Operational Ranking of Intersections: A Novel Prioritization Methodology

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Abstract

Many road agencies have incorporated network screening for identification of sites with potential for safety improvements as part of their annual safety programs. The Highway Safety Manual includes well established approaches for conducting network screening from safety perspectives. The final result of a road safety network screening is ranked lists of intersections or road sections which require operational or capital improvements. There is a growing interest among road agencies to use a systematic approach to screen their network in order to identify sites which could benefit from operational improvements. The objective of this paper is to develop a methodology for prioritizing signalized and unsignalized intersections to identify those which could potentially benefit from operational improvements. In this paper a two-level prioritization methodology is proposed: a) a high level screening to identify a short-list of intersections, and b) a detailed modeling and analysis exercise to finalize the ranking list. The first level of screening is based on relative traffic volumes on major and minor road approach of intersections. The second level of screening requires detailed lane configurations, traffic signal timing, and turning movement counts. It is also recognized that some of the safety problems at a site are as a result of operational problems. Therefore, the potential for safety improvement values calculated from road safety network screening are incorporated into the proposed methodology. In this paper, the application of the proposed methodology is demonstrated through ranking of 263 signalized intersections and 128 stop-controlled intersections within the Regional Municipality of Halton in Ontario, Canada. Among each category, 30 signalized intersections and 35 stop-controlled intersections are identified as the most in need for operational improvements. The methodology and results of this paper can be used by other municipalities in order to identify intersections which require operational improvements. This process is also beneficial in assisting municipalities in their annual budgeting practices.

1 Introduction

Traffic volumes and patterns change over time due to demographic and land use changes in a road network. Many jurisdictions and municipalities in Canada, U.S., and other countries monitor the performance of their locations (e.g. intersections, road segments, etc.) to ensure that they satisfy applicable guidelines and standards. Locations that perform substandard from traffic operations or safety perspectives are typically identified for improvements.

In recent years, many road agencies have incorporated network screening as part of their annual safety programs. Network screening consists of identifying sites that have potential for safety improvements and that could benefit from further safety investigation. The network screening process utilizes the characteristics of sites (i.e. geometric characteristics, traffic volumes, and collision history) and Safety Performance Functions (SPFs) to rank sites based on their likeliness to achieve a reduction of the collision frequency. Road agencies are now equipped with software packages such as SafetyAnalyst to produce network screening results based on the various statistics. These software packages have empowered road agencies to use the state of the art methodologies for conducting network screening with minimal efforts.

The state of practice for identification of intersections with operational problems is, however, different from identification of intersections with safety problems. Some jurisdictions conduct travel time studies of their major corridors to identify intersections which incur excessive delays but no other systematic approach is used by road agencies to identify intersections which can benefit from operational improvements.

This paper aims to develop a methodology for prioritizing intersections considering their operational performance. The proposed prioritization methodology incorporates the results of the network screening in terms of Potential for Safety Improvement (PSI) values as the supplementary component of the operational ranking list. The proposed methodology was implemented on two separate lists based on the most recent traffic volume, network screening results, and physical characteristics data: one list consists of 263 signalized intersections and the other list includes 128 stop-controlled intersections in the Regional Municipality of Halton in Ontario (Halton Region).

The organization of this paper is as follows: The prioritization methodology of the signalized and uncontrolled intersections is presented in Section 3. The data collection and assessment is presented in Section 3. This is followed by the results of the prioritization methodology implemented within the study area. Finally, the last section summarizes the conclusions of this paper.

2 Methodology

As noted earlier, a two-level prioritization methodology was developed to identify the list of intersections with the highest priority for operational improvements: a) a high level screening to identify a short-list of intersections, and b) a detailed modeling and analysis exercise to finalize the ranking list. In the following sub-sections, the proposed two-level prioritization methodology for signalized and stop-controlled intersections is discussed.

2.1 High Level Screening of Signalized Intersections

The purpose of the high-level screening is to rank intersections using a simple methodology and create a short-list of signalized intersections for detailed modeling and analysis. As noted earlier, the high-level methodology for prioritization of signalized intersections is on the basis of two components: (1) traffic operation, as the major component, and (2) traffic safety in terms of PSI, as the supplementary part. The reason to include traffic safety is that safety problems are sometimes caused by operational problems.

In terms of traffic operation, the high-level prioritization methodology of the signalized intersections is based on the following steps:

- Calculate an Initial Ranking Index (IRI) for AM and PM peak hours as follows:

$$IRI_p = \frac{Vol_p^{maj}}{Leg^{maj}} + \frac{Vol_p^{min}}{Leg^{min}} \tag{1}$$

Where,

$p =$ denotes either the AM or the PM peak periods;

$Vol_p^{maj} =$ denotes the traffic volume on Major approach for peak period *p*;

$Vol_p^{min} =$ denotes the traffic volume on Minor approach for peak period *p*;

$Lane^{maj} =$ denotes total number of intersection lanes on Major approach; and

$Lane^{min} =$ denotes total number of intersection lanes on Minor approach

- Calculate the intersection Operation Ranking Index (RI_O) from IRI:

$$RI_O = max\ (IRI_{AM}, IRI_{PM}) \tag{2}$$

- Rank the signalized intersections based on RI_O

In terms of traffic safety, the signalized intersections were ranked based on the total Potential for Safety Improvement (PSI) values, where the highest rank was given to the location with the highest PSI value. In this step, the two rankings were linearly combined together to produce a combined ranking index. Within the scope of this study the traffic operation is given more weight than traffic safety when it comes to prioritizing signalized intersections improvements (70% was assigned to the traffic operations vs 30% weight given to traffic safety) as follows:

$$RI_{High\ Level}^{Signal} = 0.7 \times R_O^S + 0.3 \times R_S^S \quad (3)$$

Where,

$RI_{High\ Level}^{Signal} =$ Combined Ranking Index for signalized intersections (high-level)

$R_O^S =$ Operation ranking of signalized intersections (high-level)

$R_S^S =$ Safety ranking of signalized intersections (high-level)

The signalized intersections were then re-ranked based on the combined rank index in an ascending order, where the highest rank (i.e. 1st) was given to the location with lowest combined ranking index. In the final step, signalized intersections with the lowest combined ranking index were selected for detailed modeling and analysis.

2.2 High Level Screening of Unsignalized Intersections

Similar to the signalized intersections, a high-level screening methodology was developed to identify a short-list of unsignalized intersections that can provide the greatest benefit to the public within the available resource constraints. The proposed methodology was based on both traffic operation and traffic safety.

In terms of traffic operations, the prioritization methodology was based on the combination of the following justifications set forth in Ontario Traffic Manual (OTM) Book 12 [1]:

- **Justification 1: Minimum vehicular volume;** is intended for applications where the principal reason for installing a traffic signal is the cumulative delay produced by a large volume of intersecting traffic at an unsignalized intersection. This justification is comprised of Justification 1A (which reflects the lowest total traffic on all approaches) and Justification 1B (which reflects the lowest volume on the minor road). The need for a traffic signal must be considered if both Justification 1A and Justification 1B are 100% fulfilled. If Justifications 1A and 1B do not reach or exceed 100%, but are at least 80% fulfilled, the lesser fulfilled of the Justifications 1A or 1B can be used in the assessment of Justifications 3, the Combination Justifications
- **Justification 2: Delay to cross traffic;** is intended for applications where the traffic volume on the main road is so heavy that traffic on the minor road suffers excessive delay or hazard in entering or crossing the main road. This justification is comprised of Justification 2A (which reflects the lowest total traffic on major road) and Justification 2B (which reflects the lowest traffic crossing the major road). The need for a traffic signal must be considered if both Justification 2A and Justification 2B are 100% fulfilled. If Justifications 2A or 2B do not meet or exceed 100%, but both are at least 80% fulfilled, the lesser fulfilled of the Justifications 2A or 2B can be used in the assessment of Justification 3, the Combination Justification.
- **Justification 3: Volume/delay combination;** is intended for applications where neither Justification 1 nor Justification 2 is 100% satisfied, but both Justifications are at least 80% satisfied.

In Ontario, the assessment of locations for traffic signal is based on the fulfillment of the above justifications. Therefore, the same logic was applied for ranking the unsignalized intersections, in a way that higher priority was given to the location with higher fulfillment for traffic signal.

In summary, the ranking process for the unsignalized intersections is based on the following steps:

- **Step 1:** Calculate the average fulfillment of justification 1 and justification 2 ($Ave_{1,2}$). For example, if warrant 1 is 85% fulfilled and warrant 2 is 64% fulfilled, the $Ave_{1,2}$ for traffic signal would be 74.5%.
- **Step 2:** Rank the unsignalized locations based on their $Ave_{1,2}$ in a descending order, where the higher Initial Rank (i.e. 1st) is given to the location with the highest $Ave_{1,2}$ value.
- **Step 3:** Calculate the Adjusted Ranking Index (ARI) based on the Initial Ranking while considering all justifications (1, 2, and 3):

$$ARI = \begin{cases} Initial\ Rank & if\ any\ warrant < 100\% \\ 0.8 \times Initial\ Rank & if\ any\ warrant = 100\% \end{cases} \quad (4)$$

- **Step 4:** Re-rank the unsignalized locations based on their ARI in an ascending order, and produce the Operation Ranking for Traffic Signal (R_O^S).

It is noteworthy that the fulfillment of Justification 3 is either 0% or 100%. This process was repeated for all of the 128 unsignalized intersections with the available traffic volume.

Similar to signalized intersections, the high-level ranking of unsignalized intersections consists of traffic operation and traffic safety. In terms of traffic safety, the unsignalized intersections were ranked based on the total PSI values in an ascending order. In this step, the two rankings were linearly combined together to produce a combined ranking index, with a split weight of 70% and 30% for traffic operation and traffic safety, respectively.

$$RI_{High\ Level}^{Unsignalized} = 0.7 \times R_O^U + 0.3 \times R_S^U \quad (5)$$

Where,

$RI_{High\ Level}^{Unsignalized} =$ Combined Ranking Index for unsignalized intersections (high-level)

$R_O^U =$ Operation ranking of unsignalized intersections (high-level)

$R_S^U =$ Safety ranking of unsignalized intersections (high-level)

The unsignalized intersections were then re-ranked based on the combined rank index in an ascending order, where the highest rank (i.e. 1st) was given to the location with lowest combined ranking index. In the final step, stop-controlled intersections with the lowest combined ranking index were selected for detailed modeling and analysis.

2.3 Detailed Modeling and Analysis of Signalized Intersections

As noted in Section 3.2, the signalized intersections with the lowest combined ranking index were selected for detailed modeling and analysis in Synchro. For the second level of screening, detailed lane configurations, traffic signal timing, and turning movement counts were required. On that basis, the evaluation criteria presented in Table 1 were selected for ranking the signalized intersections,

Table 1: Criteria for Ranking the Signalized Intersections

Category	Criteria	Description
Intersection	Average Delay (sec)	Average intersection signal delay in seconds
	Level of Service (LOS)	Intersection LOS
Movements	No. of V/C>85%	Total number of movements with the Volume/Capacity ratio of greater than 85%
	No. of LOS F	Total number of movements with LOS F
Turn storage	No. of Q>S	Total number of turning movements with the queue length greater than the available storage length

In the next step, a multi-level ranking methodology was developed to prioritize the signalized intersections. The rationale behind this multi-level ranking process was to allocate different priorities to the above-noted traffic operation criteria. In this approach, each level of ranking takes place after the results of the previous level. In summary, the ranking process consists of the following 5 levels:

- **Level 1:** Rank the locations based on the total intersection LOS, where the highest rank was given to the location with worse LOS (e.g. LOS F);
- **Level 2:** Rank the locations based on the number of movements with V/C>85%, where the highest rank was given to the location with the lower number of movements with V/C>85%;
- **Level 3:** Rank the locations based on the number of movements with LOS F, where the highest rank was given to the location with the lower number of movements with LOS F;
- **Level 4:** Rank the locations based on the number of turning movements with the queue length greater than the storage length, where the highest rank was given to the location with the lower No. of Q>S; and
- **Level 5:** Rank the locations based on the average intersection delay, where the highest rank was given to the location with a higher average intersection delay.

According to the above multi-level ranking process, the highest priority was given to the intersection LOS criterion (i.e. labeled as Level 1). Therefore, the signalized intersections were initially sorted by their respective LOS in a descending order. If a number of intersections were operating with the same LOS, these intersections were re-ranked based on the number of movements with V/C>85% in an ascending order, where the highest rank was given to the location with lower number of movements with V/C>85%. The rationale behind selecting the intersections with lower No. of V/C>85% is to minimize the operation cost and identify the locations which can provide the greatest benefit within the available resource constraints. However, it should be noted that the higher priority was given to the intersections with at least one movement with the V/C ratio of greater than 85%, comparing to the intersections with zero No. of V/C>85%. Following the same procedure, the intersections were then re-ranked based on the number of movements with LOS F and the number of movements with Q>S in an ascending order. Finally, in case of a tie in the ranking list, the intersections were ranked based on the average intersection delay, in a descending order.

In order to finalize the ranking list, it is essential to combine the operation and safety ranking of the signalized intersections. In summary, the ranking process for the signalized intersections is based on the following steps:

- **Step 1:** Calculate the Operation Ranking Index for the signalized intersections (RI_o^S) as the combination of operation rankings during AM and PM peak periods:

  $$RI_o^S = 0.5 \times R_{AM}^S + 0.5 \times R_{PM}^S \qquad (6)$$

  Where,

  $RI_o^S =$ Combined Operation Ranking Index for signalized intersections

  $R_{AM}^S =$ Operation Ranking for signalized intersections during AM Peak Period

  $R_{PM}^S =$ Operation Ranking for signalized intersections during PM Peak Period

- **Step 2:** Rank the signalized intersections in an ascending order, where the highest rank (i.e. 1st) was given to the location with lowest RI_o^S, and produce the Final Operation Ranking for the signalized intersections (R_o^S).

- **Step 3:** Calculate the Final Ranking Index for the signalized intersections $(RI_{Final}^{Signalized})$ as the combination of operation ranking (70%) and safety ranking (30%), as follows:

  $$RI_{Final}^{Signalized} = 0.7 \times R_O^S + 0.3 \times R_S^S \qquad (7)$$

  Where,

  $RI_{Final}^{Signalized} =$ Combined Ranking Index for signalized intersections

  $R_O^S =$ Final Operation Ranking for signalized intersections

  $R_S^S =$ Final Safety Ranking for signalized intersections[1]

- **Step 4:** Re-rank the signalized locations based on their Final Ranking Index $(RI_{Final}^{Signalized})$ in an ascending order, and produce the Final Ranking list.

2.4 Detailed Modeling and Analysis of Unsignalized Intersections

The detailed modeling and analysis on the selected unsignalized intersection were conducted in HCS 2010. Similar to the signalized intersections, evaluation criteria were selected for ranking the unsignalized intersections, as presented in Table 2.

[1] Similar to high-level screening process, the signalized intersections were ranked based on the total PSI values, where the highest rank was given to the location with the highest PSI value.

Table 2: Criteria for Ranking the Unsignalized Intersections

Criteria	Description
Maximum Delay (sec)	Maximum delay among all movements in seconds
No. of V/C>75%	Total number of movements with the Volume/Capacity ratio of greater than 75%
No. of LOS F	Total number of movements with LOS F

In the next step, a multi-level ranking process was developed to prioritize the unsignalized intersections, based on the following 3 levels:

- **Level 1:** Rank the locations based on the maximum delay, where the highest rank was given to the location with the highest maximum delay;
- **Level 2:** Rank the locations based on the number of movements with V/C>75%, where the highest rank was given to the location with the lower number of movements with V/C>75%; and
- **Level 3:** Rank the locations based on the number of movements with LOS F, where the highest rank was given to the location with the lower number of movements with LOS F.

Following the same methodology as the signalized intersection, a higher priority was given to the intersections with at least one movement with the V/C ratio of greater than 75%, comparing to the intersections with zero No. of V/C>75%. In the next step, the operation and safety ranking of the unsignalized locations were combined to produce the final ranking list. The following steps were taken to finalize the ranking list:

- **Step 1:** Calculate the Operation Ranking Index for the unsignalized intersections (RI_o^U) as the combination of operation rankings during AM and PM peak periods:

$$RI_o^U = 0.5 \times R_{AM}^U + 0.5 \times R_{PM}^U \tag{8}$$

Where,

$RI_o^U =$ Combined Operation Ranking Index for unsignalized intersections

$R_{AM}^U =$ Operation Ranking for unsignalized intersections during AM Peak Period

$R_{PM}^U =$ Operation Ranking for unsignalized intersections during PM Peak Period

- **Step 2:** Rank the unsignalized intersections in an ascending order, where the highest rank (i.e. 1st) was given to the location with lowest RI_o^U, and produce the Final Operation Ranking for the unsignalized intersections (R_o^U).

- **Step 3:** Calculate the Final Ranking Index for the unsignalized intersections (RI_F^U) as the combination of operation ranking (70%) and safety ranking (30%), as follows:

$$RI_{Final}^{Unsignalized} = 0.7 \times R_O^S + 0.3 \times R_S^S \tag{9}$$

Where,

$RI_{Final}^{Unsignalized} =$ Combined Ranking Index for unsignalized intersections

$R_O^S =$ Final Operation Ranking for unsignalized intersections

$R_S^S =$ Final Safety Ranking for unsignalized intersections

In the final step, the locations were re-ranked based on their Final Ranking Index ($RI_{Final}^{Unsignalized}$) in an ascending order to produce the Final Ranking list.

3 Study Data

The data used for this study was collected from the Regional Municipality of Halton, Ontario. The database included the traffic volume data, intersection inventory data, and the latest safety network screening results (in terms of PSI). Among the 442 intersections in this study, the traffic volume data was available for 263 signalized intersections (out of 271) and 128 stop-controlled intersections (out of 171); resulting in a total of 391 intersections. The traffic counts for these intersections were available for each 15 minute time period and separated for three vehicle types (i.e. cars, heavies, and trucks), as well as pedestrian counts. As for the intersection inventory data, the following relevant information was provided in the form of the Excel spreadsheets:

- Geo ID;
- Intersection location, major and minor street names, and number of approach lanes;
- Intersection type (i.e. 3-legged and 4-legged);
- Traffic control (i.e. traffic signal and stop sign); and
- Area (i.e. urban, rural, and suburban).

In addition to the available data in the Excel format, lane configuration of each intersection (i.e. number of lanes for each movement) was acquired from the Geo-coded aerial photos provided by the Region. It should be noted that for the purpose of this study, the data obtained from the Region underwent a rigorous review process for accuracy and completeness.

4 Results

The main objective of this study was to develop a methodology for prioritizing signalized and unsignalized intersections to identify those which could potentially benefit from operational improvements. In this section, the application of the proposed two-level prioritization methodology on two separate lists (signalized and unsignalized intersections) is discussed in details.

4.1 Results of High Level Screening

4.1.1 Signalized Intersections

The high-level prioritization methodology of the signalized intersections was on the basis of two components: (1) traffic operation and (2) traffic safety, as the supplementary component. Based on the given weights to traffic operation and traffic safety, the final ranking list of signalized intersections was produced. As an example, Table 3 provides the top-10 signalized intersections in the ranking list. In the final step, 30 signalized intersections were selected from the top 50-locations in the ranking list for detailed modeling and analysis.

Table 3: Top-10 Signalized Intersections in the Final Ranking List

Geo ID	No. of Lanes		Volume (AM)		Volume (PM)		Initial Ranking Index (IRI)		Operation Ranking Index (RI_O)	Operation Ranking (R_O^S)	Total PSI	Safety Ranking (R_S^S)	Final Ranking Index (RI_{Final}^{Signal})	Final Ranking $R_{Final}^{Signal})$
	NB+SB	EB+WB	NB+SB	EB+WB	NB+SB	EB+WB	AM	PM						
10057101	2	5	742	2217	803	2623	814	926	926	12	13.18	9	11	1
10029201	6	6	1947	3151	2238	2411	850	775	850	17	5.15	35	22	2
10231601	8	3	3098	365	3374	1112	509	792	792	24	7.96	22	23	3
10260801	5	1	2303	68	2171	646	529	1080	1080	6	2.17	87	30	4
10206101	8	8	2385	1016	3202	2305	425	688	688	42	12.74	11	33	5
10272701	5	2	2089	228	1269	1171	532	839	839	19	3.28	67	33	6
10007801	3	6	498	2282	575	2955	546	684	684	44	9.94	13	35	7
10230101	9	6	2869	949	3215	1880	477	671	671	47	14.05	8	35	8
10011901	2	6	353	2498	321	3745	593	785	785	27	3.70	60	37	9
10315401	2	2	1228	840	1376	414	1034	895	1034	8	1.34	108	38	10

4.1.2 Unsignalized Intersections

As noted in Section 2.2, the high-level prioritization methodology of unsignalized intersections was based on the combination of the following justifications set forth in Ontario Traffic Manual (OTM) Book 12. Similar to signalized intersections, the 128 unsignalized intersections were ranked based on the combined ranking index with a split weight of 70% and 30% for traffic operation and traffic safety, respectively. As an example, Table 4 provides the top-10 unsignalized intersections in the ranking list. In the final step, 38 stop-controlled intersections were selected from the top 60-locations in the ranking list for detailed modeling and analysis.

Table 4: Top-10 Unsignalized Intersections in the Final Ranking List

Geo ID	Warrant 1	Warrant 2	Warrant 3	Operation				Safety		Final Rank Index	Final High-Level Ranking
				$Ave_{1,2}$	Initial Rank	Adjusted Rank Index	Rank	Total PSI	Rank		
10266801	0.94	0.87	1	0.91	2	1.6	2	2.40	9	4.1	1
10016201	0.88	0.86	1	0.87	4	3.2	4	2.11	10	5.8	2
10017001	0.91	0.74	0	0.82	6	6	6	2.70	8	6.6	3
10034201	0.69	0.91	0	0.80	13	13	13	3.71	2	9.7	4
10321001	0.93	0.93	1	0.93	1	0.8	1	0.95	33	10.6	5
10310001	0.62	0.99	0	0.80	11	11	11	2.02	12	11.3	6
10020201	0.72	0.80	0	0.76	15	15	15	3.29	4	11.7	7
10242001	0.73	0.76	0	0.75	18	18	18	3.87	1	12.9	8
10241501	0.79	0.83	0	0.81	9	9	9	1.45	23	13.2	9
10033401	0.63	0.87	0	0.75	17	17	17	1.98	13	15.8	10

4.2 Results of Detailed Modeling and Analysis

4.2.1 Signalized Intersections

As stated earlier, 30 signalized intersections were selected for the detailed modeling and analysis in Synchro. Following the methodology described in Section 2.3, the selected signalized intersections were evaluated. Table 5 provides an example of the multi-level ranking methodology for the top signalized intersections with LOS F during AM peak period.

Table 5: Example of the Multi-Level Ranking Methodology (Signalized Intersections)

GeoID	Intersection		Movements		Turn storage	Final Operation Ranking (AM)
	Average Delay (sec)	LOS	No. of V/C>85%	LOS F	No. of Q>S	
10299801	158.7	F	2	1	2	1
10018601	180.1	F	2	1	0	2
10002401	210.1	F	2	2	1	3
10005601	120.0	F	2	2	1	4
10312101	83.1	F	2	2	0	5
10206101	108.4	F	3	3	3	6
10029201	137.9	F	8	8	1	7

4.2.2 Unsignalized Intersections

As noted in Section 4.2, 38 unsignalized intersections were selected for the detailed modeling and analysis in HCS 2010. Based on the multi-level ranking process described in Section 2.4, the final ranking list of unsignalized intersections was produced. It should be noted that 2 unsignalized intersections were found warranted for traffic signal, based on the most recent volume data provided by the Region in 2013. ~~Table 9 presents the fulfillment percentage of the three justifications set forth in OTM Book 12 for traffic signal for these two intersections.~~ Table 6 provides an example of the multi-level ranking methodology for the top unsignalized intersections with LOS F and LOS E during PM peak period.

Table 6: Example of the Multi-Level Ranking Methodology (Unsignalized Intersections)

Geo ID	Maximum Delay (sec)	LOS	No. of V/C>75%	No. of LOS F	Final Operation Ranking (PM)
10263301	136	F	1	1	1
10208801	96	F	0	1	2
10208101	53.2	F	2	1	3
10209601	43.7	E	0	0	4
10231801	41.7	E	0	0	5
10034201	35.6	E	0	0	6

5 Summary and Conclusions

The primary goal of this study was to develop a methodology for prioritizing intersections based on traffic operation. Given the impact of road safety on the traffic operation, the proposed prioritization methodology incorporated the results of the network screening in terms of PSI values as the supplementary component of the operational ranking list. In order to achieve the objectives of this study, the following tasks were completed:

- **Data collection**: this task involved collecting the intersection existing infrastructure inventory data, traffic volumes, the latest safety network screening results, and the signal timing for the selected signalized intersections from the Region. A quality control of the data received from the Region was conducted to ensure consistency and completeness of data.
- **Prioritization for signalized Intersections**
  - **Ranking**: The traffic operation ranking was based on an Initial Ranking Index (IRI) that was calculated for AM and PM peak periods. In the final step of traffic operation, the signalized intersections were ranked based on the Operation Ranking Index (RI_O), as the maximum value of IRI during AM and PM peak periods of each location. In terms of traffic safety, the intersections were ranked based on the total PSI values, where the highest rank was given to the location with the highest PSI value. A Combined Ranking Index for signalized intersections ($RI_{High\ Level}^{Signal}$) was then calculated to account for both traffic operation and traffic safety. In this index, a higher weight of 70% was assigned to the traffic operations and a 30% weight was given to traffic safety. Finally, 30 signalized intersections were selected from the top 50-locations in the ranking list for detailed modeling and analysis.
  - **Detailed modeling and analysis:** The selected 30 signalized intersections were analyzed in Synchro. Based on the modeling outputs from Synchro, a multi-level ranking methodology was developed to prioritize the signalized intersections. Upon completion of the ranking process, an Operation Ranking Index (RI_O^S) was defined to combine the operation ranking of locations on AM and PM peak periods, with equal weights given to each period. In the final step, the two rankings were linearly combined together to produce the Final Ranking Index ($RI_{Final}^{Signalized}$), with a split weight of 70% and 30% for traffic operation and traffic safety, respectively
- **Prioritization for unsignalized Intersections**
  - **Ranking**: The traffic operations ranking was based on a combined fulfillment of justifications 1, 2 & 3 for each unsignalized intersections. The results of the traffic operation ranking were combined with the ranking of the unsignalized intersections in terms of traffic safety to produce the Combined Ranking Index for unsignalized intersections ($RI_{High\ Level}^{Unsignal}$). Finally, 40 unsignalized intersections were selected from the top 60-locations in the ranking list for detailed modeling and analysis.
  - **Detailed modeling and analysis:** The selected 40 unsignalized intersections were analyzed in HCS 2010. Based on the modeling outputs from HCS, a three-level ranking methodology was developed to prioritize the unsignalized intersections. Following the same methodology as the signalized intersection, an Operation Ranking Index (RI_O^U) was defined to combine the

operation ranking of locations on AM and PM peak periods, with a 50-50 percentage weigh splits among the two periods. In the final step, the two rankings were linearly combined together to produce the Final Ranking Index $(RI_{Final}^{Unsignalized})$, with a split weight of 70% and 30% for traffic operation and traffic safety, respectively. It should be noted that two warranted locations for traffic signals and three all-way stop-controlled intersections were excluded from the final ranking list.

It should be noted that there is no benchmark against which the performance of this methodology can be compared.

6 Acknowledgements

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7 References

1. Ontario Traffic Manual (OTM) Book 12: Traffic Signals, Ministry of Transportation Ontario, March 2012.