Development of A Multi-Level Roadway Segmentation

Reza Omrani, Ph.D.
Transportation Analyst
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
Reza.Omrani@cima.ca

Goran Nikolic, P.Eng.
Ministry of Transportation Ontario
Head, Central Region Traffic Office
6th Floor Building D
1201 Wilson Ave.
Downsview, Ontario M3M 1J8
Goran.Nikolic@ontario.ca

Pedram Izadpanah, Ph.D., P.Eng.
Senior Project Manager, Transportation Engineering
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
Pedram.Izadpanah@cima.ca

Ali Hadayeghi, Ph.D., P.Eng.
Director, Transportation Engineering
CIMA+
3027 Harvester Road, Suite 400
Burlington, ON L7N 3G7
Alireza.Hadayeghi@cima.ca

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Abstract

The reliability and applicability of traffic operation and roadway safety analysis depend on their ability to integrate relevant input from disparate databases in a seamless and automated manner. These inputs include information on road geometry, traffic composition, accident profiles, and spatial referencing. These databases are collected by different agencies for essentially different purposes. As a result, they tend to lack a common definition of roadway segments for various applications. The objective of this paper is to create a systematic segmentation that considers the needs of various operational and planning studies. A multi-level segmentation methodology is developed to address different level of requirements for various studies: micro level, corresponding to the smallest roadway segmentation for traffic simulation studies; meso level, representing a combination of several micro segments, which corresponds to traffic operation studies; and macro level which corresponds to applications such as planning studies. The application of the proposed methodology is demonstrated for the segmentation of freeway and arterial corridors within the jurisdiction of the Ministry of Transportation Ontario's (MTO) roadway network. The application of the proposed methodology is implemented for segmentation of selected freeway and arterial corridors in Ontario. At each level, a number of criteria were selected to identify the locations where the roadway network needs to be broken down. Once the segmentation methodology of the Ontario roadway network was developed, a pilot study was designed to test and evaluate the proposed methodology. The average historical operating speed was chosen as the measure of effectiveness to compare the proposed segmentation methodology with the MTO's current interchange-to-interchange and intersection-to-intersection segmentation. It was found that the new segmentation methodology is able to fully represent the operational performance of the freeway and arterial corridors and identify the areas of congestion and queue growth / dissipation. The results of this study will assist road agencies in defining a systematic roadway segmentation that can be utilized for different types of initiatives, ranging from traffic operation to planning studies.

1 Introduction

Road agencies are responsible for the evaluation and maintenance of the roadway networks under their jurisdiction in terms of traffic safety and traffic operations for both short-term and long-term studies. These studies require input from a large number of databases, including information on road geometry, traffic volume, accidents, and travel time information. Moreover, the databases are collected by different agencies for essentially different purposes and, as a result, they tend to lack a common definition of roadway segments for various applications. For example, MTO defines a roadway segment for traffic operation studies as the road section between two consecutive interchanges for freeways and two consecutive major intersections for arterials. However, this system is different from the segmentation of traffic data providers in the market and the segmentation systems of other municipalities in the Greater Toronto and Hamilton Area (GTHA) for data collection practices. These inconsistencies among different databases and segment definitions create challenges in regards to the integration of different data sources for future various operational and planning initiatives.

The objective of this paper is to develop a dynamic segmentation methodology that considers the needs of various operational and planning studies. In the dynamic segmentation scheme, segments are defined as road sections of varying lengths with a given set of homogeneous characteristics. In order to achieve the objective of this study, a multi-level segmentation methodology is developed to address different level of requirements for various studies, namely micro level, meso level, and macro level. The primary goal of the three levels of aggregations is to create a common approach which can be easily transferable from one level to another. The application of the proposed methodology is demonstrated for the segmentation of freeway and arterial corridors within the jurisdiction of the MTO's roadway network. At each level, a number of criteria were selected to identify the locations where the roadway network needs to be broken down. Once the segmentation methodology of the Ontario roadway network was developed, a pilot study was designed to test and evaluate the proposed methodology.

The organization of this paper is as follows: first, the literature review is presented in Section 2. Next, the segmentation methodology is discussed in Section 3. The study database is described in Section 4. The design and implementation of the segmentation methodology is described in Section 5, while the results of the pilot study are discussed in Section 6. Finally, the last section summarizes the conclusions of this paper.

2 Literature Review

The objective of this section is to provide a systematic and critical review of current knowledge to identify the segmentation criteria required for different types of corridors. A preliminary review of existing literature revealed that roadway segmentation can be customized for different applications, including traffic operation, microsimulation model, roadway safety, and planning model. The following sub-sections summarize the applications of segmentation for these categories.

2.1 Traffic Operation

Various segmentation and business applications are currently in use for traffic operation studies in different jurisdictions and municipalities in Canada and other countries. For example, MTO defines a roadway segment for Travel Time Studies as as the road section between two consecutive interchanges for freeways and two consecutive major intersections for arterials (MTO, 2012). A critical review of such segmentation revealed that the real bottlenecks and the extension of queue in the transportation network especially for longer segments cannot be identified (MTO, 2015). In 2008, Southeast Michigan Council of Governments (SEMCOG) conducted a Travel Time Study to quantify the Region's overall congestion level (SEMCOG, 2008). According to this report, segmentation points along a corridor should correspond to easily identifiable elements, including major interchanges on freeways, major intersections, railroad crossings, changes in geometric profile, jurisdictional boundaries, transition points between land uses, and location where significant shifts in traffic pattern occur. Other major reference documents have provided specific guidelines of the range of segment lengths. For instance, recommendations for segment lengths in the Federal Highway Administration (FHWA) Travel Time Data Collection Handbook and National Cooperative Highway Research Program (NCHRP) Report 398 indicate that as a general rule, roadway segments belonging to a specific functional class should have lengths in the following ranges (Lomax et al., 1997; Turner et al., 1998):

- Freeways / expressways with high access frequency: 1.6 to 4.8 km (1-3 miles);
- Freeways / expressways with low access frequency: 4.8 to 8 km (3-5 miles);
- Principal arterials with high cross-street and driveway frequency: 1.6 to 3.2 km (1-2 miles);
- Principal arterials with low cross-street and driveway frequency: 3.2 to 4.8 km (2-3 miles);
- Downtown streets: 0.8 to 1.6 km (½ - 1 mile); and
- Minor arterials: 0.8 to 3.2 km (½ - 2 miles).

FHWA has recently published the latest Highway Performance Monitoring System (HPMS) manual (HPMS, 2014). HPMS is the official Federal government source of data on the extent, condition, performance, use, and operating characteristics of the U.S. highways. According to this manual, each section should be relatively homogeneous as to geometrics, traffic volume, cross-section, and condition, and should be long enough to constitute a logical section for National-level analysis purposes. In addition, site surveys or corridor reconnaissance during peak periods were among the recommendations for defining the segment termini.

2.2 Micro-Simulation Models

Traffic simulation models are widely employed today both by the research community and transportation professionals. Proper use of these models requires calibration of a number of parameters. The network coding is especially important to assure that the model represents the real word traffic condition in an accurate way. The following attributes were considered for coding the road networks in different applications:

- Climbing lane and passing lanes (Llorca et al., 2015; Omrani and Kattan., 2012);
- All intersections , driveways, and roundabouts (Soria et al., 2014; Kattan and Abdulhai, 2006);
- Change in number of lanes (Figueiredo et al., 2014; Ashok and Ben-Akiva, 2000);
- Change in lane width (Vaze et al., 2009; Appiah and Rilett; 2010);
- Special facilities, such as High Occupancy vehicles (HOV) vs. General Purpose Lane (GPL) (Mohamed, 2007);
- Change in speed limit (Mohamed, 2007);
- Railway crossings (Antoniou et al., 2005; Darda, 2002); and
- Parking zone (Balakrishna, 2006).

2.3 Roadway Safety

In contrast to traffic operation initiatives, some research studies have focused on the role of segmentation in traffic safety analysis and identification of homogeneous segments. Homogeneous segments are defined as "segments of varying lengths, each of which is homogeneous with respect to characteristics such as traffic volumes, roadway design characteristics, and traffic control features" (HSM, 2010). According to Ogle et al. (2011) and Hausman et al. (2014), the three most common approaches for segmenting linear features in a GIS are fixed-length segments, variable-length segments, and dynamic segmentation. Fixed-length segments must have a small length to accurately manage data sets. However, the issue with this segmenting method is that there is extensive redundancy when the segment lengths are small (e.g., 0.1 or 0.25 miles), but the data do not change over several segments (e.g. number of lanes). In the variable-length segmentation method, each segment starts and ends at an intersection irrespective of changes in roadway characteristics. This results in very short segments in urban areas where an intersection typically exists approximately every 183 m (600ft). On the other side, rural areas may result in extremely long segments due to lower intersection density. While the segment is continuous between intersections, intermediate shape points can provide curvature. Attribute data associated with intersection to intersection segments cannot change midblock. In the dynamic segmentation scheme, segments are defined as road sections with a given set of homogeneous characteristics. Therefore, a new segment is identified whenever there is a slight change in at least one of the set of variables collected or when there is an intersection.

Austroads examined nine corridors of Australian highways and created a correlation between geometric attributes such as pavement width and gradient with the observed collisions. The roadway corridors were broken down into smaller segments to produce variable-length segments with uniform attributes, such as cross-section elements and horizontal/vertical alignments (Austroads, 2000). In a similar study, Koorey (2009) reviewed different approaches of roadway segmentation applicable to traffic safety analysis in New Zealand. Based on available geometry and traffic data, the author concluded that the roadway network should be broken down into smaller segments according to the features, including intersections, change in average daily traffic volume, change in shoulder width, change in vertical or horizontal alignment, presence of passing lanes, change in speed limit, density of driveways, and adjacent land use.

In a project undertaken by the European researchers in Austria, a fixed segment of 2.5 km moves along the road as a template. The segments which were defined along this template and meet the specific criteria of high collision-proneness level were defined as high collision road segments (Troche, 2007). In Denmark, the dynamic segmentation was used to identify the high collision road segments. In this study, a high collision road segment was defined as a segment with 4 collisions in a period of 5 years (Vistisen, 2002). In Belgium, based on police report, every segment in which three or more collision occur during 3 years is defined as a high collision road segment. In this method, a 100 miles length of segments is used to identify high collision road segments. Therefore, the segments with the maximum length of 100 miles and 3 collisions are recorded (Geurts, 2006).

2.4 Planning Model

In contrast to previous studies, the role of roadway segmentation in transportation planning models has not been explicitly defined. For example, travel demand forecasting models in the Transportation Master Plans (TMPs) were based on Traffic analysis zones (TAZs) (Spielberg and Shapiro, 2007). There are several factors that contribute to the determination of the number of zones in a travel model, including network detail, potential future alternatives to the network and land use, data requirements of the model (e.g. auto vs. non-motorized travel), and the anticipated growth in the study area. In summary, a number of attributes were considered in defining the TAZs in the literature, including major interchanges/ intersections (Pulugurtha et al., 2013; Wang et al., 2013), socioeconomic and demographic features (Wang et al., 2013); Land use (Siddiqui et al., 2012), Employment type (Martínez et al., 2009; Wang et al., 2013), education (Siddiqui et al., 2012), municipality boundaries (Pulugurtha et al., 2013); and Financial situation (You et al., 1998).

In addition to the above-noted studies, the Data Management Group of the University of Toronto provided the background information on the development of the EMME/2 model for the GTHA roadway network. For network coding of the GTA network in EMME/2, a segment is defined by a starting node and an ending node. Segments have a set of basic network attributes and can have additional model-specific attributes as well. The basic segment attributes as defined for all segments were transportation modes, number of lanes, length, functional class, volume delay function, speed, lane capacity and spatial classification (GTA Network Coding Standard, 2004). It should be noted that these attributes were also considered in development of EMME models in other jurisdictions (Kucirek, 2012; Mily, 2003; Helbing et al., 2002, Kotsialos et al., 2002).

2.5 Summary of the Literature Review

The roadway segmentation concerns a broad audience of practitioners and researchers. Several studies have focused on the impact of segmentation of a roadway into parts that are homogeneous with respect to relevant criteria. Which criteria are the relevant ones depends necessarily on the exact purpose of the segmentation. Table 1 summarizes the findings of literature review.

Table 1: Summary of Literature Review

Category of Study	Segmentation Criteria / Method	
Traffic Operation	• Major interchanges / Major intersections • Railroad crossing • Changes in geometric profile • Jurisdictional boundaries • Transition points between land uses • Location where significant shifts in traffic pattern occur • Freeways / expressways with high access frequency: 1.6 to 4.8 km • Freeways / expressways with low access frequency: 4.8 to 8 km	• Principal arterials with high cross-street and driveway frequency: 1.6 to 3.2 km • Principal arterials with low cross-street and driveway frequency: 3.2 to 4.8 km • Downtown streets: 0.8 to 1.6 km • Minor arterials: 0.8 to 3.2 km • Rural sections range: 0.5 to 16 km • Urban access controlled: less than 8 km • Other urban section: 0.16 to 4.8 km • Dynamic segmentation based on change is any user-defined attributes, including median width, lane width, area type, etc.

Microsimulation Model	• Climbing lane and passing lanes • All intersections an driveways • Change in number of lanes • Change in lane width	• Special facilities (HOV/GPL) • Change in speed limit • Railway crossings • Parking zone
Roadway Safety	• Intersections • Change in average daily traffic volume • Change in shoulder width • Change in vertical or horizontal alignment • Presence of passing lanes • Change in speed limit	• Density of driveways • Adjacent land use • Cross-section elements • Horizontal/vertical alignments • 2.5 km fixed-length segments • Variable-length segmentation based on number of collisions
Planning Model	• Major interchanges / intersections • Socioeconomic and demographic features • Land use	• Employment type • Education • Municipality boundaries • Financial situation

3 Methodology

Based on the above-noted findings from the literature and the objective of this study, a number of criteria for segmentation of the road networks were developed. Table 2 summarizes the selected criteria for segmentation of various roadway classifications.

Table 2: List of Segmentation Criteria

Category	Criteria	Roadway Classification		
		Freeways	Multilane Highways	Arterials
Geometric Characteristics	Lane width	✓	✓	✓
	Number of lanes	✓	✓	✓
	Lane configuration (HOV / GPL)	✓	x	✓
Traffic Operation Characteristics	Speed limit	✓	✓	✓
	Historical traffic volume	✓	✓	✓
	Historical average operation speed	✓	✓	✓
Land use	Dominant land use	x	✓	✓
Boundary	Jurisdictional boundaries	✓	✓	✓

✓: Applicable **x**: Not Applicable

According to Table 2, the roadway network needs to be broken down whenever there is a change in any of the above segmentation criterion. The final segments were then defined as road sections with a given set of homogeneous characteristics. Therefore, a new segment was identified whenever there was a change in at least one of the above set of variables or when there was an intersection or interchange along the corridor. It should also be noted that land use attribute was not applicable for freeway corridors since the operations of uninterrupted flow facilities are independent of the surrounding land use.

As the number of criteria increases, the anticipated segment length for a specific application becomes smaller. For example, the length of the roadway segments for the traffic simulation studies is smaller comparing to the segment length in traffic operation studies (e.g. Travel Time Studies). On that basis, one approach for addressing different level of requirements would be to implement the network segmentation based on the following level of aggregation:

- Micro level, corresponding to the smallest roadway segmentation for traffic simulation studies;

- Meso level, representing a combination of several micro segments, which corresponds to applications such as travel time and traffic safety studies; and
- Macro level, representing a combination of several meso segments, which corresponds to applications such as planning studies.

The details of each level of segmentation are discussed in the following sub-sections.

3.1 Segmentation for Micro Level

Micro level corresponds to the smallest roadway segmentation, which is more applicable for traffic simulation studies. The first step in developing a traffic simulation model is to build the road network in a simulation environment. This process requires detailed data on roadway geometry attributes, similar to those listed in Table 2 as geometric characteristics. Figure 1 presents the conceptual flowchart of segmentation for micro level.

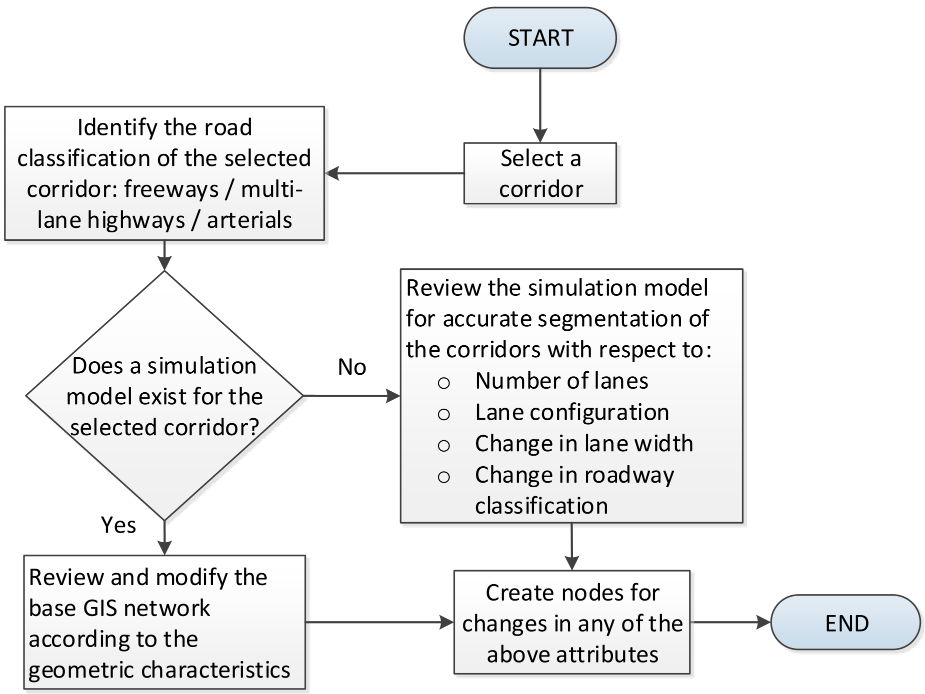

Figure 1: Flowchart of Segmentation for Micro Level

The framework starts with selecting a corridor for segmentation. If a traffic simulation model exists for the selected corridor, the model should be reviewed for accurate segmentation of the subject corridors with respect to the changes in geometric characteristics. Without a simulation model in place, the existing GIS network should be modified to accurately capture the locations where changes in geometric characteristics of the roadway occur. The final outputs of the framework are the locations where a change in one of the geometric attributes occurred.

3.2 Segmentation for Meso Level

The objective of segmentation at meso level is to identify possible nodes between interchange to interchange or intersection to intersection segment. According to Table 2, the segmentation of corridors at meso level is based on changes in historical average operation speed, historical traffic volume, and speed limit. Different sources of data for identification of such changes are discussed in the next section. Figure 2 presents the conceptual flowchart of segmentation for meso level.

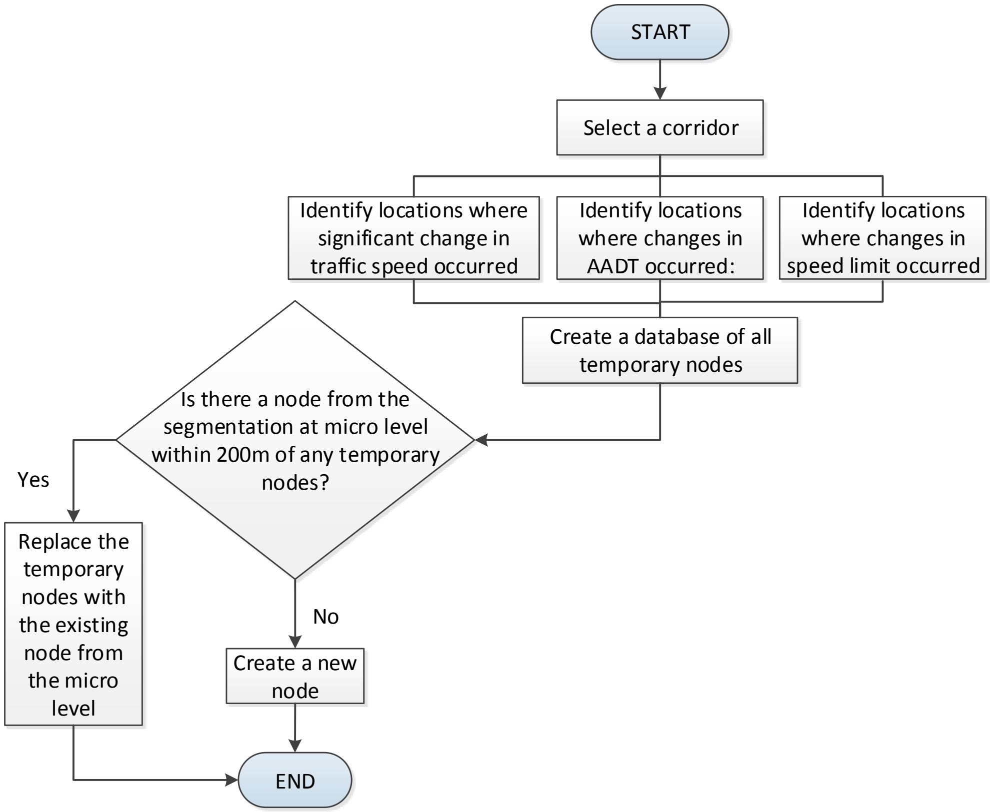

Figure 2: Flowchart of Segmentation for Meso Level

The flowchart starts with selecting a corridor for segmentation at meso level. A database is then created for each corridor to identify the locations where changes in historical average speed, traffic volumes, and speed limits occurred. In the next step, the flowchart identifies whether there is a node from the segmentation at micro level within 200 m of any temporary nodes. If yes, the algorithm replaces the temporary node with an existing node from the micro level. Otherwise, a new node is created to represent the location where changes in traffic operation characteristics occur. The purpose of this step is to ensure that the proposed segmentation methodology is transferable from one level to another and avoid creating unnecessary nodes along the corridor. The final outputs of the segmentation at meso level are the locations where changes in traffic operation characteristic occur.

3.3 Segmentation for Macro Level

Macro level corresponds to a combination of several meso segments, which is applicable to planning studies. As noted in Section 2, a number of attributes were considered in defining the TAZs and coding of the GTA network in EMME/2. Among the attributes listed in Table 2, the following criteria were applicable for segmentation macro level:

- Freeway corridors: jurisdictional boundaries; and
- Arterial corridors: jurisdictional boundaries and dominant land use.

In other words, the macro level segmentation for freeway corridors was based on changes in jurisdictional boundaries. As for arterials, the macro segment was defined as a corridor that was homogeneous with respect to the jurisdictional boundary and dominant land use.

4 Study Data

The proposed methodology was implemented for the segmentation of freeway and major arterial corridors within the jurisdiction of Ministry of Transportation Ontario (MTO) and other municipalities in the Greater Toronto and Hamilton Area (GTHA). The first step in segmentation of the Ontario road network was to identify the feasibility of the long-list of criteria in Table 2. A number of resources were used to quantify the changes in the segmentation criteria, including:

- *Google Earth*;
- *GIS Networks*, which includes various roadway attributes from Ontario Road Network (ORN) and the Aimsun model calibrated for the Toronto 2015 - PanAm/ParaPanAm Games;
- *Integrated Highway Information System (IHIS),* which contains many attributes including number of lanes, shoulder widths, average highway speeds, percent passing sight distance, and terrain class;
- *Traffic Volume Information System (TVIS),* which includes traffic attributes such as section length, current and historical Annual Average Daily Traffic (AADT), directional split, design hourly volume etc.; and
- *MTO Travel Time Studies,* which is the main source to identify the areas of congestion and queue growth / dissipation from the queuing diagrams.

A one-to-one comparison between the attributes from IHIS and Google Earth revealed that IHIS did not contain the most up to date information of geometric characteristics, including shoulder type and shoulder width. Therefore, the following criteria were excluded from further analysis:

- Shoulder type; and
- Shoulder width.

Table 3 shows the resources for identification of the selected criteria.

Table 3: Data Sources for Identification of the Selected Criteria

Category	Segmentation Criteria	Data Source
Geometric Characteristics	• Lane width • Number of lanes • Lane configuration (HOV / GPL) • Road classification	• Google Earth • GIS Networks / Google Earth • GIS Networks / Google Earth • Google Earth
Traffic Operation Characteristics	• Speed limit • Historical traffic volume • Historical average operation speed	• Google Earth • TVIS • MTO Travel Time Studies
Land use	• Dominant land use	• Google Earth
Boundary	• Jurisdictional boundaries	• Google Earth

5 Implementation

5.1 Micro-Level Segmentation

As noted in Table 3, three sources were used for identifications of the nodes where changes in geometric characteristics occurred, including the GIS network of the AimSun model, ORN, and Google Earth.

As a part of the Toronto 2015 PanAm/ParaPanAm Games, MTO initiated a project for planning and modeling a Priority Lane Network (PLN) in Aimsun. In order to develop an Aimsun network that replicates the existing roadway network, the base ORN attributes, including the above-noted criteria, were reviewed and coding errors were fixed using the Google map street/satellite view. As a result, the final GIS network of the Aimsun model represents the micro level segmentation for the corridors within the study area of the PLN model.

For the corridors outside the boundaries of the PLN model, the base geometry attributes were extracted from the GIS map of ORN. ORN is one of the datasets in the Land Information Ontario (LIO). There were two issues associated with the ORN attributes including: 1) number of lanes mismatch with the existing road network, 2) segments with duplicate records. These issues were addressed through a comprehensive quality control process. In case of any mismatch between Google Earth and ORN through visual inspection, attributes were appropriately modified in the GIS map. For sections with duplicate records, one record was used in the final GIS database. Figure 3 presents an example of segmentation for micro level along an 8.5 km section of Highway 400 in Ontario. Each node in this figure represents a location where a change in one of the geometric attributes occurred.

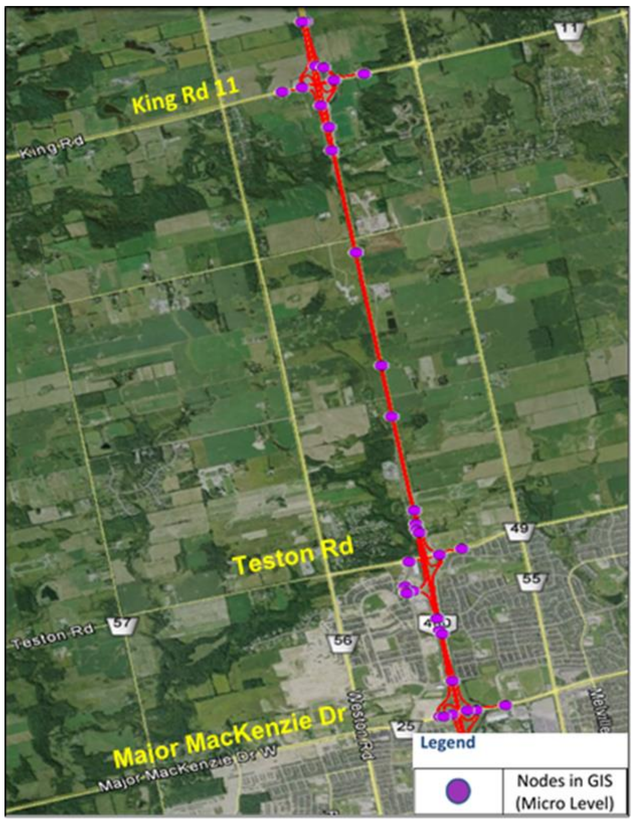

Figure 3: Sample Segmentation for Micro-Level (Highway 410)

5.2 Meso-Level Segmentation

Meso level corresponds to the combination of several micro segments, which is applicable to traffic operation studies, including Ministry's biannual Travel Time Studies. According to Table 3, a number of criteria were used for segmentation of corridors at meso level, including historical average operation speed, historical traffic volume, and speed limit. At the meso level, a new segment was identified whenever there was a change in at least one of the above set of variables or when there was an intersection or interchange. In order to capture the changes in the historical average operation speed, the speed diagrams from the MTO Travel Time Studies were used. Speed diagrams show the speed activity of the GPS-equipped survey vehicle for multiple survey-runs on a single graphic. Using the continuous speed values reported in the raw GPS data, average vehicle speed was calculated over 200 m intervals for the duration of each survey run. Figure 4 shows an example of speed diagrams. In this study, the speed diagrams from the 2010 and 2012 Travel Time Studies were used for highway and arterial corridors. It should be noted that the results of the most recent 2014 Travel Time Study were not available at the time of conducing this study.

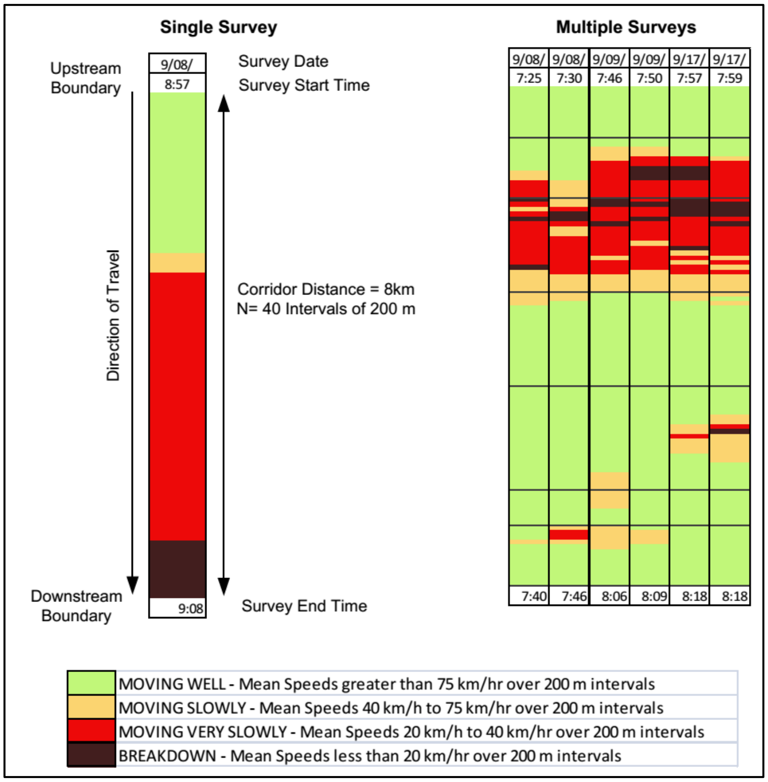

Figure 4: Example Speed Diagram

The traffic flow regimes can change from one run to another as shown in Figure 4. Therefore, it is essential to identify areas where *significant* shifts in traffic pattern or congestion occur. The significant shift in traffic pattern was defined as the change in traffic regime from congested condition (i.e. "Moving slowly", "Moving very slowly", or "Breakdown") to uncongested condition (i.e. "Moving well"). In other words, a significant shift in traffic pattern occurs at locations where the colour of speed profile changes from green to any other colours. Figure 5 shows an example of the speed diagrams along Highway 410 southbound with locations where the colour of speed profile changes from green to any other colours (i.e. orange, red, or brown).

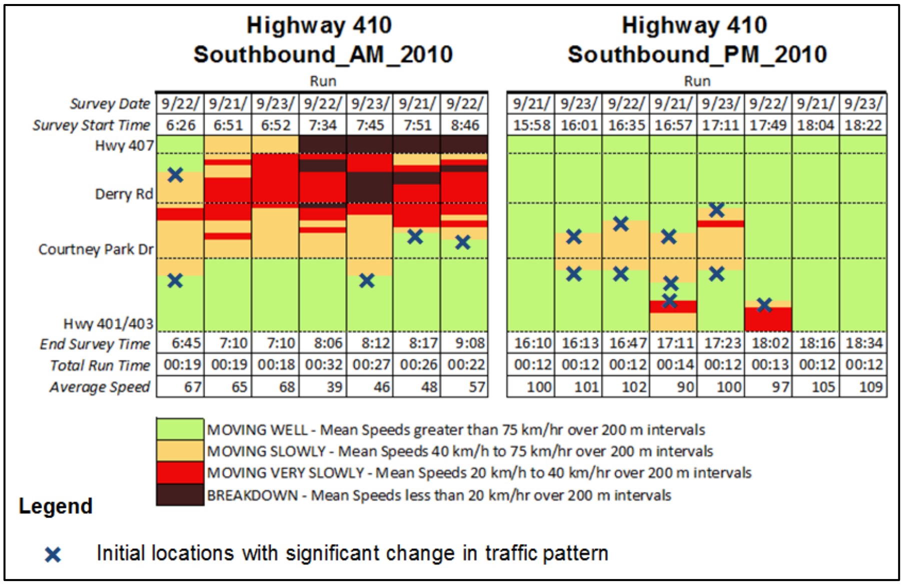

Figure 5: Initial Nodes from Speed Diagram (Highway 410 Southbound)

As is apparent from Figure 5, some of the marked locations were close to each other. As a general rule, those locations within 200 m of each other were replaced by one representative node. This process resulted in reducing the number of nodes from 15 to 3. In other words, 3 segmentation nodes were identified to represent locations where significant change in traffic pattern occurred (Figure 6). As this stage, these segmentation nodes were labelled as “temporary nodes”. A code was developed in Microsoft Visual basics for Applications (VBA) to identify the initial marked locations as well as the temporary nodes based on the historical average operation speed.

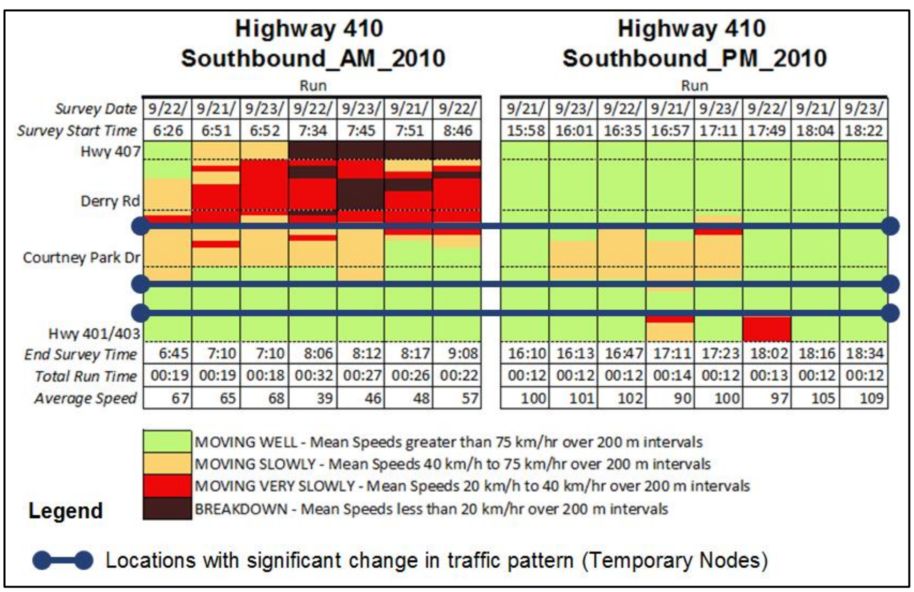

Figure 6: Temporary Nodes from Speed Diagram (Highway 410 Southbound)

In addition to the average operating speed, it was essential to identify locations where changes in the historical traffic volume and speed limit occurred. MTO collects and maintains AADT traffic counts for its provincial facilities on an annual basis and this program is called the TVIS. This database, along with the traffic volume data for arterial corridors were used to identify locations where the traffic counts were collected. Finally, the Google map street/satellite view was utilized to identify the locations where the speed limit was changing. In the next step, all of the above temporary nodes along a corridor were geocoded in the ArcGIS environment. Figure 7 shows an example of the segmentation for meso level associated with Highway 410 Southbound.

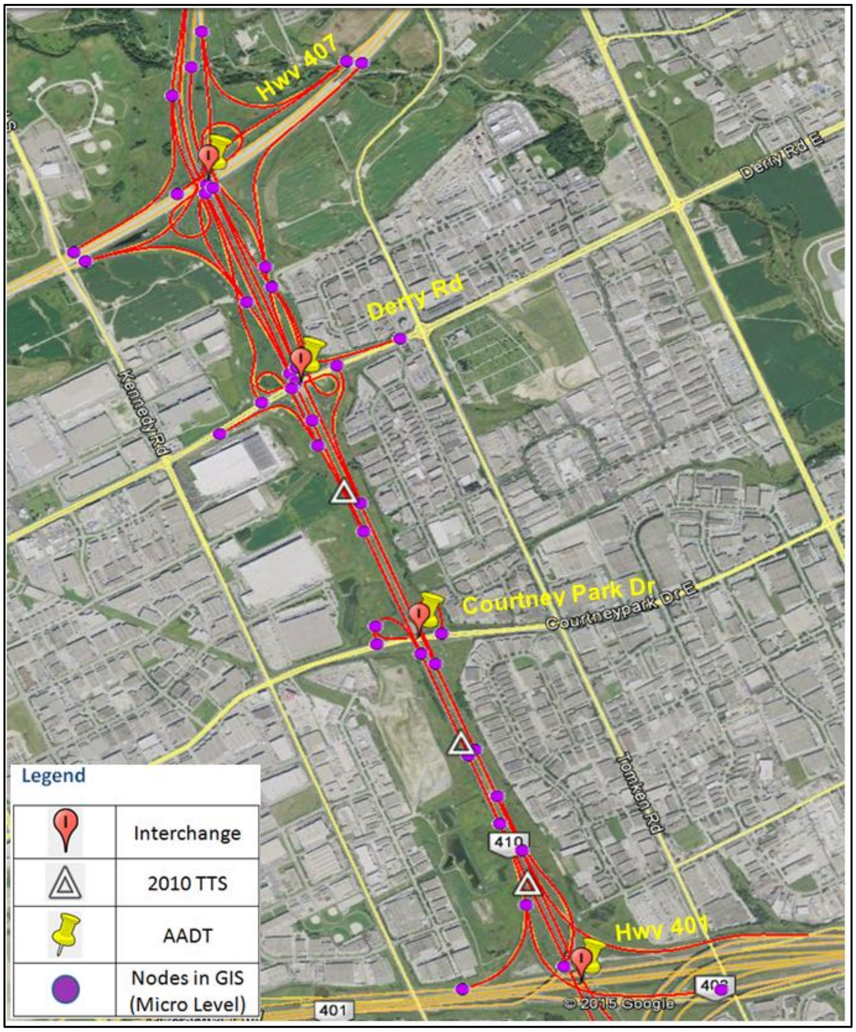

Figure 7: Initial Segmentation for Meso Level (Highway 410 Southbound)

The following observations can be made from this figure:

- The traffic volumes were changing from interchange to interchange. Therefore, no new nodes were added between the interchanges to reflect the changes in AADT values;
- The speed limit throughout this corridor was not changing (i.e. 100 km/h); and
- 3 temporary nodes were identified to represent locations where significant change in traffic pattern occurred.

According to Figure 7, some of the temporary nodes were within the vicinity of the existing nodes in the GIS network. As a result, a business rule was developed to reduce the number of locations with multiple nodes: *"If there was a node in the GIS network from the micro level within 100 m of a temporary node for meso level, the temporary node was replaced by the existing node in the GIS network. Otherwise, a new* *node was created to reflect a location where at least one of the segmentation criteria for meso level changed"*.

Based on the above business rule, one of the three temporary nodes was replaced with an adjacent existing node in the GIS network. Figure 8 shows the final locations of the nodes for the meso level segmentation associated with Highway 410 Southbound. According to this figure, the meso level segments were defined from the center of an interchange to the starting point of changes in historical operating speed or to the center of adjacent interchange.

During the segmentation process, particular attention should be put on generating segments that are not too short; as such segments tend to exhibit greater variability in travel times. Based on the recommendations for segment lengths found in the literature, the following boundaries for arterial and freeway corridors were used in this study:

- Arterials: from 200 m to 1600 m; and
- Freeways: less than 5000 m.

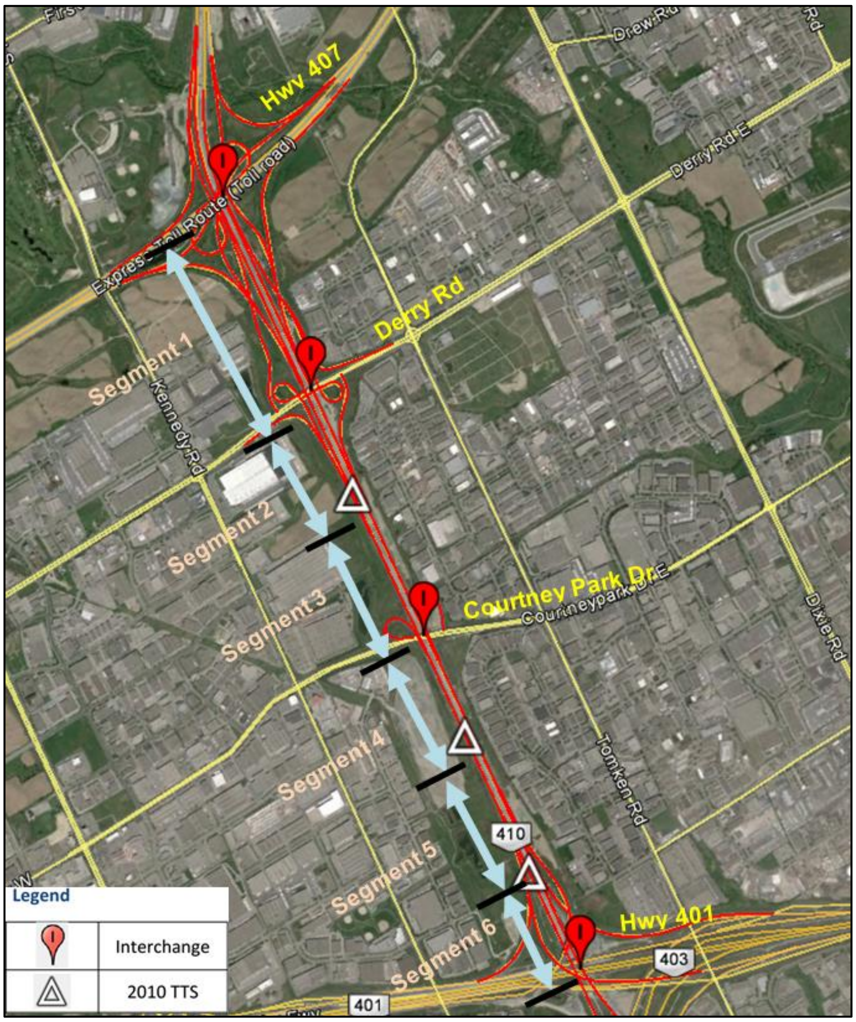

Figure 8: Final Segmentation for Meso Level (Highway 410 Southbound)

As noted in Section 3.3, the macro-level segmentation for freeway corridors was based on changes in jurisdictional boundaries, which is consistent with the MTO's definition of macro segment. As for arterials, the locations with changes in dominant land use were identified through Google Earth. A macro segment was then defined as a corridor that was homogeneous with respect to the jurisdictional boundary and dominant land use

6 Pilot Study and Evaluation

Once the segmentation methodology of the Ontario roadway network was developed, a pilot study was designed to evaluate the proposed methodology. A number of key criteria were considered in selecting the corridors for the pilot study, including:

- A mix of rural and urban environments;
- A mix of arterial and highway corridors; and
- A mix of congested and non-congested corridors.

A number of corridors were selected to test each of the above noted requirements. Table 4 presents the list of corridors for the pilot study.

Table 4: Pilot Study Corridors

Type	Corridor	From	To	Length (Km)
Arterial	Brock Rd (Durham)	Bayly St	Rossland Rd	4.0
	Yonge St (Toronto)	Dundas St	St. Clair Ave	5.3
	Hurontario St (Peel)	Williams Pkwy	Mayfield Rd	5.4
	Total Length			**14.7**
Highway	Hwy 410	Hwy 401	Hwy 407	4.6
	DVP	Eglinton Ave	Hwy 401	5.2
	QEW	Bronte Rd	Dorval Dr	5.1
	Hwy 401	Mississauga Rd	Hwy 410/403	7.9
	Hwy 400	Hwy 407	Major MacKenzie Dr	7.2
	Total Length			**30.0**

The average historical operating speed was chosen as the measure of effectiveness to compare the proposed segmentation methodology with the MTO's current interchange-to-interchange and intersection-to-intersection segmentation for meso level. The following sub-sections provide the evaluation results of a freeway and an arterial corridor.

6.1.1 Evaluation Results: Highway 401

Figure 9 provides a one-to-one comparison between the two segmentation methods along Highway 410 southbound direction. In this table, the error in speed reporting was calculated as follows:

$$Error = \frac{Speed_B - Speed_A}{Speed_B} \quad (1)$$

Where $Speed_B$ represents the historical operating speed based on intersection-to-intersection segmentation method and $Speed_B$ represents the historical operating speed based on the new segmentation method.

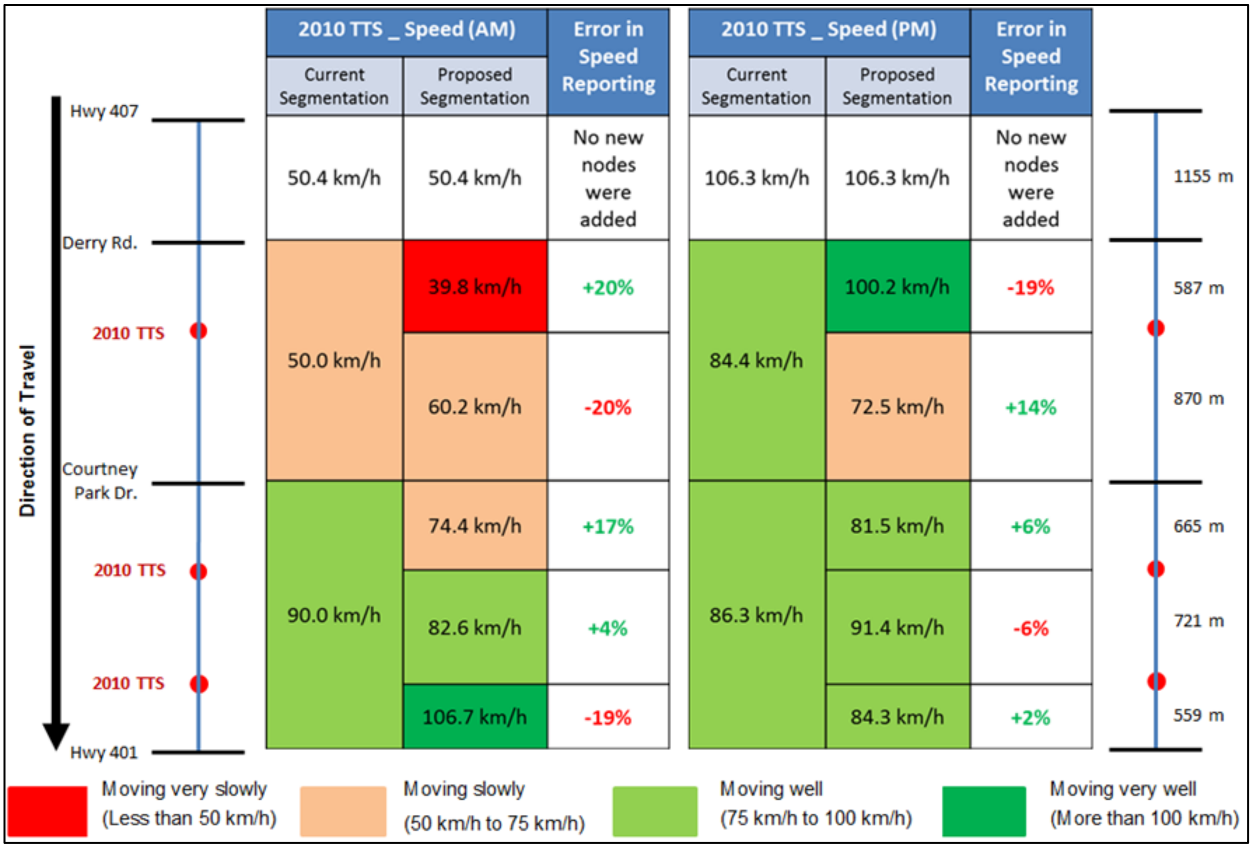

Figure 9: Sample Evaluation of the Proposed Segmentation for Meso Level (Highway 410 Southbound)

From Figure 9, the following observations were made:

- The average operating speed from Derry Road to Courtney Park Drive was reported 50 km/h in the AM peak period. The new segmentation method revealed that the traffic was moving very slowly (i.e. 39.8 km/h) within 587 m downstream of Derry Road. For the next 870 m of this segment, the average operating speed of motorists increased to 60.2 km/h. In other words, the current intersection-to-intersection segmentation overestimated the traffic condition for the first 587 m of this segment (i.e. 20% error in speed reporting) and estimated the traffic condition for the next 870 m of the segment (i.e. 20% error in speed reporting). The same observations can be made for the PM peak period; and
- The average operating speed from Courtney Park Drive to Highway 410 was reported 90 km/h in the AM peak period. However, the traffic regime was changing from “moving slowly” to “moving well” and then to “moving very well”. In other words, the proposed segmentation method was able to capture the average error of 13% in reporting the operating speed value in AM peak period. This error for PM peak period was less than 5%.

In summary, it was found that the proposed segmentation could identify the areas of congestion and queue growth / dissipation.

6.1.2 Evaluation Results: Hurontario Street North

Hurontario Street North was located in the suburban area in the Peel Region, with the mix of congested and uncongested segments. A 5.4 km section of this corridor from Williams Parkway to Mayfield Road was selected for the pilot study. Following the same methodology described in the Section 3.2, the segmentation for meso level was completed for this corridor. In summary, 4 new nodes in the northbound direction and 4 new nodes in the southbound direction were added to reflect the changes in one of the attributes for segmentation at meso level. Figure 10 shows the segmentation nodes for meso level along Hurontario Street North in both directions.

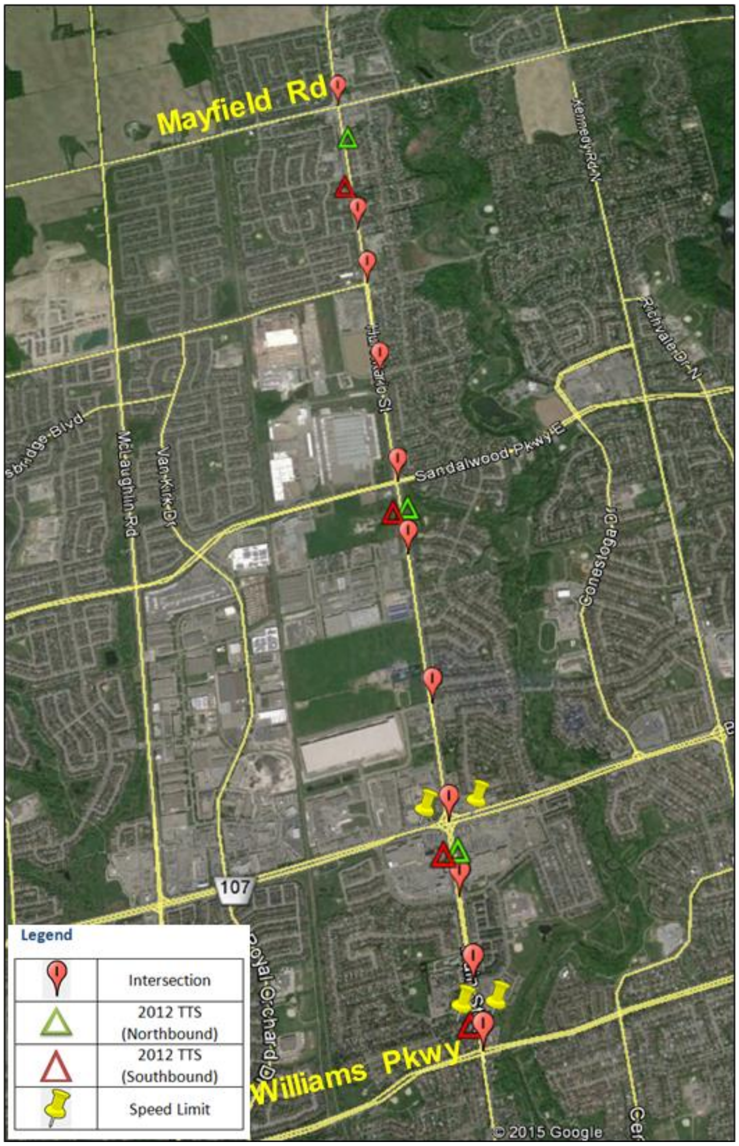

Figure 10: Segmentation Nodes for Meso Level (Hurontario Street North)

Table 5 and Table 6 provide a one-to-one comparison between the two segmentation methods along Hurontario Street North in northbound and southbound directions, respectively.

Table 5: Evaluation of the Proposed Segmentation for Meso Level (Hurontario Street North Northbound)

Direction of Travel: northbound (Williams Pkwy → Mayfield Rd)

Segment	Distance	AM Peak Current Segmentation	AM Peak Proposed Segmentation	AM Error in Speed Reporting	PM Peak Current Segmentation	PM Peak Proposed Segmentation	PM Error in Speed Reporting
Mayfield Rd – 2012 TTS	275 m	37 km/h	30 km/h	+19%	22 km/h	8 km/h	+64%
2012 TTS – Perth St	600 m		43 km/h	-16%		67 km/h	-205%
Perth St – Wanless Dr	380 m	71 km/h	71 km/h	No new nodes were added	55 km/h	55 km/h	No new nodes were added
Wanless Dr – West Access	600 m	62 km/h	62 km/h		49 km/h	49 km/h	
West Access – Sandalwood Pkwy	650 m	66 km/h	66 km/h		67 km/h	67 km/h	
Sandalwood Pkwy – 2012 TTS	200 m	37 km/h	20 km/h	+46%	51 km/h	30 km/h	+41%
2012 TTS – Fisherman Dr	200 m		53 km/h	-43%		68 km/h	-33%
Fisherman Dr – Wexford Rd	800 m	62 km/h	62 km/h	No new nodes were added	75 km/h	75 km/h	No new nodes were added
Wexford Rd – Bovaird Dr	600 m	62 km/h	62 km/h		62 km/h	62 km/h	
Bovaird Dr – 2012 TTS	200 m	29 km/h	11 km/h	+62%	27 km/h	10 km/h	+63%
2012 TTS – Quarry Edge Rd	200 m		65 km/h	-124%		72 km/h	-167%
Quarry Edge Rd – Bricyard Way	400 m	48 km/h	48 km/h	No new nodes	55 km/h	55 km/h	No new nodes
Bricyard Way – Speed Limit	150 m	40 km/h	49 km/h	-23%	33 km/h	40 km/h	-21%
Speed Limit – Williams Pkwy	150 m		26 km/h	+35%		28 km/h	+15%

Breakdown (Less than 20 km/h) | Moving very slowly (20 km/h to 45 km/h) | Moving slowly (45 km/h to 60 km/h) | Moving well (More than 60 km/h)

Table 6: Evaluation of the Proposed Segmentation for Meso Level (Hurontario Street North Southbound)

Direction of Travel: southbound (Mayfield Rd → Williams Pkwy)

Segment	Distance	AM Peak Current Segmentation	AM Peak Proposed Segmentation	AM Error in Speed Reporting	PM Peak Current Segmentation	PM Peak Proposed Segmentation	PM Error in Speed Reporting
Mayfield Rd – 2012 TTS	610 m	65 km/h	57 km/h	+12%	62 km/h	57 km/h	+8%
2012 TTS – Perth St	265 m		70 km/h	-8%		84 km/h	-35%
Perth St – Wanless Dr	380 m	71 km/h	71 km/h	No new nodes were added	41 km/h	41 km/h	No new nodes were added
Wanless Dr – West Access	600 m	61 km/h	61 km/h		55 km/h	55 km/h	
West Access – Sandalwood Pkwy	650 m	67 km/h	67 km/h		57 km/h	57 km/h	
Sandalwood Pkwy – 2012 TTS	200 m	62 km/h	66 km/h	-6%	58 km/h	72 km/h	-24%
2012 TTS – Fisherman Dr	200 m		58 km/h	+6%		47 km/h	+19%
Fisherman Dr – Wexford Rd	800 m	63 km/h	63 km/h	No new nodes were added	72 km/h	72 km/h	No new nodes were added
Wexford Rd – Bovaird Dr	600 m	33 km/h	33 km/h		33 km/h	33 km/h	
Bovaird Dr – 2012 TTS	200 m	47 km/h	58 km/h	-23%	54 km/h	49 km/h	+9%
2012 TTS – Quarry Edge Rd	200 m		30 km/h	+36%		58 km/h	-7%
Quarry Edge Rd – Bricyard Way	400 m	55 km/h	55 km/h	No new nodes	50 km/h	50 km/h	No new nodes
Bricyard Way – Speed Limit/ 2010 TTS	150 m	57 km/h	68 km/h	-19%	30 km/h	40 km/h	-33%
Speed Limit/ 2010 TTS – Williams Pkwy	150 m		42 km/h	+26%		19 km/h	+37%

Breakdown (Less than 20 km/h) | Moving very slowly (20 km/h to 45 km/h) | Moving slowly (45 km/h to 60 km/h) | Moving well (More than 60 km/h)

According to Table 5 and Table 6, the proposed segmentation made it possible to identify the areas of congestion and queue growth / dissipation. The new segmentation method was found to be the most effective for the following segments:

- Quarry Edge Road to Bovaird Drive in the northbound direction: the average operating speed was reported 29 km/h and 27 km/h in the AM and PM peak periods, respectively. The new segmentation methodology revealed that the traffic condition was underestimated for the first 200 m of this segment (i.e. 124% and 167% errors in speed reporting for AM and PM peaks). In addition, the traffic condition was overestimated the for the second 200 m part of the segment (i.e. 62% and 63% errors in speed reporting for AM and PM peaks);
- Perth Street to Mayfield Road in the northbound direction, with the 205% error in reporting the average operating speed in the PM peak period for the first 600 m (i.e. 22 km/h vs. 67 km/h) and 64% error in reporting the average operating speed for the remaining 275 m (i.e. 22 km/h vs. 8 km/h); and
- Bricyard Way to Williams Parkway in the southbound direction, with the 33% error in reporting the average operating speed in the PM peak period for the first 150 m (i.e. 30 km/h vs. 40 km/h) and 37% error in reporting the average operating speed for the remaining 150 m (i.e. 30 km/h vs. 19 km/h).

In summary, it was found that the new segmentation methodology was able to fully represent the operational performance of the freeways corridors. Table 7 presents the results of the pilot study.

Table 7: Evaluation Summary of Pilot Study

Type	Corridor	Direction	No. of New Nodes	Error in Speed Reporting
Arterials	Brock Road	NB	3	39%
		SB	2	44%
	Yonge Street	NB	0	-
		SB	0	-
	Hurontario Street	NB	4	81%
		SB	4	40%
	Average Error in Speed Reporting			**53%**
Highways	Highway 410	NB	0	-
		SB	3	15%
	DVP	NB	2	25%
		SB	2	32%
	QEW	EB	3	23%
		WB	3	17%
	Highway 401	EB	3	20%
		WB	3	19%
	Highway 400	NB	0	-
		SB	1	13%
	Average Error in Speed Reporting			**21%**

As can be seen from Table 7, the proposed segmentation methodology was able to identify the areas of congestion and queue growth / dissipation and capture the error in reporting the operating speed values comparing to the current MTO segmentation for travel time studies.

7 Summary and Conclusion

The main objective of this study was to develop a systematic segmentation methodology that considers the various operational and planning studies. A comprehensive literature review was conducted to identify the segmentation criteria required for different types of corridors and different applications, including traffic operation, microsimulation studies, roadway safety, and planning studies. Based on the findings from the literature and the objective of this study, a short-list of criteria for segmentation of the Ontario road networks was developed. The criteria were categorized into the following four groups:

- Geometric characteristics, including lane width, number of lanes, lane configuration (GPL vs. HOV), and road classification;
- Traffic operation characteristics, including historical average operation speed, traffic volume, and speed limit;
- Dominant land use; and
- Jurisdictional boundaries.

A multi-level segmentation methodology is developed to address different level of requirements for various studies, namely micro, meso, and macro level. The objective of the three levels of aggregations was to create a common approach which can be easily transferable from one level to another. Micro level corresponds to the smallest roadway segmentation, which is more applicable for traffic simulation studies. The segmentation for micro level consisted of identifying the nodes where changes in any of the geometric characteristics occurred. For micro level segmentation, three sources were used, including the GIS network of the AimSun model, ORN, and Google Maps.

Meso level corresponds to the combination of several micro segments, which is applicable to traffic operation studies. The objective of segmentation at meso level was to identify possible nodes between interchange to interchange or intersection to intersection segment. The segmentation for meso level consisted of identifying the nodes where changes in any of the traffic operation characteristics occurred. In order to capture the changes in the historical average operation speed, the speed diagrams from the previous travel time studies were used. The TVIS databases along with the traffic volume data for arterial corridors were used to identify nodes where the traffic counts were collected. In addition, the Google Earth view was utilized to identify the nodes where the speed limit was changing. In the next step, all of the nodes along a corridor were geocoded in the ArcGIS environment. The locations of the nodes were finalized based on their vicinity with the adjacent existing nodes in the GIS network. Finally, the meso level segments were defined from the center of an interchange to the starting point of changes in any of the traffic operation criteria or to the center of adjacent interchange.

Macro level corresponds to a combination of several meso segments, which is applicable to planning studies. For freeway corridors, a new macro segment was defined when there was a change in the jurisdictional boundaries (i.e. remained unchanged comparing to the previous travel time studies). As for arterials, a new macro segment was defined when there was a change in the jurisdictional boundaries or dominant land use (e.g. from urban to rural area).

Once the segmentation methodology of the Ontario roadway network was developed, a pilot study was designed to test and evaluate the proposed methodology. The average historical operating speed was chosen as the measure of effectiveness to compare the proposed segmentation methodology with the MTO's current interchange-to-interchange and intersection-to-intersection segmentation. A number of key criteria were considered in selecting the corridors for the pilot study, including a mix of rural and urban environments, a mix of arterial and highway corridors, and a mix of congested and non-congested corridors. Three arterial and five freeway corridors were selected for the pilot study (44.7 km in total). A one-to-one comparison between the two segmentation methods revealed that the proposed segmentation made was able to identify the areas of congestion and queue growth / dissipation. In addition, it was found that the proposed segmentation methodology captured 53% and 21% average error in speed reporting for arterial and freeway corridors, respectively.

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