**Approximation of 24 Hour Travel Times in the Greater Toronto Area**

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**ABSTRACT**

Travel time matrices are used extensively in many sub-components of integrated urban models including mode choice and activity scheduling models. However, the use of travel time matrices can be computationally expensive when zone systems are large, or when the model requires multiple iterations or replications. As 24-hour models of activity and travel demand are developed, the computation involved in developing and storing travel time matrices compounds. Therefore, approximate methods for estimating origin-destination travel time matrices over a 24-hour period are valuable since they can very significantly reduce computational effort. Four patterns for approximating hourly origin-destination travel time matrices over a 24-hour period are developed and compared against modeled travel times from hourly user-equilibrium traffic assignments in EMME/2. It is found that two of these four patterns provide very good approximations of modeled 24-hour travel times resulting in the potential for a much more efficient method for providing inputs into various sub-components of integrated urban models.

## INTRODUCTION

The use of travel time matrices is pervasive in integrated urban modeling. Travel times play a key role in a wide variety of sub-components in such models, including the estimation and application of mode choice models, location choice models, and the development of activity scheduling models that incorporate realistic time allocation for travel between activities.

Recent experience in the development of such models for the Greater Toronto Area (GTA), Canada, has shown that the use of travel time matrices is computationally expensive, particularly when detailed zone systems are used.

First, a single travel time matrix can be very large and difficult to generate. For the GTA, a system of approximately 1700 traffic zones is used as the spatial representation for most current modeling applications. A zone system of this scale results in a travel time matrix with approximately 2.9 million cells. The traditional method for generating travel time matrices involves running a user-equilibrium traffic assignment using a travel demand modeling package, such as EMME/2 (*1*). For a transportation network of 1700 zones, a single traffic assignment can take upwards of 30 minutes, depending on the computing platform and the modeling software being used.

Second, there has been a significant effort to move towards the development of 24-hour models of travel demand for the GTA to replace traditional peak hour models [see, for example Miller and Roorda (*2,3*)]. Spatial patterns of congestion vary significantly over time within a 24-hour period, making it necessary to generate and store travel time matrices for numerous points in time throughout the day. For example, outbound travel times from downtown Toronto to suburban areas are particularly high in the p.m. peak and are relatively low in the morning, while inbound travel times display roughly the opposite trend. Depending on the temporal aggregation assumed and the level of temporal precision desired for the modeling application, the number of traffic assignments necessary to develop the required travel time matrices compound.

Third, iterative approaches in modeling are commonly used in modeling scenarios where there is a two-way relationship between the component of travel demand being modeled and roadway congestion. For example, the development of an activity schedule, which is sensitive to auto travel times (i.e., one must allocate an appropriate amount of time for travel within one's schedule), also involves scheduling choices that affect travel on the traffic network (i.e., one may choose to travel before the morning peak hour to arrive at work on time). A common method for ensuring consistency between the modeled component of travel demand and congestion on the traffic network is to *iterate* between the demand model and the traffic assignment model. This, however, further increases the number of travel time matrices to be generated.

Finally, microsimulation is an approach that has become popular for modeling individual behavior within a complex urban system (*4*). One of the characteristics of microsimulation, however, is that a single model run represents only one possible outcome of a large series of random events. Therefore, to distinguish "random noise" from actual trends in travel demand behavior it is necessary to run multiple *replications* of a microsimulation model. Multiple replications become enormously expensive computationally if travel time matrices are generated for large zone systems for multiple time periods, for multiple model iterations.

For these reasons it is essential to develop efficient means of approximating travel time matrices that are sensitive to minor changes in peak period travel demand (which are experienced iteration to iteration or from replication to replication, as described above), without necessitating computationally expensive traffic assignments at all points in a 24-hour period. In this work, a number of very simple methods are compared for approximating EMME/2 user-equilibrium model travel times over a 24-hour period based on a minimal number of explicit user-equilibrium assignments.

The approximation procedure presented is specifically designed to be used with conventional static, deterministic user-equilibrium assignment models. As such, it is potentially of interest to virtually all transportation planning agencies since these conventional models are the norm for most current transportation demand modeling applications. The model could also be applied to average travel time matrices extracted from dynamic traffic assignment models when these are run over less than a full 24-hour period. The approximation procedure is useful in either of these two contexts because it provides a simple method for providing computationally efficient, but reasonably accurate, hourly travel time approximations as feedback to other travel demand model components such as activity scheduling, trip distribution, and mode choice.

## METHOD

The travel time matrices to be approximated are based on user-equilibrium traffic assignments conducted for the Greater Toronto Area using the EMME/2 modeling software. The road network used for these assignments extends from the City of Hamilton, at the west tip of Lake Ontario, to the Region of Durham, approximately 65 km east of the Toronto city core. The study area with the model zone system is shown in Figure 1. A total of 33 origin – destination vehicle trip matrices were developed, including 24 1-hour time intervals beginning on the hour, and 9 additional 1-hour time intervals beginning on the half-hour during the a.m. and p.m. peak periods. These trip matrices are based on travel demand data from the 1996 Transportation Tomorrow Survey (TTS), a large-scale 24 hour trip diary survey conducted on a 5% sample of households in the Greater Toronto Area with a total of approximately 115,000 surveyed households and 313,000 persons (*5*). In the TTS survey, respondents report on the attributes of all trips made over a 24 hour period (including origin, destination, mode and trip start time), allowing for the direct development of vehicle trip matrices for any time period within 24 hours. The 33 trip matrices were generated by extracting reported trips whose start times fall within each time period.

*(Figure 1 about here)*

Each of the 33 observed trip matrices was assigned to the EMME/2 road network for the GTA, resulting in travel time matrices for each hourly assignment. EMME/2 uses a static user equilibrium assignment algorithm with travel time calculated using a BPR volume-delay function for each functional classification of roadway. Some interpretation in travel time is necessary for time periods that overlap in the peak periods (for example, the hour from 5:00 to 5:59 p.m. overlaps with the hour from 5:30 to 6:29 p.m.). In these cases, the travel time for a given hour would be applied to all trips whose start times fall within the first 30 minutes in that hour. This is appropriate because trips that begin in the first 30 minutes are most likely to experience the delays and congestion in the current hour than trips that begin in the second 30 minutes, which would be more likely to experience delays in the following hour.

This method is further justified by the fact that in the TTS travel survey, respondents are most likely to report trip start times on the hour and, to a lesser extent, on the half hour (e.g. "I left work at 5:00 yesterday evening" or "I left for the mall at about half past eight"), rather than reporting more precise start times. This tends to weight the trips toward the earlier part of the hour, which include these "spikes" in reported travel demand at the beginning of the hour (e.g.

the 5:00 p.m. rush is included at the beginning of the 5:00 to 5:59 p.m. hour). In the same vein, traffic assignments are not run for time periods less than one hour, since it would result in artificial "spiking" in the travel times due to imprecision in the reporting of trip start times.

Modeled travel times were reviewed in detail for selected origin-destination pairs within the Greater Toronto Area, shown in Figure 2. The origin-destination pairs were selected to represent traffic flow with different peaking characteristics, including:

- Inbound travel to the core area of Toronto (Mississauga, Scarborough, Etobicoke, and North York to Toronto)
- Outbound traffic from the core area of Toronto (Toronto to Vaughan, Toronto to York)
- Cross-town travel through Toronto (Mississauga to Pickering)
- Shorter distance travel outside of the core area (Richmond Hill to North York, Brampton to Mississauga, Scarborough to Markham)

*(Figure 2 about here)*

Based on the review of these selected origin destination pairs and the average travel times over all origin destination pairs, four alternative travel time patterns were identified for the approximation of EMME/2 model travel times. Each of the four patterns is outlined in Figures 3a to 3d, respectively, and compared to the average EMME/2 travel times over all O-D pairs.

The first, shown in Figure 3a, assumes a triangular peak in each of the a.m. and p.m. periods and assumes that travel times are linearly distributed between peak hours and the hours with the minimum travel demand between peaks. Pattern 1 can be represented by the equation:

$$t_i = t_o + (t_{peak} - t_o)*(i/n)$$

where:

| | | |
|---|---|---|
| $t_i$ | = | travel time in period i |
| $t_o$ | = | free-flow (off-peak) travel time which occurs at the hour with the lowest travel demand between peaks |
| $t_{peak}$ | = | peak-hour travel time |
| i | = | $i^{th}$ hour before the first free-flow time period (post-peak) or the $i^{th}$ hour after the last free-flow time period (pre-peak) |
| n | = | number of hours between the peak hour and the hour with the lowest travel demand |

The second pattern, as shown in Figure 3b, assumes a flat 2-hour peak from 6:30 to 8:29 a.m. and a 1.5-hour peak from 4:30 p.m. to 5:59 p.m. All travel times in the off peak periods, from 9:00 a.m. to 2:00 p.m. and from 7:00 p.m. to 5:00 a.m. are considered to be the free flow travel time (i.e. no congestion). The travel time during the peak is assumed to be the travel time associated with the average hourly traffic volume over the 2-hour and 1.5-hour peaks and "shoulder periods" are assumed prior to and after the these peaks. Travel times in the shoulder periods for both "pre" and "post-peak" for the a.m. and p.m. peak periods are estimated in Pattern 2 as follows:

$t_i = t_o + (t_{peak} - t_o)*(i/n)$

where:

| | | |
|---|---|---|
| $t_i$ | = | travel time in shoulder period i |
| $t_o$ | = | free-flow (off-peak) travel time (9:00 a.m. to 2:00 p.m. and 7:00 p.m. to 5:00 a.m.) |
| $t_{peak}$ | = | peak travel time (6:30 to 8:29 a.m. or 4:30 to 5:59 p.m.) |
| i | = | $i^{th}$ half-hour period before the first free-flow time period (post-peak shoulder) or the $i^{th}$ half-hour period after the last free-flow time period pre-peak shoulder) |
| | = | 1,2 -- a.m. pre-peak and post-peak shoulders<br>1,2,3,4 -- p.m. pre-peak shoulder<br>1,2,3 -- p.m. post-peak shoulder |
| n | = | 3 -- a.m. pre-peak, and post-peak shoulders<br>5 -- p.m. pre-peak shoulder<br>4 -- p.m. post-peak shoulder |

The third pattern, shown in Figure 3c, assumes two triangular peaks with vertices in the hours beginning at 7:00 a.m. and at 5:00 p.m. As with Pattern 2, travel times in the off-peak periods are assumed to be the free flow travel time. A two-hour "shoulder period" before and after the a.m. peak is assumed. For the p.m. peak, a two-hour shoulder is assumed after the peak and a three-hour "shoulder" is assumed prior to the peak and the travel times for the "shoulders" are assumed to be linearly distributed over time. Travel time in the shoulder periods in Pattern 3 is estimated by the equation:

$t_i = t_o + (t_{peak} - t_o)*(i/n)$

where:

| | | |
|---|---|---|
| $t_i$ | = | travel time in shoulder period i |
| $t_o$ | = | free-flow (off-peak) travel time (9:00 a.m. to 2:00 p.m. and 7:00 p.m. to 5:00 a.m.) |
| $t_{peak}$ | = | peak-hour travel time (7:00 to 7:59 a.m. or 5:00 to 5:59 p.m.) |
| i | = | $i^{th}$ half-hour period before the first free-flow time period (post-peak shoulder) or the $i^{th}$ half-hour period after the last free-flow time period pre-peak shoulder) |
| | = | 1,2,3 -- a.m. and p.m. pre-peak and p.m. post-peak shoulders<br>1,2,3,4,5 -- p.m. pre-peak shoulder |
| n | = | 4 -- a.m. and p.m. pre-peak and p.m. post-peak shoulders<br>6 -- p.m. pre-peak shoulder |

The fourth pattern, shown in Figure 3d, is an attempt to further improve the very good level of fit provided by the third pattern by simply lengthening the peak vertices 30 minutes later in the a.m. peak and 30 minutes earlier in the p.m. peak. All other points in the a.m. period and the p.m. period are the same as for the third pattern, with the exception of the "shoulder period" after the p.m. peak, which is reduced slightly. Specifically, shoulder period travel times both "pre-" and "post-peak" for both the a.m. and p.m. peak periods are estimated in Pattern 4 by the equation:

$$t_i = t_o + (t_{peak} - t_o)*(i/n)$$

where:

$t_i$ = travel time in shoulder period i
$t_o$ = free-flow (off-peak) travel time (9:00 a.m. to 2:00 p.m. and 7:00 p.m. to 5:00 a.m.)$t_{peak}$ = peak-hour travel time (7:00 to 8:29 a.m. and 4:30 to 5:59 p.m.)
i = $i^{th}$ half-hour period before the first free-flow time period (post-peak shoulder) or the $i^{th}$ half-hour period after the last free-flow time period (pre-peak shoulder)
= 1,2,3 -- a.m. pre-peak shoulder
1,2,3,4 -- p.m. pre-peak shoulder
1,2 -- a.m. post-peak shoulder
1,2,3 -- p.m. post-peak shoulder
n = 4 -- a.m. , pre- and post-peak shoulders
6 -- p.m. pre-peak shoulder
5 -- p.m. post-peak shoulder

It is recognized that the fourth pattern is basically a curve-fitting exercise intended to improve the goodness of fit by recognizing the asymmetries which exist in the peak period travel time profiles. It does not, however, require additional model data points to generate the curve for each O-D pair.

*(Figure 3 about here)*

The four travel time patterns were assessed for their ability to approximate travel time between individual zone pairs for each of the 33 1-hour time intervals, given the model-generated travel times for a small number of points (i.e. the peak hours) on the travel time distribution. The objective of the exercise was to discover the travel time pattern that could best approximate the 33 1-hour model travel times requiring the smallest number of data points. This assessment was done visually for the selected origin-destination pairs, and then goodness of fit statistics were generated for all origin destination pairs.

## RESULTS

The visual inspection of selected origin-destination pairs indicates that in all cases Pattern 3, triangular peaks with free flow off-peak, provides a very good approximation of travel time. This approximation is further improved by Pattern 4, adjusted triangular peaks, which most closely fits the model generated travel times for all of the 1-hour time intervals, as shown for seven of the selected origin-destination pairs in Figure 4. The a.m. and p.m. peak congestion consistently occurs within the periods from 7:00 to 8:29 a.m. and from 4:30 to 6:00 p.m., and the "shoulder" periods appear to be fairly well represented by both the third and fourth travel time patterns. Virtually all travel times outside the assumed peak periods (5:00 to 9:00 p.m. and 3:00 to 7:00 p.m.) are either at the free-flow travel time, or just marginally higher.

*(Figure 4 about here)*

Goodness of fit statistics over all origin-destination pairs in the Greater Toronto Area were also generated for each of the four travel time approximation patterns and are shown in Table 1. Although Pattern 2 provides slightly better goodness of fit statistics than Pattern 3, Pattern 3 better catches the absolute peaks in both the a.m. and p.m. periods, as shown in Figure 3c. Since peak periods are of great interest in modeling urban transportation, Pattern 3 is recommended over Pattern 2. Clearly, Pattern 4, which was purposely fitted to the travel time curve, has the best goodness of fit. Again note that this enhanced fit is achieved without any increase in computational effort.

*(Table 1 about here)*

The modeled travel times for all origin-destination pairs were also checked to assess the choice of peak hour and the accuracy of the off-peak travel times. This assessment shows that for 96.4% of origin-destination pairs, the a.m. peak hour (i.e. the hour with the highest travel time) falls in the period between 7:00 and 8:29 a.m. For the p.m. peak, 97.0% of origin-destination pairs have the peak hour within the period between 4:30 and 6:00 p.m. During off-peak hours the travel time is with 5% of the free-flow travel time 95.0% of the time.

The approximation method saves a significant amount of computation time and computer memory storage in modeling situations that involve multiple iterations between demand estimation and network assignment modules, and in simulation exercises that require multiple replications. Table 2 shows the estimated savings for an example application using the GTA transportation network. It is noted that although the approximation method requires an upfront effort to determine the parameters of the appropriate approximation pattern, far fewer EMME/2 model runs are required each time it is necessary to assess the travel time implications of small adjustments in travel demand (for example, for each replication in a microsimulation modeling system).

## DISCUSSION AND CONCLUSIONS

The development of an accurate method for approximating modeled origin-destination travel times is computationally desirable in modeling situations where travel time matrices must be repeatedly generated and stored. The results reported herein show that such approximate methods can be developed and that they are able to approximate travel times with a high degree of accuracy. The recommended travel time approximations are Patterns 3 and 4. Due to its marginally superior goodness of fit, Pattern 4 is recommended for approximating 1996 travel times in models developed for the Greater Toronto Area. Pattern 3, due to its simplicity and good performance, may be considered a more appropriate starting point for developing travel time approximations for other urban areas or for the Greater Toronto Area in years other than 1996.

It is notable that Pattern 3 and Pattern 4 are each based only on the results of two EMME/2 user-equilibrium model assignments and one free-flow assignment. Therefore, they represent a significant reduction in computational effort over a process in which individual EMME/2 traffic assignments are run for each hour.

However, the travel pattern has only been tested on available travel demand data from the 1996 Transportation Tomorrow Survey in Toronto, Canada. For future year model runs and for different geographic areas, it is recognized that the assumed parameters for the travel time pattern could change. For example, if there was a significant increase in traffic from 1996 to some future model year, it is likely that peak periods would expand to reflect travelers that would travel earlier or later to avoid increasing congestion in the peak hours. Similarly, the position of the actual peak hour may shift in time as travel trends change. Therefore it is important to review how well the travel time approximation adopted for the GTA in 1996 performs when large changes in travel demand occur, or major transportation infrastructure improvements are made over time, or the model is transferred to a different geographic area.

**ACKNOWLEDGEMENTS**

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## LIST OF TABLES AND FIGURES

**Tables**



**Figures**

**TABLE 1 Comparison of Travel Time Patterns to Model Travel Times Over All GTA Zone Pairs.**

| Travel Time Pattern | Mean Squared Error | $R^2$ |
|---|---|---|
| Pattern 1: Linear- four point model | 39.59 | 0.285 |
| Pattern 2: 2/1.5 hour peaks with free flow off-peak | 2.97 | 0.901 |
| Pattern 3: Triangular peaks with free flow off-peak | 3.36 | 0.899 |
| Pattern 4: Adjusted triangular peaks | 1.89 | 0.928 |

**TABLE 2 Estimated Savings in Travel Time Computation and Data Storage for the GTA (1700 zone system)**

| | Initial EMME/2 model runs used to test approximation patterns | Computation Savings **per Iteration or Replication** | | |
|---|---|---|---|---|
| | | Number of travel time matrices requiring calculation | Approximate EMME/2 assignment time[1] | Computer memory required to store travel time matrices[2] |
| No Approximation Method | 0 | 24 | 8 hours | 132 MB |
| Using Approximation Method (Pattern 1, 2, 3 or 4) | 33 | 2 | 40 minutes | 16.5 MB (3 matrices) |

[1] EMME/2 user equilibrium assignments take approximately 20 minutes per assignment on the computing platform used for the GTA EMME/2 traffic network. It is noted that the free-flow assignment, required for the recommended approximation methods, does not depend on travel demand and therefore only needs to be calculated once, initially

[2] Assumes storage of travel times as short integers (2 kilobytes)

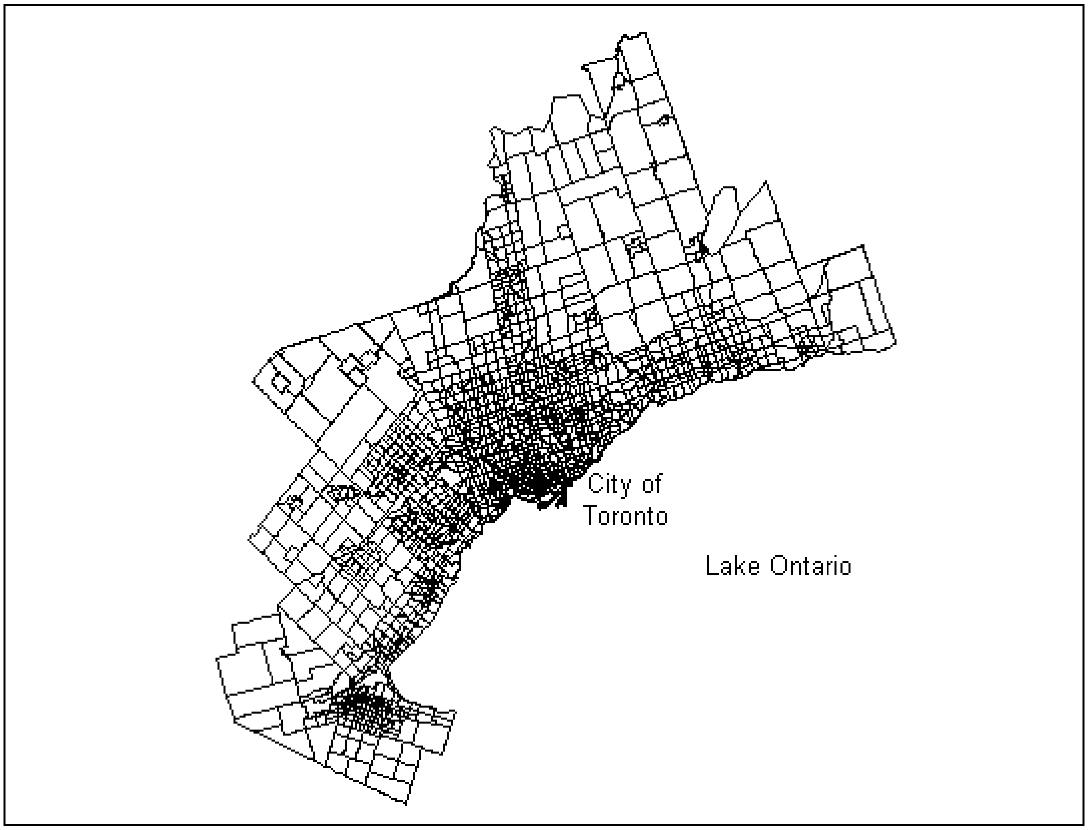


**FIGURE 1 The Greater Toronto Area zone system.**

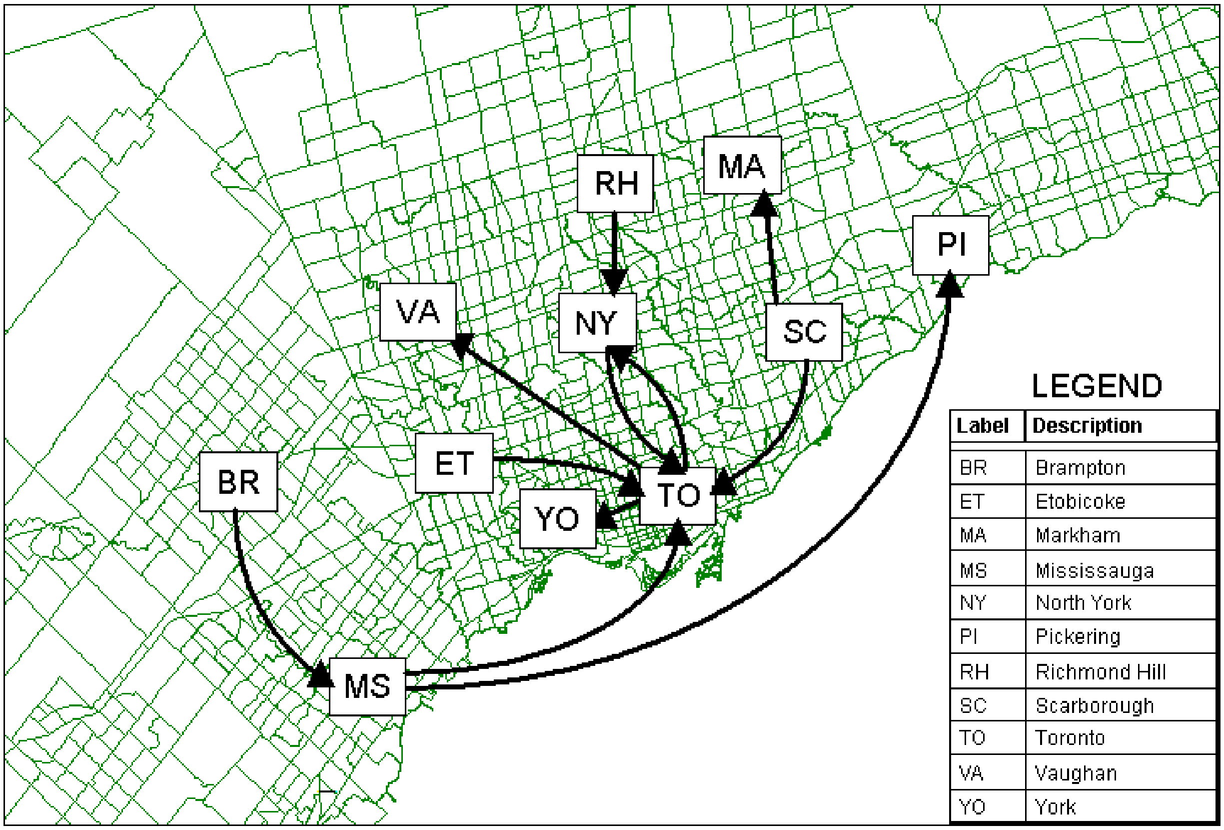


**FIGURE 2 Origin – destination pairs selected for detailed evaluation.**

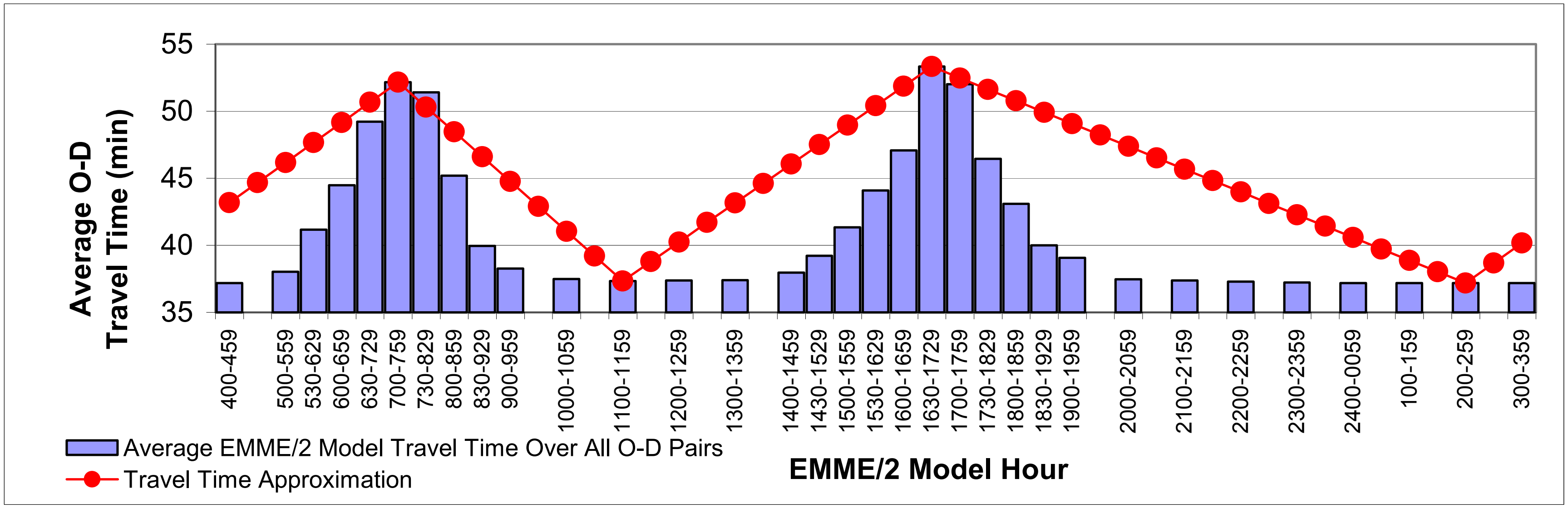


**FIGURE 3a Pattern 1: Linear 4-point model.**

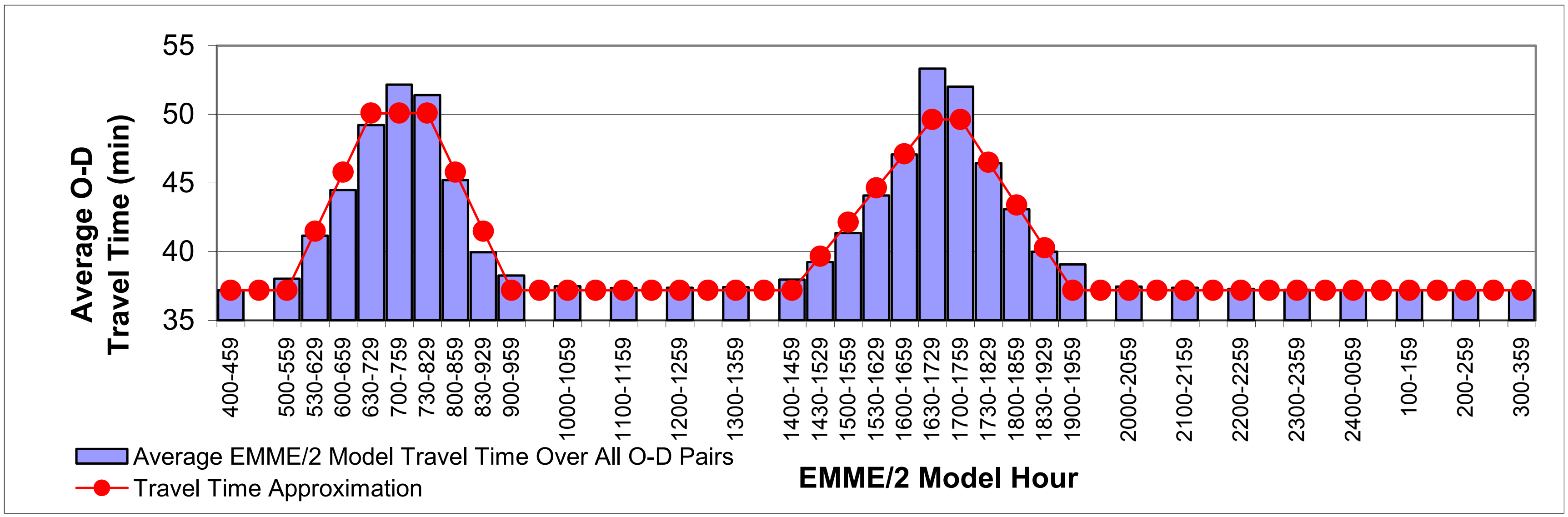


**FIGURE 3b Pattern 2: 2/1.5 hour peaks with free flow off-peak.**

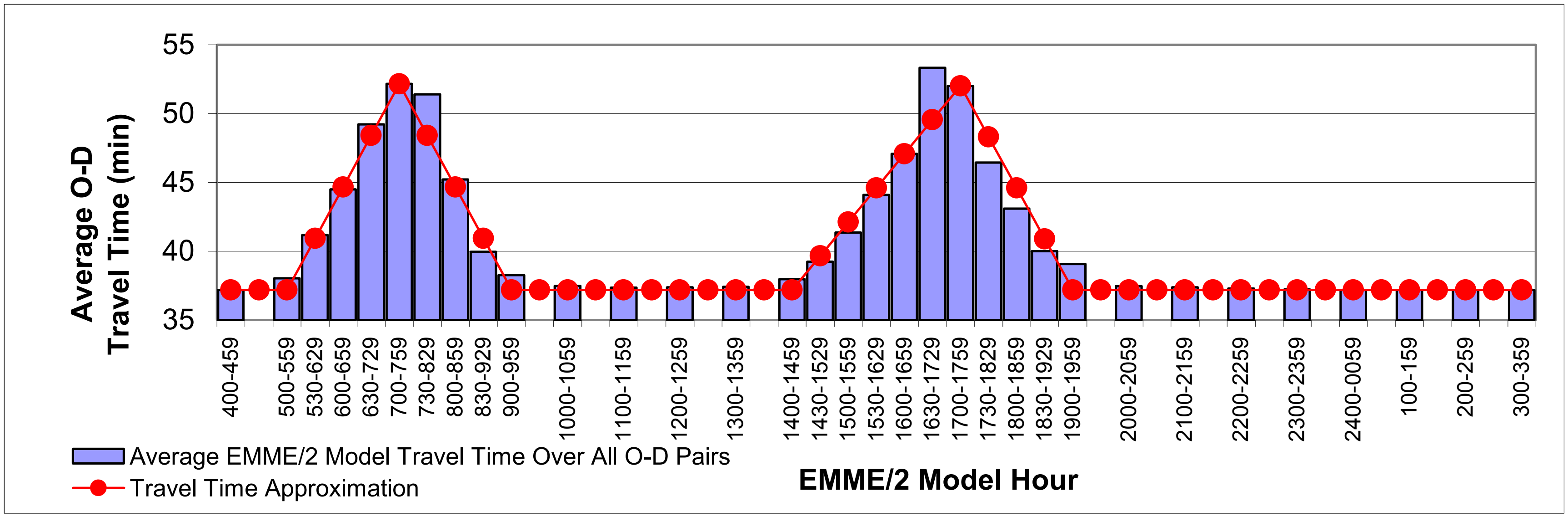


**FIGURE 3c Pattern 3: Triangular peaks with free flow off-peak.**

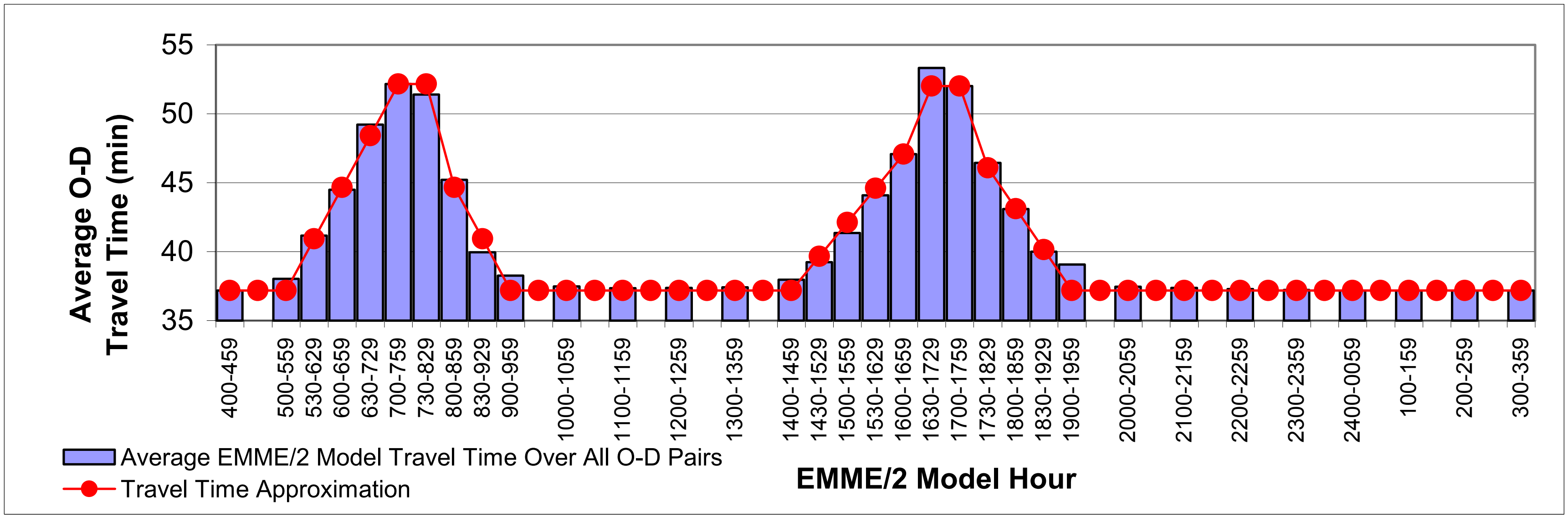


**FIGURE 3d Pattern 4: Adjusted triangular peaks.**

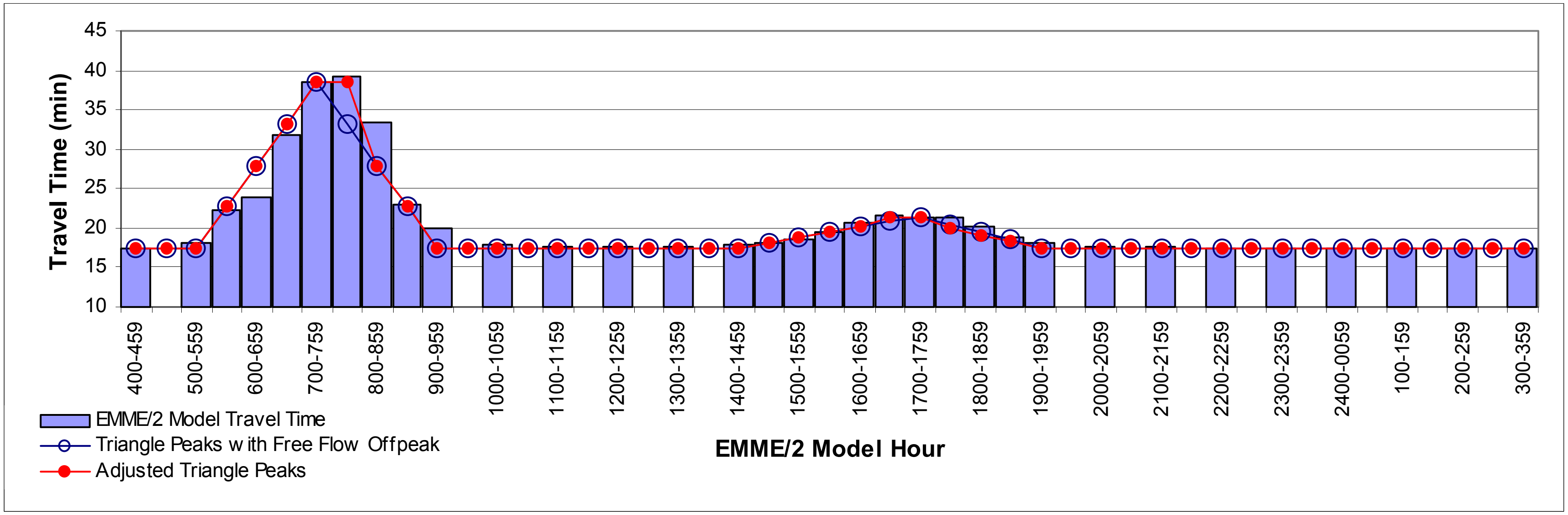


**FIGURE 4a Travel time from Scarborough to Toronto.**

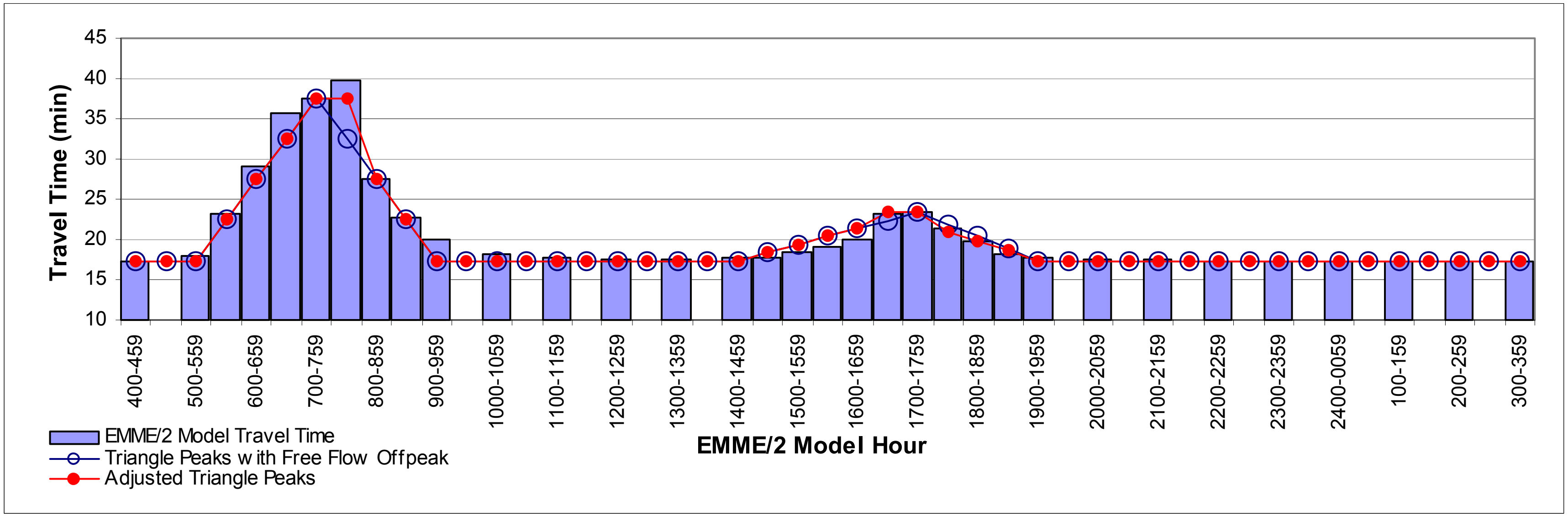


**FIGURE 4b Travel time from Mississauga to Toronto.**

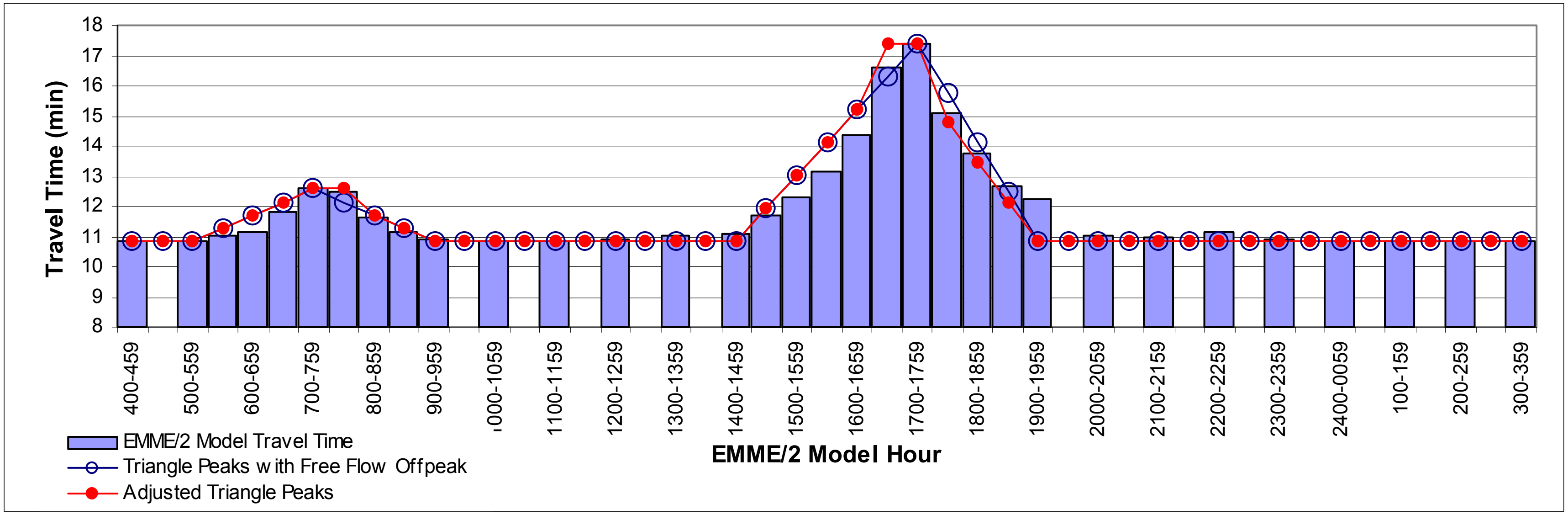


**FIGURE 4c Travel time from Toronto to York.**

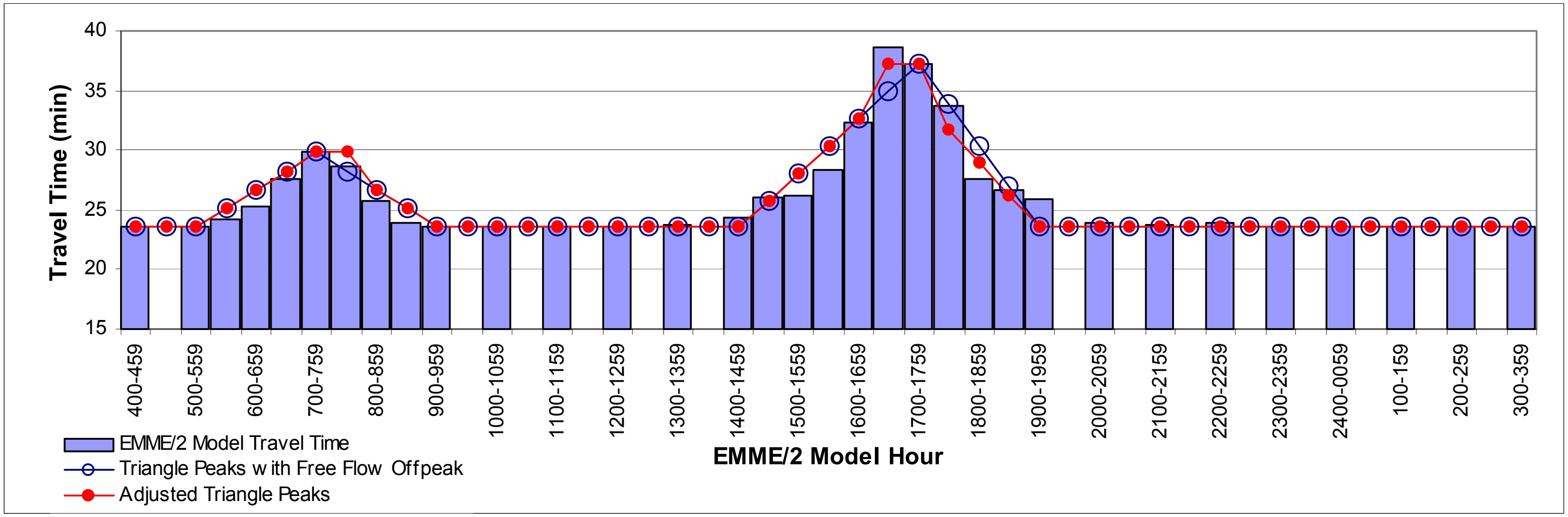


**FIGURE 4d Travel time from Toronto to Vaughan.**

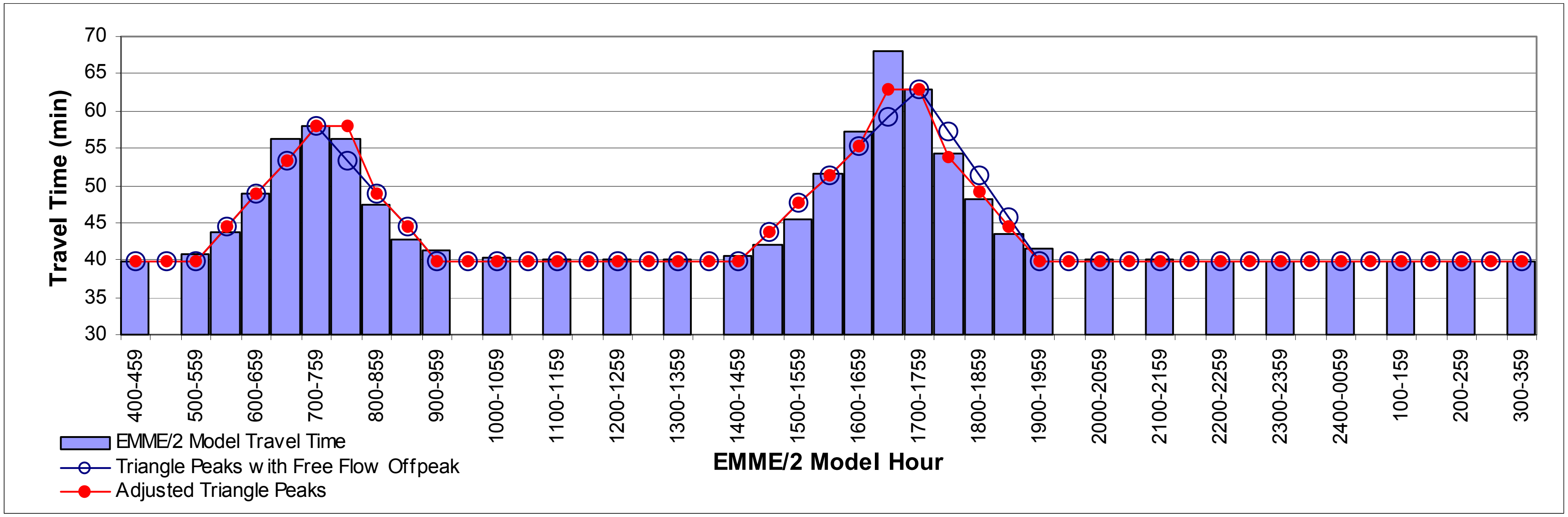


**FIGURE 4e Travel time from Mississauga to Pickering.**

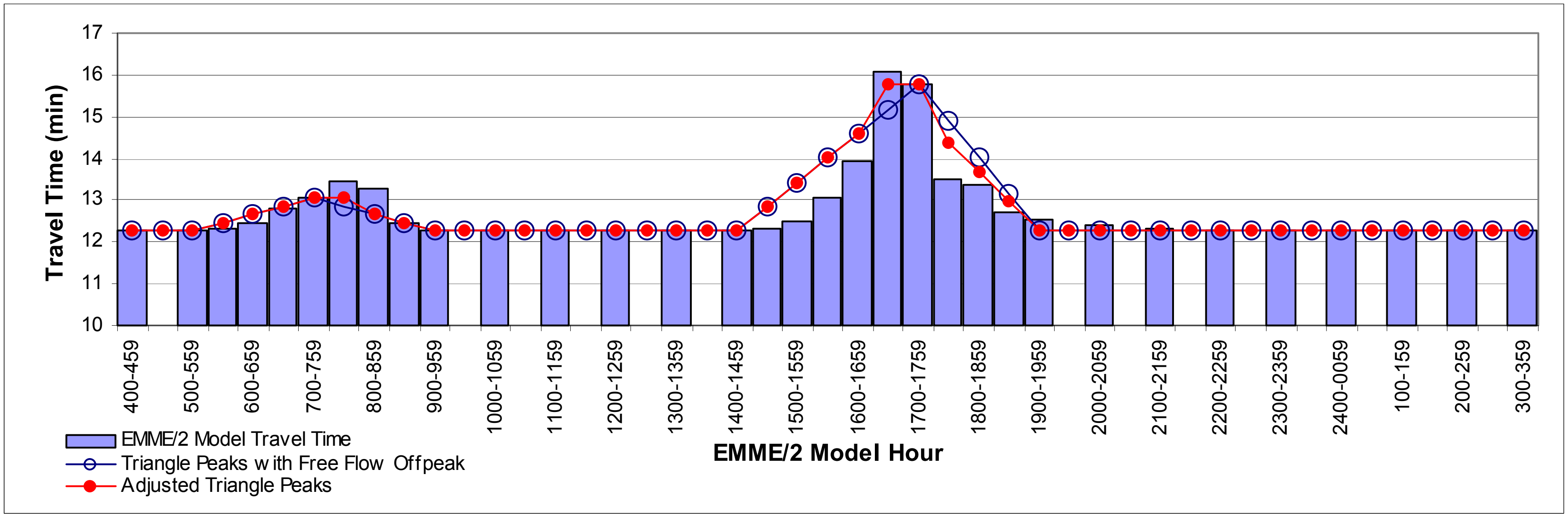


**FIGURE 4f Travel time from Scarborough to Markham.**

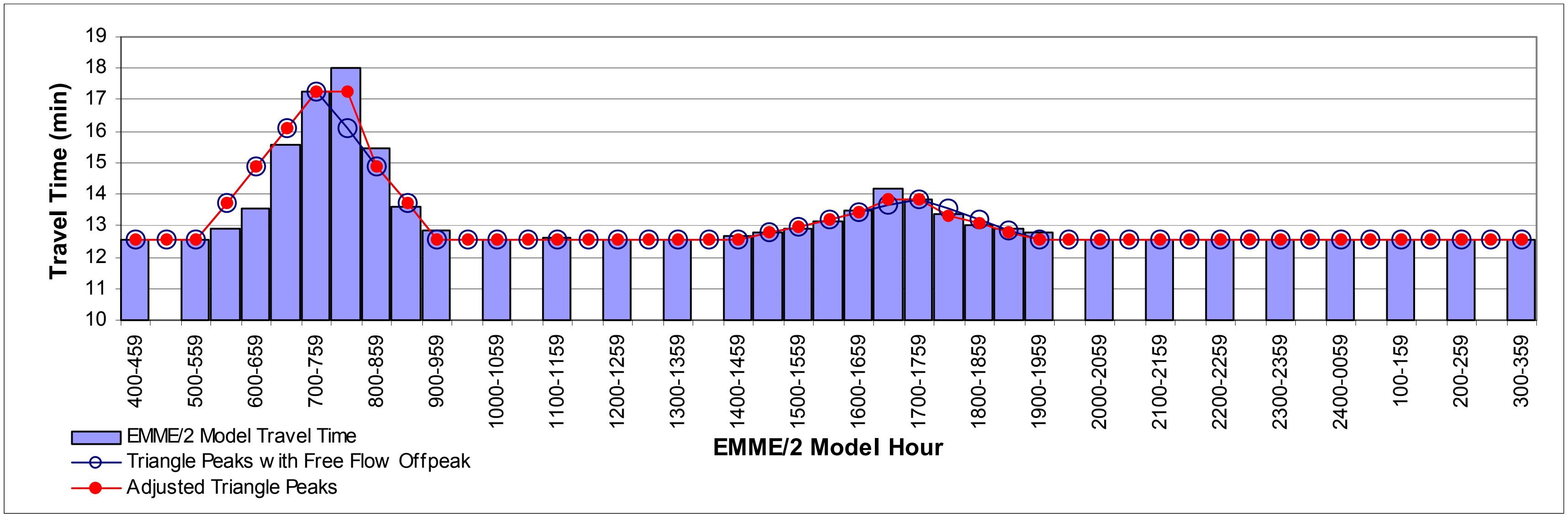


**FIGURE 4g Travel time from Richmond Hill to North York.**