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Synthesis on the Safety of Right Turn on Red in the United States and Canada

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ABSTRACT

The Government of Quebec is currently considering the introduction of right turn on red (RTOR) at signalized intersections in Quebec, with the possible exception of the City of Montreal. The Province of Quebec and New York City are the only jurisdictions in North America where the RTOR is not permitted. Following more than 25 years of intense political debates, the Government agreed in 2000 to commission a policy study, aimed at either adopting or rejecting the RTOR once and for all. In order to fully understand all the issues surrounding the introduction of such a measure, the Ministry of Transportation of Quebec (MTQ) mandated the author of this paper to perform a study on the safety, traffic operational improvements, and other characteristics resulting from RTOR based on information gathered from various agencies in the United States and Canada. The study aimed at collecting crash statistics; gathering and reviewing recent research documents and papers; and surveying the opinions of transportation experts and researchers on this topic. The outcome of this study shows that the RTOR is not a dangerous maneuver at signalized intersections for either vehicles or pedestrians in most circumstances. The people interviewed in this study have corroborated this outcome. In short, the proportion of RTOR crashes is usually very low (less than 0.5% of all crashes in a given jurisdiction) and, in the event of crash, the outcome is generally not severe. Based on the respondents' comments, it is obvious that many transportation professionals do not consider the RTOR to be a safety problem. The author addresses several issues and unanswered questions on the safety and traffic operational enhancements resulting from RTOR. The final decision as to whether or not introduce the RTOR in Quebec resides with government officials and should be based on the characteristics presented in this research, but should also consider the habits of Quebec drivers and the crossing behavior of pedestrians at signalized intersections.

INTRODUCTION

The Government of Quebec is currently considering the introduction of right turn on red (RTOR) at signalized intersections for the entire province, with the possible exception of the City of Montreal. The Province of Quebec and New York City are the only jurisdictions where the RTOR is not permitted. Over the last 25 years, the Government of Quebec has been pressured on numerous occasions to allow the RTOR in Quebec to bring the province in line with the rest of North America. In 2000, the Government agreed to commission a policy study, aimed at either adopting or rejecting the RTOR once and for all. In order to fully understand all the issues surrounding the introduction of such a measure, the Ministry of Transportation of Quebec (MTQ) prepared a pilot-study in the spring of 2001. The pilot-study was divided into two parts. The first part consisted of conducting a study on driver behavior at selected cities in Quebec. To perform the pilot-study, the Quebec National Assembly was required to modify the Highway Traffic Act to authorize the RTOR in 26 cities for a period of 9 months. The results of this study can be found in SAAQ (*1*). The second part, which is presented here, consisted of gathering all the relevant information related to the safety and traffic operational improvements resulting from RTOR from various agencies in the United States and Canada. This study is therefore the product of the statistics and opinions obtained from state, provincial and local agencies, transportation engineers and traffic safety experts in North America. The study was performed within a 4-month period at the request of the MTQ.

This paper documents the results of the study mandated by the MTQ. It primarily focuses on the safety of the RTOR; with particular consideration given to pedestrian safety. Many sections of this report are not covered in this paper. The reader is referred to the original document (*2*) for additional information on the complete history of the RTOR in the United States (US) and Quebec, the traffic operational enhancements following the introduction of RTOR, fuel savings, driver behavior and violation rates at signalized intersections, potential countermeasures, safety issues about mobility and visually impaired pedestrians, and as well as safety campaigns aimed at improving pedestrian safety. The RTOR as defined in this paper is a maneuver that allows a motorist who is facing a red light to turn right, unless specifically prohibited, after stopping and yielding to pedestrians, cyclists and cross traffic. This definition does not include special phases that allow vehicles to turn right on a green arrow or with an exclusive right-turning bay. The first section of this paper covers the methodology used to collect crash statistics and survey the opinions of transportation experts. The second section summarizes crash statistics on RTOR. The third section contains a summary of the opinions obtained from safety and transportation professionals surveyed in this study. The last section presents a discussion on important issues related to the safety and operational efficiency of the RTOR.

METHODOLOGY

The study was divided in three parts. First, a literature search was performed on the Transportation Research Information Services (TRIS) Database to obtain a list of documents and papers related to the safety and operational efficiency of the RTOR, pedestrian and bicycle safety, and driver behavior at signalized intersections. At the same time, several transportation organizations, such as the Federal Highway Administration (FHWA), the Transportation Research Board (TRB), the Insurance Institute for Highway Safety (IIHS), the Texas Transportation Institute (TTI), and the Highway Safety Research Center (HSRC) at the University of North Carolina were also contacted for the same purpose. Overall, a substantial number of people contacted were able to provide recent research reports and other documents relevant to this study.

Second, the department of transportation (DOT) of each Canadian province, a number of state DOTs in the US, the Highway Safety Information System (HSIS) at the University of North Carolina and all major cities in Canada were contacted to obtain crash statistics on RTOR. The data requested did not include information on traffic flow or geometric characteristics since it was beyond the scope of this study. Data for injury and property damage only (PDO) were requested for:

- Crashes involving a RTOR and a pedestrian, another vehicle or a cyclist;
- Crashes involving a right turn on green (RTOG) and a pedestrian, another vehicle or a cyclist;
- Crashes involving two or more vehicles at signalized intersections;
- Crashes involving a vehicle and a pedestrian or cyclist at signalized intersections;
- All crashes at signalized intersections;
- All crashes in the city, state or province for pedestrians, cyclists, single and multi-vehicle crashes; and,
- The number of signalized intersections in the city, state or province whenever available.

Despite the number of agencies contacted, the data proved to be difficult to acquire. Crash data involving a RTOR is not commonly collected by many agencies. Nonetheless, crash statistics were obtained for 2 Canadian provinces, 3 cities and 4 states. Some agencies were only able to provide statistics for all right-turning crashes.

Third, a survey was sent to every person or agency contacted for this study, members of the Institute of Transportation Engineers (ITE) Transportation Safety Committee, private organizations, and a substantial number of researchers in traffic safety and transportation engineering (including many members of the TRB Pedestrian Committee). The survey covered topics related to the safety and traffic operational improvements resulting from RTOR. The people contacted were encouraged to pass on the questionnaire to colleagues who may have had a useful opinion on these topics. The opinions received from the respondents were very diverse, since they included people from the public sector (e.g., city engineers, state and federal employees) as well as researchers.

CRASH STATISTICS

This section contains the description on the typology of reported crashes in the US and Canada. It first focuses on the magnitude of the safety problem in both countries before describing crashes involving a RTOR. Due to the tight time-constraints, the author was unable to perform sophisticated statistical analyses, such as developing predictive models for comparing RTOR and RTOG.

Table 1 summarizes the total number of crashes occurring in the US, Canada and Quebec. Between 1995 and 1999, about 2,600 fatal and 150,000 injury crashes occurred annually in Canada (3). During this period, Quebec roads saw about 650 fatal and 33,000 injury crashes annually (4). The magnitude of the safety problem in the US is much higher, with about 6,200,000 crashes per year; of which 37,000 and 2,100,000 are fatal and injury crashes respectively (5).

TABLE 1. Number of Fatal and Injury Crashes in the US, Canada and Quebec (2, 3, 4)

	United States		Canada[1]		Quebec	
Year	Fatal	Injury	Fatal	Injury	Fatal	Injury
1995	37,241	2,217,000	2,854	164,190	731	34,146
1996	37,494	2,238,000	2,708	156,282	762	33,354
1997	37,324	2,149,000	2,646	150,118	653	33,459
1998	37,107	2,029,000	2,598	148,376	624	32,704
1999	37,043	2,054,000	2,621	151,099	676	34,034

[1] includes the Province of Quebec

Table 2 shows the number of fatal and injury crashes involving pedestrians in the US and Canada. This table shows that between 5% to 10% of all reported injury (fatal and non-fatal) crashes, as shown in table 1, involve a pedestrian. The proportion of fatal collisions between a vehicle and a pedestrian is about 10%. It should be pointed out that approximately 25% of all crashes involving a pedestrian in Canada occur in Quebec (note: the disrespect of traffic signals by pedestrians is a widespread phenomenon in this province). According to the statistics obtained from the US and Canada, the proportion of crashes between a vehicle and a bicyclist is around 4% for fatal injuries and 10% for non-fatal injuries.

TABLE 2. Number of Crashes Involving a Pedestrian in the US, Canada And Quebec (3, 4, 5)

	United States		Canada[1]		Quebec	
Year	Fatal	Injury	Fatal	Injury[2]	Fatal	Injury
1995	5 584	86 000	416	----	129	3 643
1996	5 449	82 000	465	----	138	3 703
1997	5 321	77 000	402	----	113	3 625
1998	5 228	69 000	402	----	103	3 465
1999	4 906	85 000	414	----	111	3 574

[1] includes the Province of Quebec
[2] Transport Canada did not tabulate crash statistics for non-fatal pedestrian crashes

According to the NHTSA (5), 665,000 crashes (32%) in the US occurred at signalized intersections, including 2,259 fatal (6%) and 289,000 non-fatal injuries (14%) respectively. These statistics include only collisions occurring at the intersection. NHTSA notes that a little less than 50% of crashes occur at mid-block locations.

Tables 3 to 5 present the number of crashes by type involving a RTOR for Manitoba, Maine, Illinois and Minnesota respectively. The latter two states are presented into one single table. A summary of the statistics shown in these tables is presented at the end of this section.

TABLE 3. Number of Crashes involving a RTOR by Type in Manitoba (1999)

Crash Type	Number of Crashes			
	Fatal	Injury	PDO	Total
RTOR-Pedestrian	0	4	0*	4
RTOR-Rear-end	0	0	3	3
RTOR-right turn (with another vehicle)	0	1	4	5
RTOR-left turn (with another vehicle)	0	0	1	1
RTOR-Other	0	3	4	7
RTOR-All Types	**0**	**8**	**12**	**20**
RT-Pedestrians	0	6	0	6
Crashes involving a pedestrian at signalized intersections	2	104	2	108
Crashes at signalized intersections	8	1883	3267	5158
Crashes involving a pedestrian in Manitoba	19	481	8	508

RTOR = right turn on red
RT = all right turns (green and red)
* pedestrian crashes categorized as PDO are relatively rare events. PDO crashes are reportable if the damages are above anywhere between $500 to $1,000 depending on the province or the state.

(Crash data provided by the Ministry of Transportation of Manitoba)

TABLE 4. Number of Crashes involving a RTOR by Type in Maine (1989-2000)

Crash Type	Number of Crashes			
	Fatal	Injury	PDO	Total
RTOR-Pedestrians	1	28	0	29
RTOR-Cyclists	3	20	0	23
RTOR-Rear-end	0	37	154	191
RTOR-Angle	1	5	0	6
RTOR-Run-off-road	0	1	3	4
RTOR-Intersection related	1	26	242	269
RTOR-Other	0	0	3	3
RTOR-All Types	**6**	**117**	**402**	**525**
Crashes involving a pedestrian at signalized intersections	----	----	----	476
Crashes at signalized intersections	----	----	----	43398
Crashes involving a pedestrian in Maine	----	----	----	4427
Crashes in Maine	**----**	**----**	**----**	**459112**
Number of Signalized Intersections				631

(Crash data provided by the Maine DOT)

TABLE 5. Number of Crashes Involving a RTOR by Type in Minnesota (1985-1998) and Illinois (1985-1999)

Crash Type	Number of Crashes			
	Fatal	Injury	PDO	Total
RTOR-Pedestrians	2	455	5	462
RTOR-Cyclists	0	672	32	704
RTOR-Rear-end	0	272	649	921
RTOR-Sideswipe	1	32	347	380
RTOR-Angle	1	177	578	756
RTOR-Other[1]	2	511	2,517	3,030
RTOR-All crashes	**6**	**2,119**	**4,128**	**6,253**
RT-Pedestrians	37	2,978	77	3,092
RT-Cyclists	14	5,596	465	6,075
Crashes involving a pedestrian at signalized intersections	209	7,919	322	8,450
Crashes at signalized intersections	1,240	224,334	425,071	650,645
Crashes involving a pedestrian in Minnesota and Illinois	2,117	32,753	1,611	36,481
Crashes involving a cyclist in Minnesota and Illinois	301	26,054	2,089	28,535
Crashes in Minnesota and Illinois	**17,652**	**946,846**	**2,048,143**	**3,011,768**
[1] no explanation was provided by HSIS for this type of crash. It is likely that many of these crashes are in fact rear-end, sideswipe or angle multivehicle crashes.				

(Crash data provided by the HSIS)

Tables 6 and 7 show the number of crashes involving a RTOR in Hamilton and Toronto, Ontario respectively. The Toronto data include only pedestrian crashes and are taken from a study performed by Lyon et al. (6). In this study, the authors manually verified each crash occurring between a vehicle and a pedestrian for 1998 and the first six months of 1999. It should be noted that no pedestrian was killed as a consequence of a RTOR in either Hamilton or Toronto.

TABLE 6. Number of Crashes Involving a RTOR by Type for Hamilton (1998-1999)

Crash Type	Number of Crashes
RTOR-Pedestrians	35
RTOR-Cyclists	39
RTOR-Two vehicles	25
RTOR-All Crashes	**99**
Crashes involving a pedestrian at signalized intersections	200
Crashes at signalized intersections	2,905
Crashes involving a pedestrian in Hamilton	572
Crashes in Hamilton	**10,121**
Number of signalized intersections	443

(Crash data provided by the City of Hamilton)

TABLE 7. Number of Pedestrian Crashes at Signalized Intersections in Toronto (1998-1999) (6)

Crash Type	Number of Crashes
Through	249
Left-turn	342
RTOR	111
RTOG	86
Other	197
Crashes involving a pedestrian at signalized intersections	982
Crashes involving a pedestrian in Toronto (intersection and mid-block)	2,645

The data obtained from the US and Canada, presented in Tables 3 to 7, show the following characteristics:

- Between 5% and 20% of crashes at signalized intersections involve a pedestrian;
- Between 5% and 15% of pedestrian crashes at signalized intersection implicate a RTOR;
- Pedestrian crashes involving a RTOR account for less than 1% of all reported crashes in the US and Canada;

- Less than 4% of multi-vehicular crashes at signalized intersections involve a RTOR;
- Similar to pedestrians, the proportion of RTOR crashes is below 0.5% of all reported crashes;
- RTOR is rarely fatal with less than 0.05% of all reported crashes; and,
- The proportion of RTOR-related crashes involving a bicycle is slightly higher than the proportion of pedestrian crashes.

The statistics presented in this section are very similar to results presented in other recent studies. For instance, Compton and Milton (*7*) found that RTOR crashes account for less than 1% of all crashes for the states of Missouri, Indiana, Maryland and Illinois. They examined crash data from 1982 to 1991. In a study performed in San Francisco, Fleck and Yee (*8*) showed the proportion of pedestrian crashes involving a RTOR to be less than 1% of all pedestrian crashes. According to these authors, the percentage is apparently similar to what Ray (*9*) found in 1956. Hunter et al. (*10*) noted that crashes between a vehicle turning right on red and a bicyclist is about 23% of all bicycle crashes at signalized intersections (16% of crashes at signalized intersections involve a bicyclist). The crash statistics reported as part of the pilot-study in Quebec (*11*) show similar, if not better, results than the rest of North America, with less than 5% of all injury crashes at signalized intersections (see Table 8). Further, all these reported crashes were classified as non-serious injury that did not require any hospitalization. The results of the behavior study (*1*) (i.e., violation rate, etc.) indicate that Quebec drivers are no worse than other drivers in North America, as reported in Zegeer and Cynecki (*12*), ITE (*13*), and Huang (*14*).

Table 8. Number of Crashes Involving a RTOR in 26 Quebec Cities (*11*)

Crash Type	Number of Crashes			
	Fatal	Injury	PDO	Total
RTOR-Pedestrians	0	5*	0	5
RTOR-Cyclists	0	11*	0	11
RTOR-All crashes	**0**	**21***	**39**	**60**
Crashes at signalized intersections[2]	2	416	----[2]	418[1]

[1] Total injury crashes, * all were categorized as non-serious injuries (requiring no hospitalization)
[2] The MTQ was unable to provide PDO crashes; the police no longer reports them. The MTQ did request however that police departments report all crashes involving a RTOR during the study period.

It is important to note that several factors affect the number of reported crashes: these include the number of vehicles, pedestrians and cyclists using the road network; the characteristics of the road network (e.g., number of signalized intersections, etc.); how RTOR crashes are reported by the police; weather patterns; and the threshold of what constitute a reportable accident in each jurisdiction. Obviously, these factors vary from one jurisdiction to the next.

SURVEY RESULTS

The objective of the survey was to obtain the opinions of transportation and traffic safety professionals on important issues related to the RTOR. The questionnaire focused on two areas: 1) the safety and 2) the traffic operational enhancements resulting from RTOR. The respondent had the opportunity to provide suggestions to the MTQ.

All surveys were sent by e-mail to transportation professionals across North America. This included people working in jurisdictions that were, as of 1975, either classified under the “Eastern” (prohibited unless permitted by a sign) or “Western” (permitted unless prohibited by a sign) rules. The author has put much effort to obtain the opinions of experts, such as directly communicating with many respondents by phone or e-mail, but has been marginally successful. The people who did not answer generally provided two kinds of reasons. First, many people were simply not interested in answering the questions, mainly because this subject was not considered any kind of interest. Many people commented that the RTOR is not a safety problem. Second, some experts felt they were not qualified to provide useful information. In total, 18 people provided feedback on RTOR. More than half of the people who responded worked in the public sector (7 people from city transportation agencies and 4 individuals from state transportation agencies), whereas the other respondents consisted, interestingly enough, of internationally known researchers and traffic safety experts (7 people from private research organizations and universities). The comments received were very informative and provided new insights on issues related to RTOR.

SAFETY CONCERNS ON RTOR

The comments provided by the respondents on the safety of the RTOR are summarized according to each question presented in the survey.

Based on your own research and/or work experience, do you know if the number of collisions at signalized intersections increased significantly since the introduction of the RTOR maneuver?

- Many people indicated that crash statistics are now too old to make proper conclusions about the increase of RTOR-related crashes. Some experts mentioned that many studies performed in the late 70s and early 80s were poor or inconclusive. Others had no opinion about the quality of the data, the statistical analyses performed on this topic, or whether or not crashes increased in their jurisdiction.

Do you think the RTOR is an important safety hazard to either pedestrians, cyclists or motorists?

- Almost everyone pointed out that the RTOR is not a very dangerous maneuver to pedestrians and cyclists. Only one person stated the opposite. Some people indicated that cyclists are more at risk since they are more difficult to detect by drivers and the speed at the moment of the collision is usually higher. One person argued that left-turning vehicles are far more dangerous to pedestrians than right-turning vehicles. According to one respondent, some signalized intersections are more problematic than others and should therefore be analyzed on a case-by-case basis. Two persons claimed that a RTOG is more dangerous to pedestrians since the vehicle speed is usually higher during the green phase.

What type(s) of crashes occur more often resulting from RTOR in your jurisdiction (e.g., pedestrian, cyclist, right-angle, rear-end, etc.)? Do you have statistics? How severe are these crashes (e.g., PDO, injury, fatal)?

- Many people mentioned the quality of the crash data is not good enough to properly determine which crash type cause serious injuries. One person claimed that pedestrians are usually not critically injured since the speed of the vehicle during a right-turning maneuver is not high. According to another respondent, exclusive right-turning bays are more dangerous to pedestrians than a RTOR.

Do you know if RTOR accidents are properly reported in police accident reports?

- Everyone agreed that the quality of the data recorded on the accident form is average at best. It may be difficult to determine if the crash occurred on the green or on the red phase. According to one respondent, crashes involving pedestrians and cyclists are more likely to be properly reported than a crash involving two vehicles (they usually are PDO crashes). One specialist indicated that the accident report in many states now have a code designated for RTOR crashes. Another one mentioned that RTOR crashes are sometimes coded under other crash types.

In your opinion, should the RTOR be rescinded?

- With the exception of one person, all respondents indicated that RTOR should not be rescinded. One researcher indicated that the elimination of RTOR will not eliminate all RTOR crashes.

Do you know what, if any, criteria there may be to prohibit RTOR at signalized intersections in your jurisdiction (e.g., high pedestrian crossing volume, visibility impediment, speed limits, safety, etc.)?

- Some respondents indicated the following criteria: high number of crossing pedestrians, inadequate sight-distance, signalized intersections located near railway crossings and the angle at which the roads meet at the intersection. One person indicated that many local and transportation agencies apply the criteria proposed in the MUTCD manual (*15*). However, they are usually applied with additional input from traffic engineers.

Based on your own research and/or work experience, do you know if motorists respect the proper procedure when they perform the RTOR maneuver (i.e., stop at the red light, look for other road users, then turn right)? Did your organization conduct any study on this subject?

- All respondents commented that the violation rate by drivers was high, though some also mentioned that this phenomenon was not unique to the RTOR (e.g., red light running, stop signs, etc.). The violation rate is apparently no different for drivers turning right at stop-controlled intersections. One person argued that drivers usually follow the "the spirit of the law" rather than the actual definition written in the Law. Nonetheless, the poor performance by drivers, as strictly defined by the Law, was not a critical issue according to many respondents. It appears that drivers tend to stop most often when pedestrians are present.

TRAFFIC OPERATIONAL IMPROVEMENTS

The comments provided by the respondents on the traffic operational improvements resulting from RTOR are summarized according to each question presented in the survey.

Based on your own research and/or work experience, do you think the RTOR maneuver actually decreases air pollution, travel time and minimize vehicle delay? Did your organization perform a study on this subject?

- All the people interviewed agreed that the RTOR reduces vehicle delay. On the other hand, some people were more skeptical about the potential benefits related to the reduction in air pollution, as such effects would be difficult to measure. According to one person, the reduction in delay would be more noticeable for vehicles turning from the minor approaches than for vehicles turning from the major approaches.

Do you think the gains in operational efficiency outweigh the potential decrease in safety?

- About half of the respondents argued that the gains in operational efficiency outweighed the potential decrease in safety. One person disagreed as too much safety was compromised. Two people mentioned the overall effects should be analyzed on a case-by-case basis.

Do you think that alternative traffic light designs or technology (e.g., detectors, pedestrian push buttons, etc.) could be substituted for RTOR?

- The answers to this question have been evenly split. Some people thought that upcoming technologies, such as automatic detection of pedestrians could be an alternative to the RTOR. One person noted that shadowing techniques (i.e., allowing RTOR during exclusive left-turning phases) could be useful for the

RTOR. Many people did not agree with the fact that actuated signals are a good substitute for the RTOR. According to one person: “Why make everyone stop on the principal arterial, and increase the overall delay, to allow one vehicle coming from the minor approach to turn right?”

Do you think the RTOR maneuver restricts the mobility of disabled pedestrians, such as the visually or mobility impaired?

- On this question, many people indicated that the RTOR could have adverse safety effects for visually impaired people. It would be important to prohibit the RTOR at locations where many visually impaired people cross the intersection. According to three respondents, the mobility of disabled pedestrians would not be restricted since the driver must give the right-of-way to pedestrians. One respondent who works in a rural jurisdiction was not concerned about the mobility of disabled pedestrians as very few pedestrians cross intersections in his jurisdiction.

In summary, the results of the survey show that most of the interviewees were in favor of the RTOR. Many claimed that there are much more important safety problems than a RTOR. Although the feedback was generally positive, all agreed the RTOR should be studied carefully and should only be introduced after proper guidelines are developed. In other words, the RTOR should be prohibited at intersections or approaches only where it is justified to do so. The reader is referred to the ITE (*16*) for additional information on new criteria currently under development for RTOR. The suggestions proposed for the MTQ include the application of the same standards as the rest of North America (e.g., MUTCD) and the prohibition of the RTOR when early-release signal phasing is used for pedestrians (the City of Montreal has many intersections with this type of signal phasing).

DISCUSSION

Since its official introduction nationally in 1975, the RTOR has been the subject of much politicized debate in the US. In Quebec, the debate has been, if any thing even more so than the rest of North America (see *17* or *18*). Consequently, many transportation engineers and traffic safety experts have been carefully studying the benefits and drawbacks associated with the introduction of the RTOR. The opinions of these researchers have been extremely polarized. Those in favor based their arguments on the potential gains in traffic operations, fuel consumptions and decrease in air pollution whereas those against the RTOR argued on potential decreases in safety, particularly for pedestrians. After reviewing a large number of documents and discussing relevant issues with many experts, it appears that many researchers from both sides of this debate have exaggerated the facts about the safety and traffic operational improvements resulting from RTOR. Thus, it is important to reassess important issues related to these topics. The author addresses several of these issues and other unanswered questions.

The safety of the RTOR, particularly as applied towards pedestrians, has been investigated thoroughly by a number of researchers (19, 20, 21, 22, 23, 24, 25, 26, 27, and 28). Although they were well intentioned in their endeavors, a substantial number of studies had methodological deficiencies. The statistical techniques used in some of these studies were inappropriate to properly estimate the increase in the number of crashes involving a RTOR (e.g., simple before-after study with or without control groups, χ^2 test, no distinction between sites categorized under the "Eastern" and "Western" rules, etc.). In fact, the methods proposed by the TRB (29) and Council et al. (30) and applied by some researchers above are no longer used. Griffin (31), Griffin and Flowers (32) and Hauer (33) provide a good overview of the shortcomings for many of these statistical techniques.

The latest statistical methodologies on before-after studies include the following three factors: 1) the exposure (e.g., traffic flow) for the before and after periods, 2) the non-linear relationship between the exposure and crashes, and 3) the regression-to-the-mean phenomenon. Recent statistical techniques include the Empirical Bayes (EB) method (34) and Hierarchical Bayes method (35, 36). These methods must be used in combination with safety performance functions (SPFs) or predictive models, which are used to estimate the relationship between crashes and traffic flow and other covariates (36, 37). Persaud et al. (38) provide a very good description on the application of the EB method for before-after analysis. The document shows how to incorporate the three factors described above. It is very likely that the application of the EB method would have shown a different picture on the true safety of RTOR.

Without conducting any statistical analyses, it is understood intuitively that the introduction of the RTOR should increase the number of crashes at signalized intersections. Indeed, a conflicting maneuver that did not previously exist is introduced at the intersection. However, the main question consists of determining if the risk of crashes involving a RTOR is actually high and, if so, by how much and for which users. The proper procedure would be to calculate the risk of a collision, with the help of SPFs, for this maneuver with the risk for other maneuvers at the signalized intersections for similar exposure, or to compare this risk to an acceptable societal risk. Recent studies on this topic show that a pedestrian is about 4 times more likely to be hit and severely injured by a vehicle making a left-turn than by a right-turning vehicle (this includes a RTOR) (Table 7 in 6, 39, 40, 41, 42, 43, 44, 45, and 46). This outcome is attributed to the low speed of right-turning vehicles, human factors and vehicle design (see 44, 47). This conclusion has been corroborated by some of the people interviewed. The risk of a collision can also vary by the time of day, hence the use of prohibition signs for specific time periods (48). Unfortunately, there is not study that specifically compares the crash risk calculated from SPFs for RTOR maneuver for collisions involving two vehicles or a cyclist.

As discussed in a document produced by the Association of Professional Engineers of Ontario (49), there is no such thing as a "safe road" or "collision free" roads. Indeed, the document maintains that it is inappropriate to say that a road is "safe" insofar as collisions are bound to occur. The document also suggests that one should never claim that a road is safe, only that it is relatively more or less safe than another. Thus, as discussed above, we ought to compare the risk of the RTOR with the risk for other maneuvers within the intersection. Similarly the risk, again determined by SPFs, should be estimated for pedestrians when the RTOR is prohibited to see how it affects the risk for other maneuvers, particularly for a RTOG; this analysis was beyond the scope of this study. As indicated in the previous section, two researchers indicated that an increase in the number of crashes during the green phase is likely to occur.

Some people have argued the danger of the RTOR resides in the fact that when a driver turns right, he or she usually looks more frequently to the left to observe for oncoming vehicle traffic (*50*). It would be interesting to compare the right-turning maneuver at a signalized intersection with the turning maneuver at a stop-controlled intersection (stop signs only on the minor approaches). In both cases, the driver arrives at the intersection, stop (in theory), conducts a visual search, and turns once there is an adequate gap in the traffic and no pedestrian or cyclist is present. In downtown Toronto for instance, there are many 2-stop controlled intersections that have as many pedestrians as adjacent signalized intersections (the city cannot install traffic signals at each intersection). The questions that warrant further thinking is how different is the risk to pedestrians between unsignalized and signalized intersections? Would the fact of an increase in driver workload significantly decreases pedestrian safety? Would pedestrians perceive the risk differently at signalized intersections (i.e., increase in false sense of security) than at unsignalized intersections? Would pedestrians become more intimidated? These questions merit further study.

Gangbè et al. (*51*) stated that crashes involving a RTOR should only be analyzed with respect to crashes occurring at signalized intersections. Although this approach can be useful for comparing how an entity or a crash type fares with the average population of similar entities or crash types, it may not be suitable for transportation policy purposes. For example: a particular type of road user may represent 80% of all road users involve in a crash for a given entity (say 4 out of 5), but can only account for 3.5% of all crashes involving that particular road user in a jurisdiction (4 out of 125). On the other hand, the same type of road user may represent 10% of all crashes occurring at a second entity (say 100 out of 1000), but account for 80% of all crashes involving the target road user (100 out of 125). Under the assumption that both entities have the same exposure (flows and number of entities), logic would dictate that the second entity would be more hazardous. Nonetheless, this example reinforces the general statement that accident risk (computed as a function of probability, exposure and outcome) should be used for determining the safety of an entity or a maneuver.

Dussault et al. (*17*) and Gou (*52*) claimed that potential gains in mobility are insignificant for drivers making a RTOR. They argued that small increments of time cannot be cumulated and, therefore, becomes insignificant when comparing a few seconds saved by the RTOR over the total trip time. Based on a limited survey to assess driver behavior in selected regions of Quebec, Gou even stated that Quebec drivers would only save about 15 to 30 seconds per day (drivers will execute on average two right-turn maneuvers per day); similar values were also found in previous US studies (*19*, *20*, *21*, *24*). This argument is unfortunately flawed. Drivers do not consider the value of time as stated by the authors. The simple fact that a driver selects the best lane position based on the queue of vehicles in each lane at signalized intersections contradicts this argument. For instance, it is unlikely that a driver arriving at an intersection will select the lane with a queue of say 5 vehicles over an adjacent lane that is empty. In this example, the driver at least perceives he or she saves about 10 seconds if one assumes a 2-second headway between each vehicle. Thus, why should we treat the value of time differently between this situation and the RTOR? A similar argument could also be made if one were to stop vehicles for unnecessary reasons (e.g., unwarranted traffic signals or stops signs). Nobody would accept to be told that the total cumulated time one is stopped is negligible, especially if it happens frequently. One respondent, who recently experienced first-hand this observable fact in Quebec City, commented passionately on this issue. Several cities in Quebec are well known for using unwarranted traffic control measures (see *2*, *53*).

The gains in traffic operations should therefore be instead estimated by computing the operational efficiency of the signalized intersections. Recent studies on this subject have shown the RTOR can substantially improve the capacity of the signalized intersection, especially if a large proportion of vehicles turn right at the approach. For instance, Virkler and Rao Maddela (*54*) have argued that the level of service (LOS) could significantly be improved both for the lane group and the approach when RTOR is introduced. In some cases, the volume to capacity (v/c) ratio could be reduced by as much as 20%. Nonetheless, further work is needed on this topic to fully comprehend the gains in traffic operational enhancements as detailed in Quershi (*55*). The reader is referred to Virkler and Chen (*56*), Stewart and Hodgson (*57*), Abu-Lebdeh et al. (*58*), and Virkler and Krishna (*59*) for additional information. Although fully covered in the report, the author purposely did not address issues related to fuel savings in this paper, since all the studies reviewed had no or limited scientific validity (*26*, *52*, *60*, *61*, *62*).

In the light of the above, Gou (*52*) stated that the use of fully actuated signals, coordinated traffic signals, and intelligent transportation systems (ITS) can be considered substitutes to the RTOR (note: fully actuated and coordinated signals are commonly used in Quebec, as elsewhere in North America). Although this assertion has been disputed by most of those interviewed, Gou has indicated that average vehicle delay at signalized intersections could be reduced by 10% to 20%, while at the same time improve safety. Interestingly, when one takes a closer look at the data and analyses, it can be easily demonstrated that drivers, using his assumptions, would save about 30 to 60 seconds per day. Hence, if saving 30 seconds per day is considered insignificant for RTOR, the same value should also be insignificant under these other proposed schemes. Most importantly, this approach warrants an important question: What is the boundary at which the cumulative small increments of time become significant? Is it 1 minute, 2 minutes, 15 minutes or 1 hour? Many systems mentioned above can indeed improve intersection safety. However, the documents referred to by Gou do not target crashes involving a RTOR and have, therefore, limited applicability (see *63*, *64*, *65*). In addition, these documents all have important methodological deficiencies similar to the ones raised previously. For instance, ITS America (*64*) claims that ITS can virtually eliminate all crashes with severe injuries at signalized intersections. This has been proven to be patently not the case.

Galin (*66*) has argued that the RTOR significantly decreases the respect of traffic signals and, more specifically, the general power of the red light. Transportation professionals in Quebec have frequently used this argument. Unfortunately, there has been no formal study that examined the existence of such a phenomenon. Most of the comments are based on anecdotal evidence. One respondent made similar comments on this topic. The disobedience of traffic signals, especially related to red-light running, is a complex phenomenon that cannot be solely attributed to the RTOR, as it also exists elsewhere in the world where the RTOR does not exist (*67*, *68*). The phenomenon obviously warrants further studies.

One of the most important arguments against the RTOR is based on the fact that North America is the only place in the world where the RTOR is allowed. It has been argued by some researchers (see *1*, *17*, *52*) that North America is actually the exception in the world rather than Quebec being the exception in North America. All this shows however is that each country or jurisdiction should be able to regulate its own transportation system independently. One cannot argue that, because a single jurisdiction applies traffic rules differently than the majority, the policy of the majority is wrong. Obviously, the same analogy applies on how the Government of Quebec currently views the RTOR. One jurisdiction could, however, certainly learn from the experiences of the other and vice-versa.

The author surveyed national agencies, organizations or lobbying groups who have a specific agenda on pedestrian safety (e.g., see www.walkinginfo.org, Pedestrians Educating Drivers on Safety, Inc. (PEDS), www.saferoads.org, and AAA Foundation for Traffic Safety). Although a few agencies were highly concerned that the RTOR be used appropriately, none of them were interested in abolishing the measure. The experts contacted for this work also share this view. In the words of one respondent: “it is here to stay.” Overall, they agreed that the RTOR in North America works relatively well. Despite this positive note, there is still a need to prohibit the RTOR where there could be significant adverse safety effects (see *14*, *48*, *69*, *70*, *71*, *72*, *73*, *74* for additional information on potential countermeasures for the RTOR maneuver). Like for any traffic control measures, there will always be exceptions to the rule. The application of roundabouts at intersections is a good example. Although they can greatly enhanced safety, they cannot be used everywhere (*38*, *75*).

SUMMARY AND CONCLUSION

The analyses carried out in this project and the opinions obtained from various experts indicate that certain safety aspects of the RTOR may not be fully understood by the research community. Some of these topics were addressed in this paper. This fact can partly be attributed to outdated data and studies performed in the 1980s that had methodological deficiencies. Nonetheless, the crash statistics presented in this study have shown that RTOR is not a dangerous maneuver at signalized intersections either for vehicles or pedestrians in most circumstances. A substantial number of recent studies that examined pedestrian and RTOR safety have arrived at similar conclusions. In general, the proportion of crashes is usually very low and, in the event of crash, the outcome is usually not severe. It is estimated that less than 0.5% of all crashes involving a RTOR maneuver. Based on the comments received, it is obvious that the safety issues related to the RTOR do not concern many transportation professionals. Several people even indicated that it was not a safety problem. However, even though a subset of researchers and professionals do not consider it a safety problem, the RTOR should nonetheless be prohibited at locations where it may create a substantially higher crash risk to road users.

In conclusion, the final decision as to whether or not introduce the RTOR in Quebec resides with government officials. This decision should be based on the results presented in this paper and on the existing standards in Canada and the US, where the RTOR has been used for many years. Nevertheless, government officials should take into account current transportation policies, the habits of Quebec drivers and the crossing behavior of pedestrians at signalized intersections in their final decision.

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