes, extremely large diameters, tangential approach angle)	4	10,295
c6_s	2 lane arterials near commercial or institutional land use and very high flow ratios.	6	14,840

TABLE 6 Random effects speed regression

Cluster	Coefficient	p-value
_cons (c1_s)	3.0212	0.000 ***
c2_s	0.3781	0.001 ***
c3_s	0.1612	0.090 *
c4_s	0.2569	0.019 **
c5_s	0.4667	0.000 ***
c6_s	0.1498	0.177
sigma_u	0.1638	
sigma_e	0.3183	
R-squared within	0.0000	
R-squared between	0.4225	
R-squared overall	0.2477	
Prob > Wald chi2(5)	0.0003	
No. observations	58379 (37 groups)	

TABLE 7 K-means cluster profile for TTC regression

Cluster	Description	Group size	Observations
c1_t	Small single and double lane residential collectors	11	4,200
c2_t	Single-lane regional highways and arterials with speed limits of 70-90 km/h and mostly polarised flow ratios	16	26,243
c3_t	2-lane arterials with very high flow ratios	5	13,307
c4_t	Hybrid lane 1->2 2->1 arterials with very low flow ratios	3	4,809
c5_t	Traffic circle converted to roundabout (2 lanes, extremely large diameters, tangential approach angle)	4	10,295
c6_t	Single-lane regional highway with large-angle quadrants (140 degrees) and mixed flow ratios	2	2,235

317 Small, residential, local roundabouts are associated with the second-worst (lowest) TTC perfor-
 318 mance, after traffic circle conversions which were noted for their issues with higher speed. The
 319 best performing group, in terms of safety appears to be 2-lane arterials with excessively high flow
 320 ratios (c3_s). This is probably explained due to the extremely low amount of interactions gener-
 321 ated at the weaving zone—instead these results are probably governed by TTC measures generated
 322 from lane changing manoeuvres. Clusters c4_t (Hybrid lane arrangement arterials with very low
 323 flow ratios) and cluster c2_t (single-lane regional highways and arterials with speed limits and po-
 324 larised flow ratios) offer the next best TTC performance. The most striking aspect in this model
 325 is that higher TTC appears to be associated with flow ratio extremes where as lower TTCs (more
 326 dangerous) appear to be associated with highly mixed flow ratios. This might be explained by the
 327 increase in the generation of complex merging manoeuvres when flows are equivalent on both the
 328 roundabout and it's approach.

329 **TTC Distributions by Cluster**

330 Using the comparison methodology described in (22), Figure 4 provides the cumulative distri-
 331 bution functions of TTC for the clusters c1_t through c6_t. The unambiguous left-shift of TTC
 332 observations for cluster c3_t and right-shift for cluster c5_t are consistent with the results of the
 333 TTC regression model presented in 5.4: c3_s is associated with the greatest benefits in safety.
 334 Clusters c1_s, c2_s, c4_s, and c6_s are inconclusive using this approach.

335 **CONCLUSION**

336 This research looked at two indicators of traffic behaviour—speed and time-to-collision—associated
 337 with road safety (collision severity and collision probability) for 37 weaving zones at 20 round-
 338 abouts in the province of Quebec. Random effect regression was used to perform a disaggregated
 339 behaviour regression across 37 groups over nearly 80,000 observed vehicles, one of the largest
 340 applications of surrogate safety indicators to date.

341 Among the major findings, direct regression of factors suggest that the number of exit lanes
 342 and width of the apron have a significant negative effect on driving speed within the weaving zone,

TABLE 8 Random effects TTC regression (higher is better)

Cluster	Coefficient	p-value
_cons (c1_t)	3.0212	0.158
c2_s	0.4843	0.001 ***
c3_s	0.6924	0.001 ***
c4_s	0.5123	0.073 *
c5_s	0.1035	0.636
c6_s	-0.3385	0.238
sigma_u	0.3707	
sigma_e	0.6541	
R-squared within	0.0000	
R-squared between	0.4171	
R-squared overall	0.1376	
Prob > Wald chi2(5)	0.0005	
No. observations	61089 (37 groups)	

343 while more obvious factors, such as roundabout diameter and flow ratio do not have an effect on
 344 speed. Flow ratio is found to have an important effect on time-to-collision however, for evenly
 345 mixed flow ratios produce the most complex traffic conflicts.

346 Traffic circle conversions are found to be associated with the highest speeds. Surprisingly,
 347 roundabouts in residential areas on collector roads are associated with higher speeds and TTC in
 348 the weaving zone. This may be explained by low flows overall and drivers accustomed to not
 349 having to yield. Roundabouts located in regional highways generated relatively higher speeds
 350 within the weaving zone despite comparable size, though only moderate TTCs.

351 While this research provides some important insight into traffic behaviour at North American
 352 roundabouts, it is not yet complete. The time-to-collision indicator still needs more validation
 353 so these results will need to be revised for better interpretation regarding safety. Results are also
 354 somewhat inconclusive regarding multi-lane roundabout configurations. A more detailed analysis
 355 targeting lane changing behaviour and conflicts specifically may be warranted for these types of
 356 manoeuvres are frequently cited as problematic.

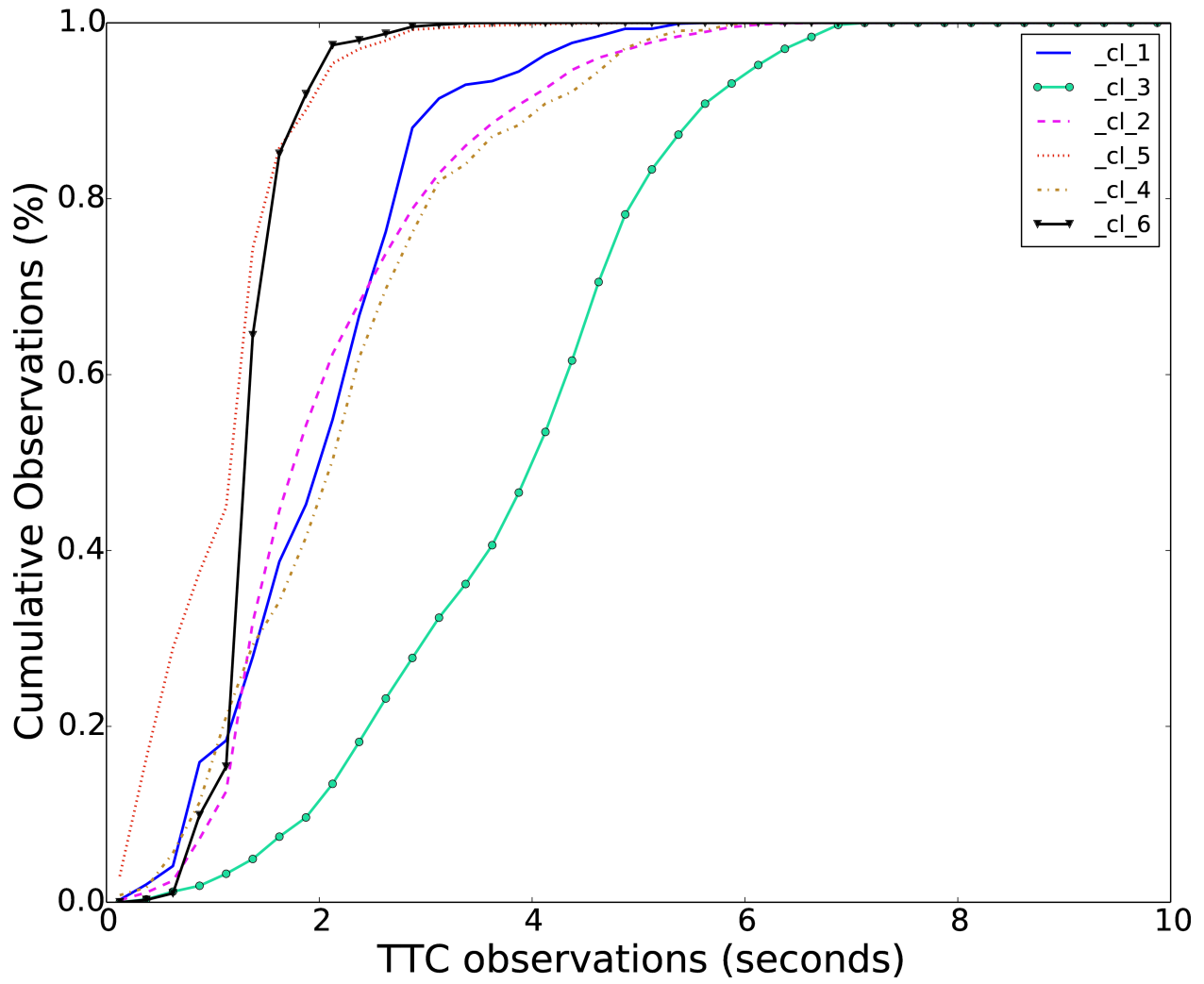


FIGURE 4 Cumulative distribution functions for TTCs aggregated by cluster.

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