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A practical approach to cost functions in large scale models: A case study from the Tactical Adelaide Model (TAM)

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Abstract

Static traffic assignment at the macroscopic level is commonly used in the strategic transport/travel demand models. Path building, using macroscopic traffic assignment as the steppingstone to inform dynamic mesoscopic/microscopic traffic simulation is also a common and accepted practice in tactical and operational models.

From the simplest assignment method of All or Nothing (AoN) to more advanced forms of equilibrium assignment methods, the route selection is based on calculating the costs associated with alternative route choices for any given pair of origin and destination.

Costs associated with alternative routes are determined via different cost functions, including the Volume Delay Function (VDF), Turn Penalty Function (TPF), and Junction Delay Function (JDF).

In this research, we have investigated a simplified approach in determining the generalised cost for routes where we combined the TPF and JDF and used a network-wide average delay for the signal-controlled junctions.

The simplified cost function proved advantageous in terms of reducing the computation time and achieving convergence with fewer iterations. It also made it possible to benefit from the Frank and Wolfe (F&W) method as the network-wide average delay assumption for signalised and unsignalised intersections provides a solution for the no interaction between routes which is fundamental to the F&W method.

1. Introduction

Traffic assignment is the backbone of many transportation analysis and studies. It is also the last step of the conventional foutr-step travel demand models (Ortúzar et al., 2011). Traffic assignment models usually consist of two main components, namely a route choice model and a network flow model. Traffic assignment models are classified as per their method of route choice, i.e. deterministic or stochastic, the treatment of time, i.e. static or dynamic, and the level of vehicle aggregation, i.e. macroscopic, mesoscopic and microscopic(Oregon Department of Transportation, 2018).

Several combinations for the method of route choice, treatment of time and the level of vehicle aggregation exist but the combination of deterministic static macroscopic traffic assignment is most commonly used in the conventional travel demand model and also as the steppingstone for the development of other classes of models (Brederode et al., 2019).

Deterministic static macroscopic traffic assignments use as series of cost functions to determine the route choice and the flow. Generally speaking, the cost of a route from a given origin to a given destination is a derivative of the travel time between the origin and the destination. At the link level (also applies to centroid connectors), the travel time, or the link delay to be more specific, is a derivative of the volume assigned to the link and the capacity of the link. Voume Delay Function (VDF) is used for macroscopic static models to help determine the delay and accordingly the travel time during congestion period at the link level. Aggrating the delay and/or travel time information for all links within a route can help determinine the delay (or travel time) for the whole route from a given origin to a given destination.

Due to its link-based nature, the analysis limited to VDF lacks considering the delays at the nodes. It means that the analyses done with traffic assignment models, using restricetd forms of the functions which relate the cost of travel to volumes of traffic, i.e. VDF, cannot be used for networks which include the details of signalised and unsignalised junctions (Heydecker, 1983). Deriving the delay (or travel time during congestion period) and accordingly the associated cost as a function of volumes of confilicting turns can help enhance the route travel time (generalised cost). In this respect, Junction Delay Functions (JDF) calculates the delay caused in a turn based on the volume of the turn, the volume of the conflicting turns and the volume of the turn origin section (Aimsun, 2022).

The length and speed of turns can also be considered in calculating the primary generlised cost of crossing a turn which is known as the Turn Penalty Function (TPF). Congestion and control delays, e.g. signal delay, are allowed for in the TPF (Aimsun, 2022).

While there are benefits in having details, such as JDF and TPF, in a static model, the benefits come at the expense of increased computation time and more iterations to achieve convergence. This is particularly the case when static assignments are used for OD adjustment process of the base year model. In this paper, we discuss a simplified method for juction modelling which can be used for largescale networl models. It is, therefore, a middle ground between a static assignment with detailed TPF and JDF assumption and one with none. The model runtimes, number of iterations as well as the network flow model results are compared in this paper for a staic assignment model built with detailed assumptions against the one built with simplified assumptions.

2. Literature review

A Highway Assignment Model, also known as the Traffic Assignment Model, is the last step of a convential four-step travel demand model and a critical component of the travel demand forecasting exercise (Oregon Department of Transportation, 2018, Ortúzar et al., 2011, Saw et al., 2015).

A Traffic Assignment Model is usually made up of two main components, i.e. a route choice model and a network flow model (Oregon Department of Transportation, 2018).

The route choice model, which determines the trip-maker’s path between a given pair of origin and destination, can be classified according to the method of route choice, the treatment of time and the level of vehicle aggregation.

Due to the strategic nature of travel demand models, it is an acceptable practice to keep their highway assignment model component away from the details expected from a tactical and/or operational models (Brederode et al., 2019). In this respect, it is common for the route choice model of a strategic transport model's highway assignment model to use a deterministic method (as opposed to stochastic), a flat demand for the analysis period, i.e. the model is static as opposed to dynamic, and has a high level of vehicle aggregation, which means it is at the macroscopic level (as opposed to mesoscopic or microscopic). In other words, it is common for the highway assignment models of strategic transport models / travel demand models to be deterministic, static, and macroscopic in nature (Oregon Department of Transportation, 2018).

The network flow models indicate how the links and nodes of a transport network will perform under the assigned demands, determined in the route choice model.

The highway assignment models of strategic travel demand models are, therefore, based on series of assumptions to simplify the real-world operations. Depending on the method of assignment, route selection follows Wardrop's first principle which states that "the used paths travel times between a given pair of origin and destination are less than, or equal to, the travel times of other paths" (cited in Krylatov et al., 2020).

Extension of Wardrop's first principle will introduce the concept of generalised costs. In this respect, Wardrop's first principle can be rephrased to state that the costs of used paths between a given pair of origin and destination are less than, or equal to, the costs of other paths.

As discussed, strategic models commonly use deterministic, static macroscopic traffic assignment which uses as series of cost functions to determine the route choice and the flow. Generally speaking, the cost of a route from a given origin to a given destination is a derivative of the travel time between the origin and the destination. At the link level (also applies to centroid connectors), the travel time, or the link delay to be more specific, is a derivative of the volume assigned to the link and the capacity of the link. Voume Delay Function (VDF) is used in macroscopic static models to help determine the delay and accordingly the travel time during congestion period at the link level. Aggrating the delay and/or travel time information for all links within a route can help determinine the delay (or travel time) for the whole route from a given origin to a given destination.

Due to its link-based nature, the analysis limited to VDF lacks considerations for the delays at the nodes. It means that the analyses done with traffic assignment models, using restricted forms of the functions which relate the cost of travel to volumes of traffic, i.e. VDF, cannot be used for networks which include the details of signalised and unsignalised junctions (Heydecker, 1983). Deriving the delay (or travel time during congestion period) and accordingly the associated cost as a function of volumes of confilicting turns can help enhance the route travel time (generalised cost). In this respect, Junction Delay Functions (JDF) calculates the delay caused in a turn based on the volume of the turn, the volume of the conflicting turns and the volume of the turn origin section (Aimsun, 2022).

The length and speed of turns can also be considered in calculating the primary generlised cost of crossing a turn which is known as the Turn Penalty Function (TPF). Congestion and control delays, e.g. signal delay, are allowed for in the TPF (Aimsun, 2022).

Application of the static traffic assignment models built at the macroscopic level is also extended to the development of the mesoscopic and microscopic models where the paths built from the macroscopic traffic assignments are used to inform the lower level of traffic assignment model tiers (South Australian Department for Infrastructure and Transport, 2019).

Application of the static traffic assignments in the strategic transport models, as well as their use as the steppingstone into the development of dynamic mesoscopic and microscopic models, underpins the importance of developing assignment models with accurate and reliable outcomes while considering the practicality of the details included in the model with respect to the data availability and computation time.

Computation time and the number of iterations for the model to converge are critical issues for largescale models, particularly when the static assignments are used for Origin-Destination adjustment process using observed Real Data Sets (RDS).

3. Problems faced and the proposed solution

To understand the context of the problem some details about the Tactical Adelaide Model (TAM) are provided here. The model boundary is the same as the boundary defined in the Strategic Adelaide Model (SAM) with more road network details suitably coded for operational analysis as befitting of a mesoscopic Dynamic Traffic Assignment simulation. In overview, the study area covers Burra to the north, Port Wakefield to the west, Victor Harbour to the south, and Morgan / Blanchetown to the east. The model covers an approximate area of 140km x 215km as shown in Figure 1. It has 24985 sections and 8428 nodes. The model consists of 843 signalised intersections, 97 signalised pedestrian crossings, and 122 at-grade crossings. It also has 1705 disaggregated centroids, i.e. origin/destination of the trip matrices. Two peak periods are modelled: AM peak (7:00 – 10:00 AM) and PM peak (03:00 – 07:00 PM).

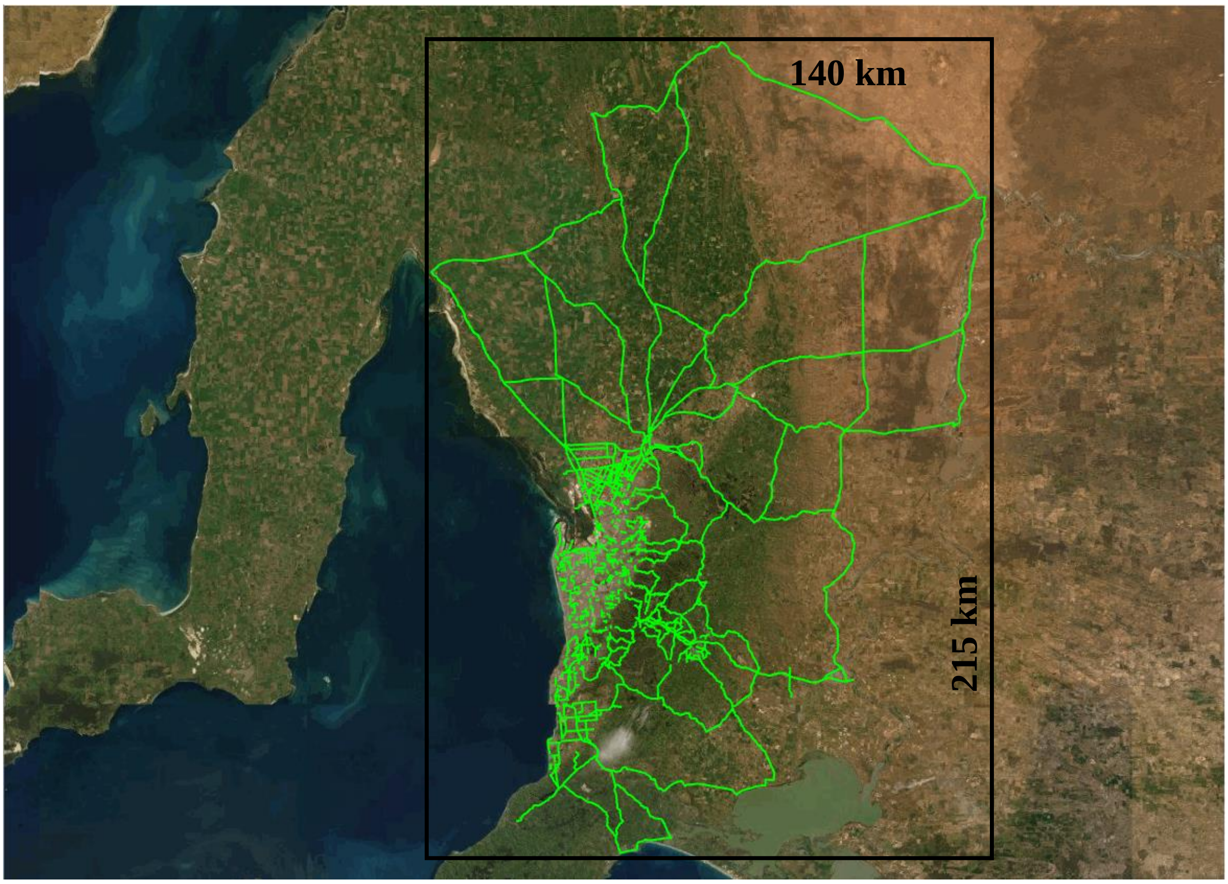


Figure 1: Study area of TAM – With TAM road links indicated in green

Managing such a large model for dynamic simulation is quite a demanding process. Aimsun Next's integrated multi-level approach has been deployed for TAM. The static/macroscopic version of the model is used to build a connection with SAM, mostly to interchange the origin/destination matrices between TAM and SAM. The macroscopic simulation also serves other purposes such as:

- Adjusting the base year OD matrices based on the collected real data for each model period
- Creating time-dependent demand (profiling) based on the real data
- Calculate the static equilibrium path to be used as the initial path for the dynamic simulation

The macroscopic model calculates the static equilibrium based on link cost that has three components:

- Section costs are defined as volume delay functions that provide an estimation of the travel time based on the volume/capacity ratio.
- The road sections of the model have been categorised into 17 road types with specific VDF defined for each of them.
- Turn costs depend on different types of the turns:
    - For non-signalised turns a generic turn penalty function (TPF) is used
    - For signalised turn, more sophisticated TPF has been used that incorporates average delay from the signal timings
    - For priority turns, junction delay functions (JDF) are used to model the travel time or the cost on a turn as a function of volumes of conflicting turns.
- The model has applied two different TPFs
- Also, 11 different JDFs has been developed to better reflect the conflict delay caused by different configurations of the priority intersections.
- All these TPFs and JDFs are legacy functions that were developed for Metropolitan Adelaide Traffic Simulation and Assessment Model (MATSAM), an earlier version of the dynamic model for the metropolitan Adelaide area (South Australian Department for Infrastructure and Transport, 2019).

Table 1 - Available TPFs and JDFs used in TAM

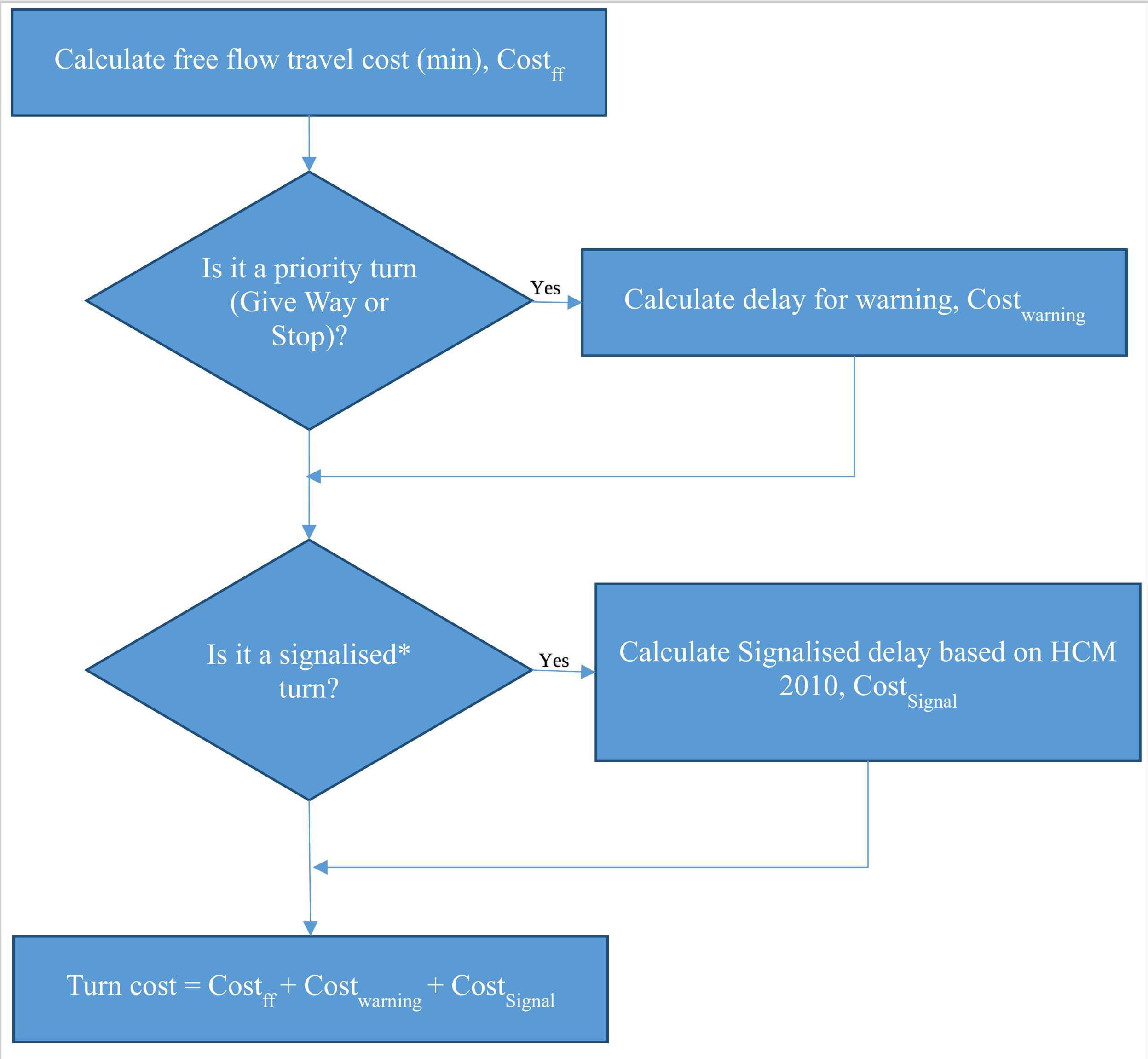
	Function type	Name /Description of the Function
1	TPF	TPF Adelaide
2	TPF	TPF Adelaide Signal Delay
3	JDF	JDF Adelaide Roundabout [Circulating >1 Lane, Entry >=1 Lane]
4	JDF	JDF Adelaide Left Minor 4-Lanes
5	JDF	JDF Adelaide Left Minor 2-Lanes
6	JDF	JDF Adelaide Right Major 4-Lanes
7	JDF	JDF Adelaide Right Major 2-Lanes
8	JDF	JDF Adelaide Right Minor 4-Lanes
9	JDF	JDF Adelaide Right Minor 2-Lanes
10	JDF	JDF Adelaide Through Minor 4-Lanes
11	JDF	JDF Adelaide Through Minor 2-Lanes
12	JDF	JDF Adelaide Roundabout [Circulating =1 Lane, Entry >=1 Lane]
13	JDF	JDF Adelaide Left Slip Lane

Applying such a complicated list of TPF and JDFs created some issues during the model calibration process of TAM. As a lot of additional details have been applied for a better simulation outcome, maintaining model consistency becomes a challenging process. Also, for any new development for the future year's networks, the user needs to maintain these functions as they have been applied in the base model. Therefore, any user who will work on the model in the future needs to be conscious of these functions' presence. For example, TAM has around 9000 priority turns, and maintaining the 11 different JDFs for those turns would be a cumbersome process.

A simplified approach has, therefore, been contemplated and eventually adopted for TAM to combine all the turn penalty functions and junction delay functions into one single function. The function automatically checks and applies correct penalty based on the turn type. The generalised cost function for all turns is explained in the next section.

Turn Penalty Function (TPF) used in TAM

A single Turn Penalty Function (TPF) is used to define all turn costs in TAM. The TPF can identify whether it is a non-signalised, signalised, or priority turn, and will apply an appropriate cost for it. The following flowchart explains how this TPF works.



* A turn is considered signalised if the cycle time >0.0s AND [0 < green time < cycle time]

Figure 2: Flowchart showing TPF function details

It is to be noted that the TPF used in TAM incorporates the junction delay where a warning sign (e.g. GiveWay or STOP) is placed. The yield cost is calculated with the volume/capacity for the turn itself and a user-defined delay (s) for give-way and stop signs (via a second user-defined cost). Hence, no separate junction delay function is required. For all turns, apply the following setup as shown in Figure 3:

Turn Penalty Function = TAM combined TPF and JDF
Junction Delay Function = None.

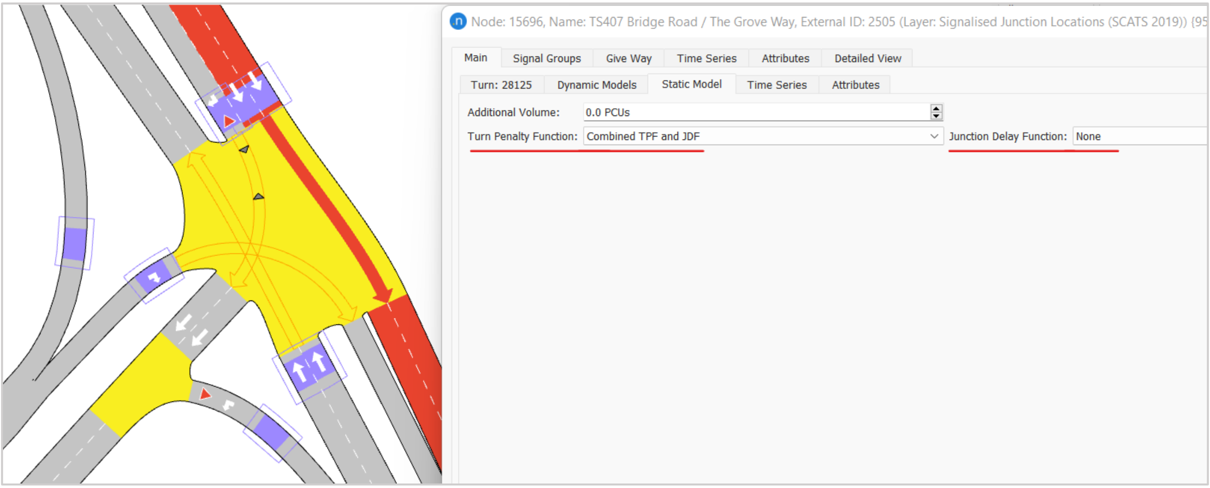


Figure 3: Application of Combined TPF and JDF for each turn

The benefit of using a combined TPF and JDF function:

- Easy to apply/update for any turns,
- Users can select all turns and apply the function for all with a single command in the Aimsun Table view,
- Easy to manage (one function to worry about),
- No manual intervention is needed to check if the turn is a signalised turn, priority or just a normal turn,
- The penalty for give-way and stop can be calibrated locally (if needed),
- Tthe TPF function avoids conflicting movement volume, hence, Frank and Wolfe (F&W[1]) assignment method can be used which converges faster than MSA[1].

4. Research methodology

To understand the difference in usability and performance of the two methods defined in the preceding section, they have been applied separately in the same model and the assignment performance and run time has been analysed in detail in the following section. The two methods will be called as

1) Traditional method - TAM with all the 13 TPFs and JDFs applied accordingly
2) Proposed method – TAM with single Turn Penalty function i.e. combined TPF and JDF in a single function and applied to all turns

[1] The Method of Successive Average (MSA) and Frank & Wolfe (F&W) are the two most common traffic assignment algorithms. Both of those redistributes the flows among the available paths in an iterative procedure. Both have a decreasing step size at each iteration. Step size determines how much volume of traffic can be moved to the lowest cost path. The step size for MSA is the inverse of the iteration number (e.g. step size at iteration *k* would be *1/k*). The F&W algorithm calculates the step size such that the objective function is minimized. A detail discussion on MSA and F&W can be found in the paper Bezembinder, et. Al. 2016.

The following analysis will be carried out to understand the impact of the two methodologies

- Assignment runtime
- Convergency measures
- Stability in Turn costs
- Assigned volume comparison on selected sections

5. Results analysis and discussions

5.1 Assignment Performance comparisons

The following Table 2 explains the runtime results for the two methods in two simulation periods (AM and PM). It is evident that in both cases the runtime for the proposed approach is much lower (around 27.4% reduction for AM and 26.7% reduction for PM period is observed). Also, the assignment converges (i.e. reaches equilibrium) to a Rgap[2] below 0.1% within 100 iterations for the proposed method. However, in the traditional method, none of the periods converges within the 100 iterations. The final Rgap after 100 iterations is much higher than 0.1% which indicates that both the assignments in the traditional method need to run for longer iterations to reach the desired convergency level.

Table 2: Assignment performance

Assignment method	Model period	Comparison criteria	Traditional method	Proposed method
MSA	AM	Runtime	7 m 26 s	5 m 24 s
		Number of iterations	100	73
		Final Rgap	0.5430%	0.0992%
MSA	PM	Runtime	8 m 6 s	5 m 56 s
		Number of iterations	100	83
		Final Rgap	0. 4529%	0.0931%

5.2 Turn cost stability and distribution

Table 3 summarises the turn cost statistics, followed by Figure 4 with histograms of turn costs for the two methods and the two simulation periods. Table 3 suggests that the mean and standard deviation of the turn costs in the proposed method is much lower than in the other method. From Figure 4 it is evident that the proposed method has produced significantly lower turn costs compared to the traditional method. With the histogram and summary statistics, it is clear that the turn costs produced by the single turn cost function is more stable than the traditional method with multiple cost functions. The reason could be that the use of one function creates a continuous cost profile which helps the assignment to easily identify the alternative paths for the equilibrium process. Whereas, with different cost functions, the traditional method creates more fluctuation in the turn costs which would make the equilibrium process slower.

[2] The relative gap (Rgap) function proposed by Janson (1991) is an estimate of the relative difference between the total travel time actually experienced and the total travel time that would have been experienced if all the vehicles had a travel time equal to that of the current shortest path.

Table 3: Turn cost statistics

	Simulation Period	Minimum	Median	Mean	Maximum	Std Deviation
Traditional method	AM	0.01	0.03	0.4974	302.28	4.197
Proposed method	AM	0.01	0.03	0.2072	126.16	1.026
Traditional method	PM	0.01	0.03	0.5854	474.66	5.984
Proposed method	PM	0.01	0.03	0.2142	61.76	0.883

* All costs are in minutes.

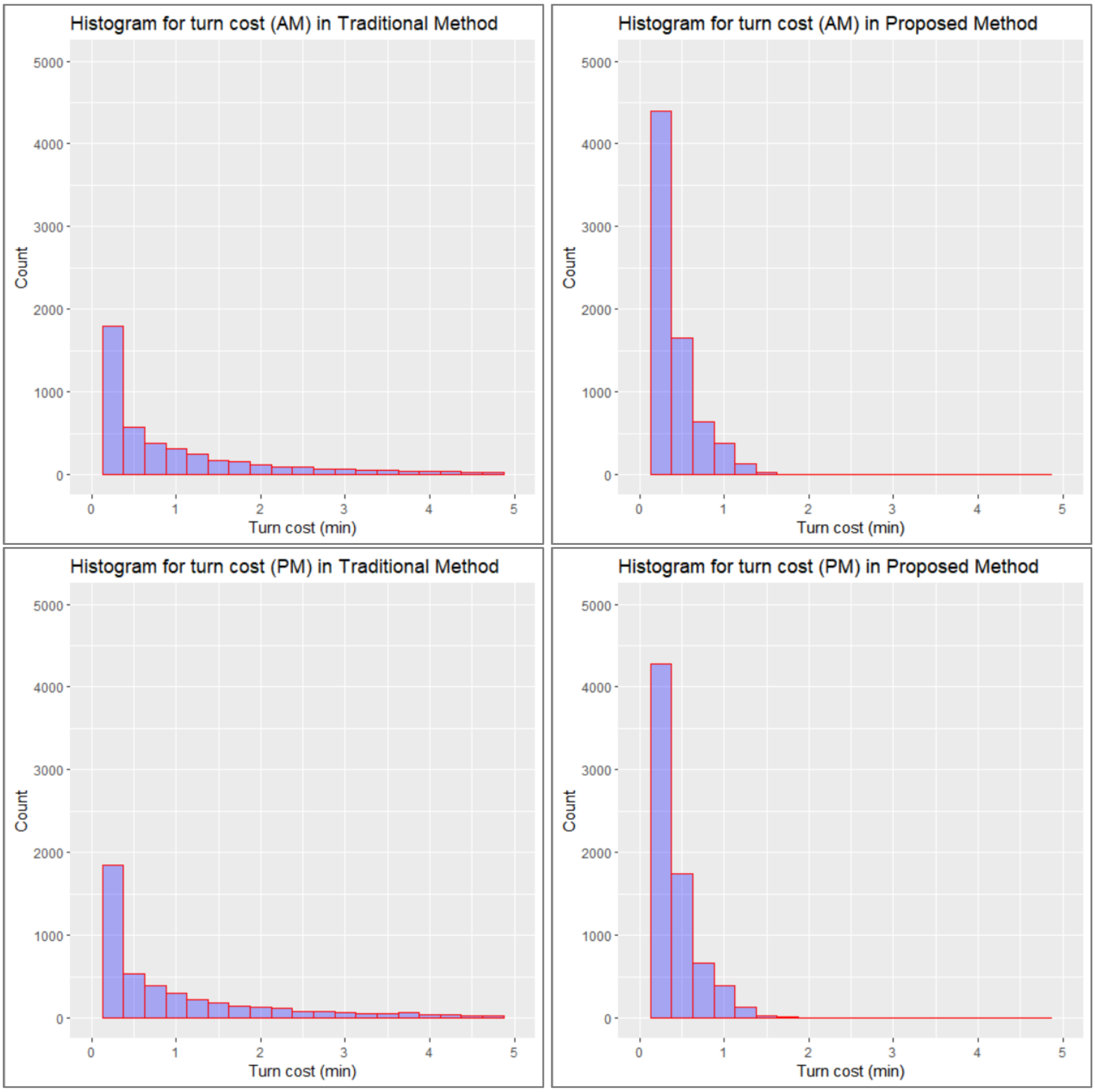


Figure 4: Histogram of Turn costs for traditional and proposed method in AM and PM simulation periods

5.3 Comparison of assigned volumes on selected sections

A set of sections has been selected in the model that is also available in SAM. A total of 133 Aimsun sections have been used for the comparison. Their locations are highlighted in Figure 5. The comparisons of the simulated volume on these sections for the two simulation periods are presented in Figure 6. It shows that for AM period the assigned volume for the proposed method matches quite well with the assigned volume from the traditional method. An R-squared value of 0.9958 is observed with GEH<5 % being 93.23%. For the PM period the comparison is still acceptable with a R-squared value of 0.9911 and the GEH<5% standing at 75.19%.

The volume comparison suggests that even though a different cost function has been used in the proposed method, the route choice is quite similar to the traditional method. This finding would provide confidence that a simplified cost function can still produce similar equilibrium paths as found in the traditional method with more detailed turn cost functions.

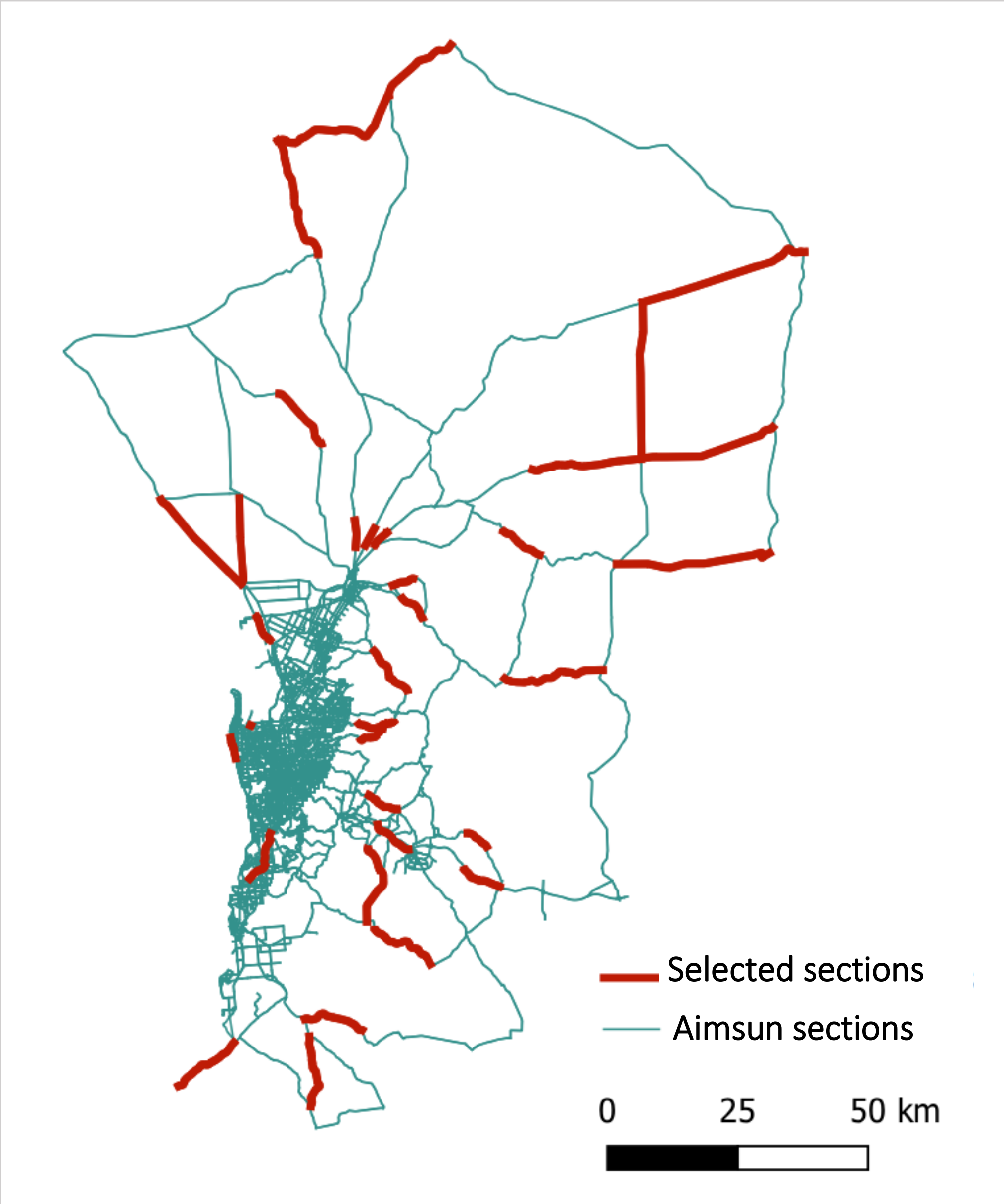


Figure 5: Location of sections used for the assigned volume comparison

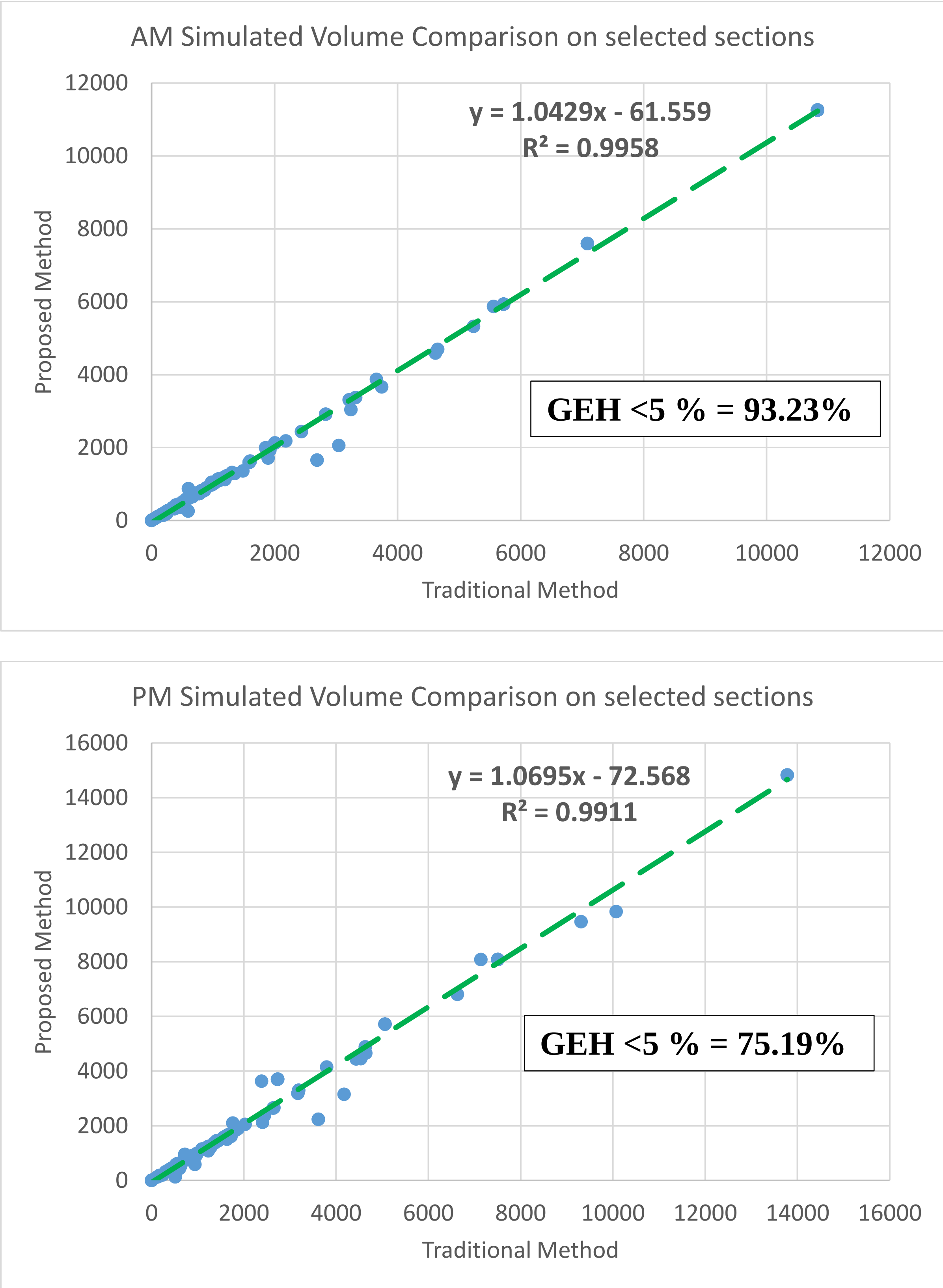


Figure 6: Simulated volume comparison on selected sections

6. Conclusions

A simplified turn cost function has been proposed, discussed and assessed. The simplied function can automatically assign turn penalty based on the type of turns, e.g. signalised, non-signalised and/or priority turns.

The use of a simplified combined TPF and JDF in one function would significantly reduce the modellers' effort to fix turn cost functions accordingly.

Moreover, the analysis results suggest that the proposed method of combining TPF and JDF in a single turn cost functions would help the assignment to converge faster. Overall, a 27% reduction in runtime is observed and the assignment converges with lower iterations than the traditional method with multiple TPFs and JDFs.

A stability check of the equilibrium turn costs suggests that the proposed method produces lower fluctuations in turn costs. Also, the assigned volume comparisons from the two methods shows similar route choice performance.

One point to note here is that the static assignment serves as the steppingstone of the dynamic model processes in TAM. To elaborate on that note, the static assignment creates the equilibrium path file that would be used as the initial path for dynamic user equilibrium in TAM. The final result of the model comes from the dynamic simulation. Therefore, any small sacrifice in the equilibrium quality that may occur from the use of a simplified turn cost function would be compensated during the dynamic equilibrium process.

On the other hand, a lot of benefits of using a simplified cost function are highlighted in this paper. The most significant advantage of the proposed method would be a faster convergence, which in-turn helps reduce the run time. Moreover, the static assignment will be used to adjust the traffic demand for different simulation periods with the help of real data. A total of 25 iterations have been used for the demand adjustment process in TAM, i.e. 25 times the static assignment needs to be run to adjust the traffic demand for one time period. Therefore, a 2minutes time savings in one assignment run would add up to be 50minutes of time savings for each demand adjustment period. In addition, the simplicity of managing one single turn cost function would reduce the overall turnover time of any projects related to TAM.

The positive findings of using the simplified turn cost function in TAM suggest the suitability of use for large-scale dynamic models like TAM.

7. Acknowledgements

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