Automatically Balancing Intersection Volumes in A Highway Network

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Abstract

On simulating an existing highway network, traffic engineers and planners use existing traffic counts which may be collected during different times and days. On simulating a future highway network, they use future intersection volumes post-processed from projected counts or travel demand models. For both cases, an up link volume is usually not balanced with a down link volume in a highway network. To have more reasonable traffic operation simulation results, we should use mathematical techniques for balancing all intersection up link and down link volumes, as well as an intersection arrival and departure volumes.

This presentation introduces two different techniques of balancing intersection volumes in a highway network – a successive link averaging with doubly constraint origin-destination balancing technique and VISUM T-Flow Fuzzy technique. Using intersection level doubly constraint origin-destination balancing technique, we may lose the balance in volumes between up and down links in the highway network. Therefore, both link level volume balancing by successive averaging and intersection level volume balancing using doubly constraint will need to be run concurrently and iteratively until the system reaches its defined convergence criteria.

T-Flow Fuzzy technique in VISUM travel demand modeling software is also introduced and compared in resolving the balancing issue. Statistical analyses of goodness of fit are used to compare the balanced intersection volumes with the unbalanced ones by both techniques. The successive averaging with doubly constraint O-D balancing technique shows better statistical fit to the unbalanced volumes than the T-Flow Fuzzy. This method also keeps the total of the balanced volumes in network the same as that of unbalanced volume, not losing volumes like T-flow Fuzzy technique.

A balanced network with more reasonable intersection volumes will provide engineers, planners and policy makers more confidence in network operational or simulation results.

Issues on Balanced Volumes

Balanced traffic volumes are an essential input for a micro-simulation process. Micro-simulation programs such as CORSIM and VISSIM operate from the outside to the inside [*1*]. During simulation process vehicles only generated at the entry nodes at the perimeter of the model. As vehicles travel to the interior of the model, each individual vehicle is assigned a direction based on the turning percentages calculated at each junction. Unbalanced traffic volume will cause inappropriate turning proportion resulting simulation outputs whacky or unconvincing. Traffic volumes must be balanced in order for the simulation model to run as expected and to be calibrated. However, existing counts or post-processed future volumes do not usually balance in terms of link upstream and downstream flows [*2*].

Obtaining an accurate and consistent set of traffic counts at stations is a challenging task. Traffic counts at various stations are inter-dependent [*3*]. However, Traffic counting does not take place during the same day or even the same season or year at each station. There is also a chance of counting errors. These results unbalanced traffic counts over the network. Similar sort of situation happens to forecasting volume [*3*]. Due to the post processing of forecasted volume or different growth rates for links in a network, balancing is lost in the future volumes. Therefore traffic engineers are desperately looking for an easy way to resolve this issue. Balanced traffic volumes not only give traffic engineers a more reliable simulation results but also help them to build confidence in traffic simulation results among the model users and audience.

Current Balancing Techniques

Mekky [*3*] has proposed some methods on balancing turning movement using Furness iteration method. He also proposed a link level volume balancing technique using adjusting O-D matrix. Martin [*4*] suggested using linear programming techniques to estimate turning movements from link flows. However, not many readily applicable volume balancing techniques are found available in the academia and practice. Practitioners tend to use a manual adjustment method to match volumes departing one intersection to those arriving at the downstream intersection, or vice versa. Synchro software has a module to identify the unbalanced volume differences among all links, but it still lacks in an automatic balancing algorithm or procedure. Although the turning volumes can be manually adjusted to match between upstream and downstream by using Synchro software or spreadsheet calculations, balancing one link volume between two intersections could cause other adjacent link volumes unbalanced in the nearby links. When numerous balancing iterations are usually required a manual adjustment process can be very time-consuming.

A demand model, such as EMME or VISUM, can be used to create a balanced intersection turning volumes and link flows. Once intersection turns and/or link volumes are input into EMME network, EMME demand adjustment procedures can be utilized to create a trip table. Then, EMME can run a trip assignment with the trip table on the network with a strong goodness-of-fit to the intersection turns and link flows. VISUM T-Flow Fuzzy technique can also emulate the turns with the traffic assigned turns closely matching the counts. The goodness of fit R-square can be higher than 0.95. However, the intra-zonal traffic assignments cause volume losses over the network. The volume loss through the demand modeling process is also worrisome to modelers because under-estimation of traffic flows is not recommended in traffic simulation and scenario evaluation. Beside that, for network coding and initial setup for this sort of operation in VISUM or EMME requires substantial amount of time. Planners also require the expensive travel demand modeling package to accomplish the task.

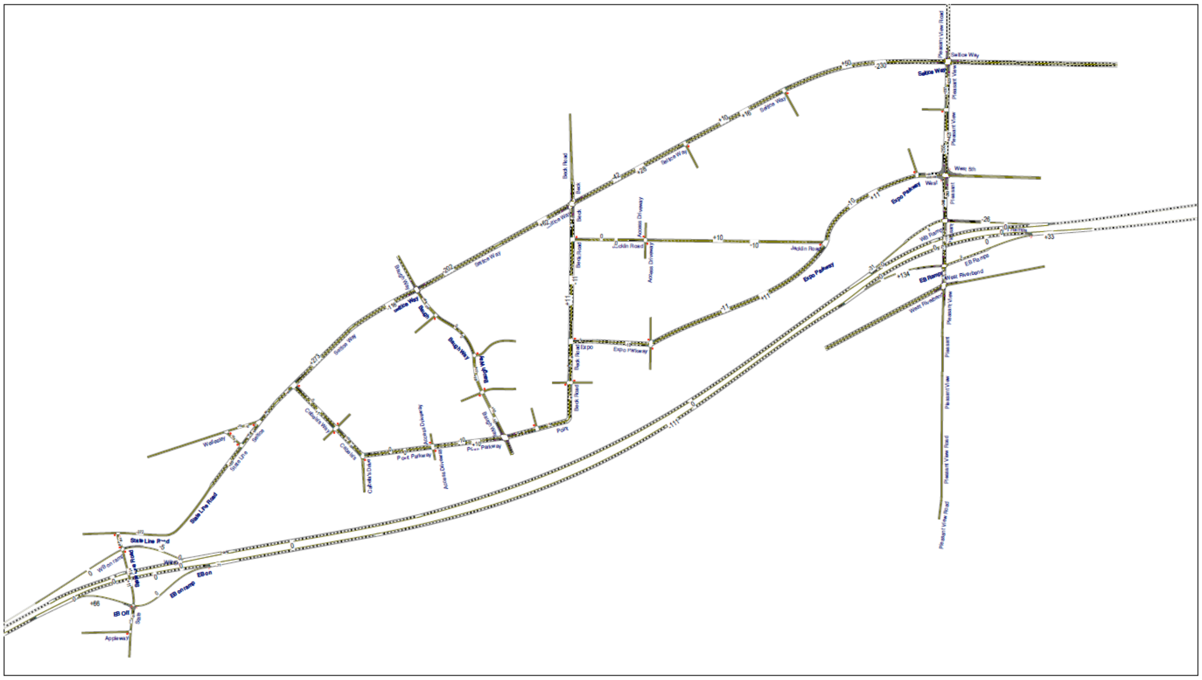

Figure 1: An Example of Large Commercial Development Traffic Network

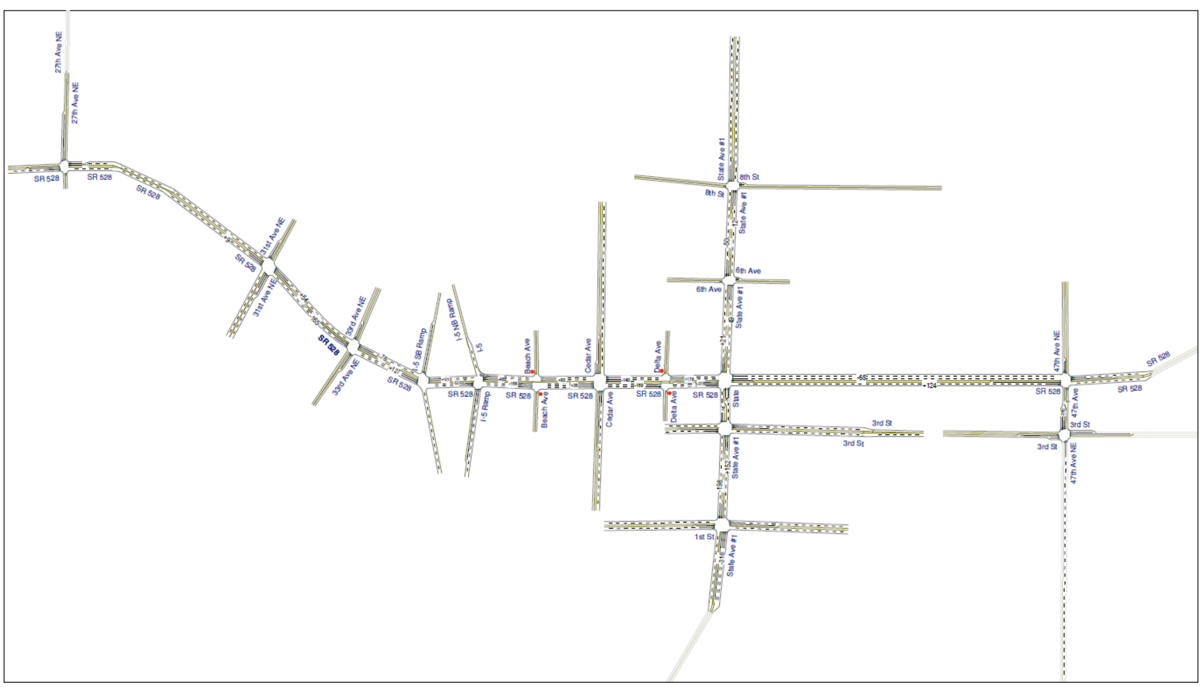

Figure 2: An Example of Downtown Access Network

Considering the above facts, this paper proposed a technique to balance existing or forecasted traffic volumes on highway or street network with several intersections and interchanges. On the basis of the doubly constrained or bi-proportional method [*5*] and using spreadsheets, a technique is described and applied to two practical examples. Figure 1 and Figure 2 shows the networks that are used for the investigation. Both the proposed technique and the VISUM T-Flow Fuzzy procedures are applied on the practical examples to balance intersection turns and link flows.

The paper starts with the overview and the algorithm of the proposed balancing technique. Thereafter, it focuses some core components of the techniques in detail. Brief descriptions are provided on the spreadsheet templates organization, formation of the intersection turn matrix, and the doubly constrained or bi-proportional method. Statistical result of the proposed technique as well as VISUM T-Flow Fuzzy technique are presented and analyzed. A conclusion is followed by this.

Proposed Automatic Balancing Techniques

The caveats of both the manual adjustment process and demand model balancing technique lead us to explore a statistically sound theory and mathematical algorithm to balance intersection volumes in a highway network. To reduce labor time on balancing and generate more acceptable turning volumes are our goals for this research. It is also expected to create an automatic process which is user-friendly and affordable.

The spreadsheet application package aided by its macro-programming capability is used for iteratively averaging downstream and upstream link flows and then balancing intersection volumes. This approach is referred to as Successive Averaging and Iterative Balancing (SA/IB) technique. One can also used this technique to create a worst case scenario by maximizing downstream and upstream link flows and then balancing intersection volumes. This method is referred to as Successive Maximizing and Iterative Balancing (SM/IB) technique.

Successive Averaging and Iterative Balancing Technique

In this method, a user requires to input the unbalanced intersections volumes and to define the connectivity among the links in the network. On running the macro, a spreadsheet automation process will handle all iterative calculations and produce the balanced volumes as the output.

This method takes the unbalanced volumes for each intersection. From that, it estimates the inbound and outbound volume for each links for each intersection. As a result, estimated link volume at the upstream and at the downstream of each link are found. Then it considers the link connectivity information and calculates targeted inbound and outbound volume for each link by averaging or maximizing the upstream and the downstream volume. With this link level volume balancing done, the next step is the formation of Intersection turn matrices. In each intersection turn matrix, origin and destination volumes are normalized to prepare each turns matrix suitable for implementing doubly constrained matrix balancing method. Then iterations of the intersections turns matrices start to achieve the target origin and destination volumes. The iteration of intersection matrix balancing continues until each balancing matrix meets the percent error convergence criteria. When the network wide convergence criterion is met, resulting new turn matrices are considered as balanced intersections volumes. However, if it is observed that percent error does not change for quite a few consecutive iterations, then those intersections turn matrix values are considered as new intersection unbalanced volumes. It starts the process from the beginning and iterates until the convergence criteria is met for all intersections. Figure 3 shows the schematic diagram of the algorithm discussed above.

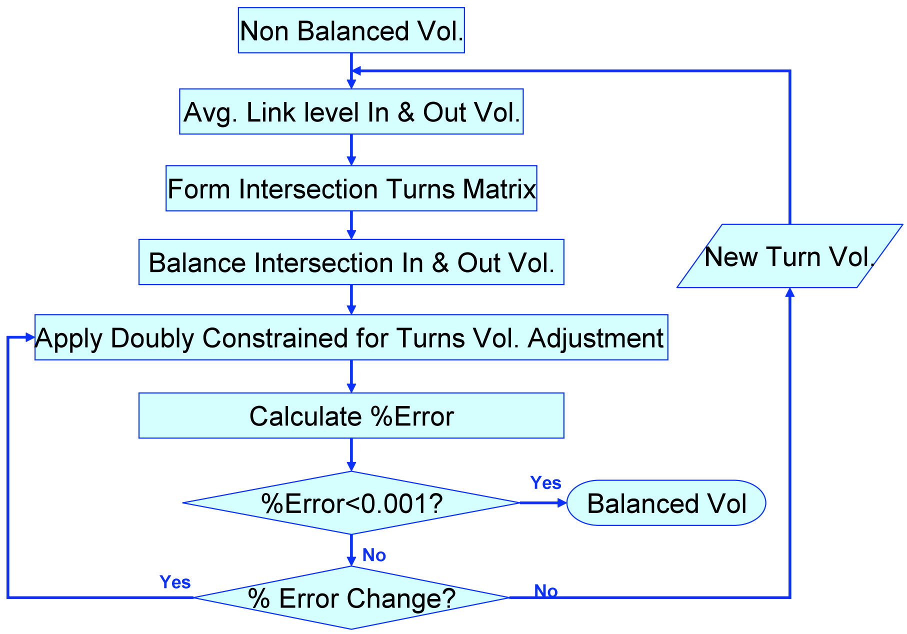

Figure 3: Successive Averaging or Maximizing and Iterative Balancing Diagram

Formation of Intersection Turn Matrix

By using an Excel Spreadsheet and its built-in Visual-Basic programming extension, three separate spreadsheet templates can be created. The inter dependency of this spreadsheets helps to form the intersection turn matrices as shown in Figure 4 below.

- Template 1: The left upper template shows the standard intersection layout with left-turn, through and right-turn volume input;

- Templete2: The left lower template shows the estimated and targeted values of approach arrivals and departures from/to north, south, east and west, respectively. Values of this template are derived from the template 1. Sum of the Turns count in Template 1 will be the estimated arrivals and departures and the average or maximum of the estimated arrivals and departures of the same link between two adjacent intersections will give the targeted arrivals and departures values.

- Template 3: The right template shows an intersection turn flow matrix with turning volumes and estimated and targeted arrival (destination) and departure (origin) volumes from north, south, east and west approaches, respectively. Color coding shows the location of the values taken from template 1 and template 2 for each intersection.

With multiple intersections linked together, turn flow matrices are formed for each intersection and then the doubly constrained method is applied iteratively for matrices balancing against the target values.

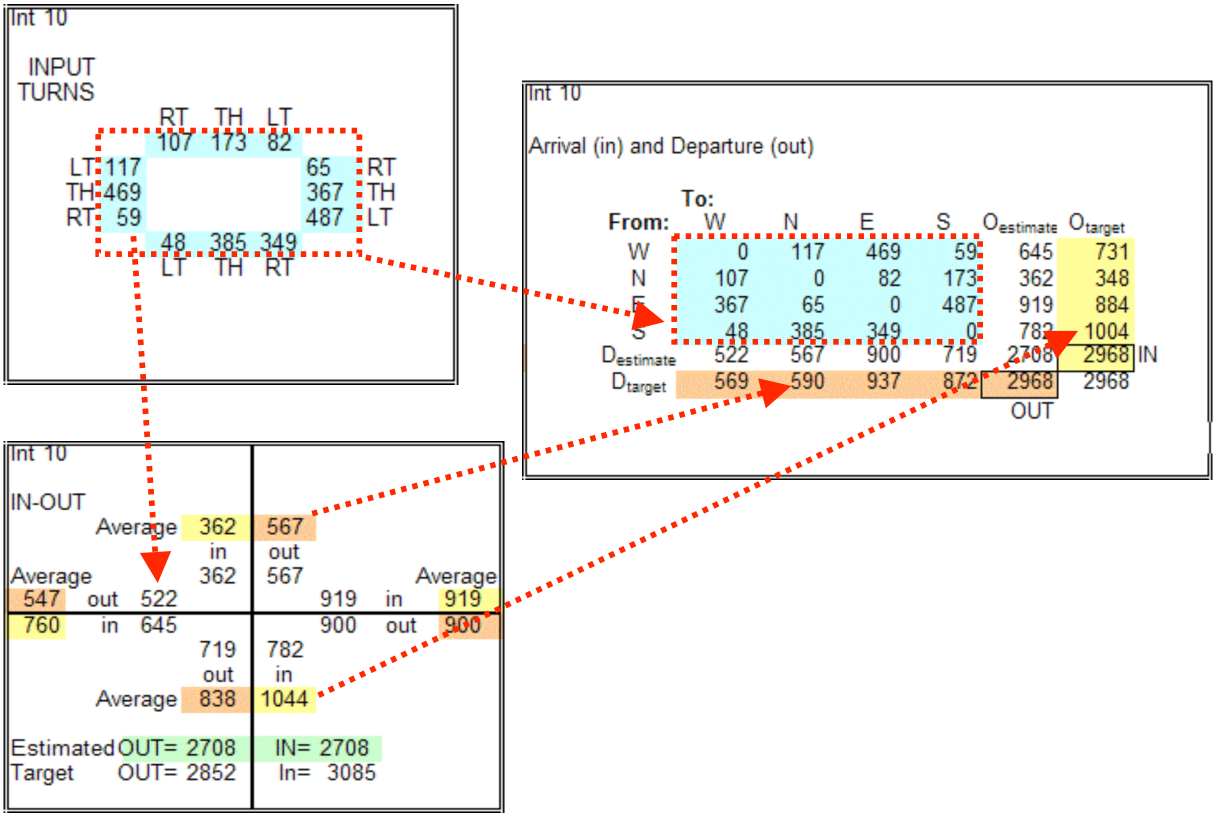

Figure 4: Formation of Intersection Turn Matrix in Excel Spreadsheet

Doubly Constrained Balancing Method

Bi-proportional algorithm [5] is implemented to iteratively update the factors for origins and destinations. This method requires the base turn matrix [t_{ij}] and the vectors of targeted total origins [O_i^{target}] and destinations [D_j^{target}]. It involves alternate balancing of the rows and the columns of a given matrix [t_{ij}] to make it reflect the new totals [O_i^{target}] and [D_j^{target}]. The basic formula is

$$T_{ij} = a_i b_j t_{ij}$$

Underlying assumption for this formula is

$$\sum_i O_i^{\text{target}} = \sum_j D_j^{\text{target}}$$

which means that traffic can neither generate nor terminate at the junction.

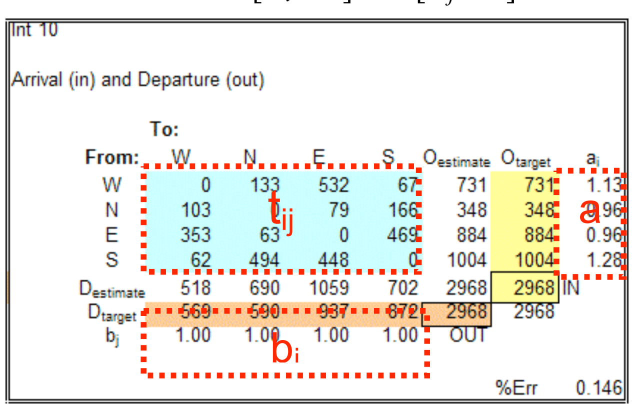

Figure 5: Illustration of Turn Tij, ai and bj factors

In this equation, a_i and b_j are adjustment factors which are iteratively updated during the process of achieving targeted values of O_i and D_j. First, assume initial values for b_j and solve for a_i, which can be used to get an improved b_j. For next iteration, use previous iteration values of a_i and solve for improved b_j which in turns give an improved a_i. This way, the iteration continues until both sets of values converge to their limits. Usually the sum of percent of errors is considered as the convergence parameter and 0.001 is considered as its limit. Figure 6 shows the schematics of the doubly constrained or bi-proportional iteration method. Figure 7 clearly illustrates the equations and spreadsheet templates for the calculation.

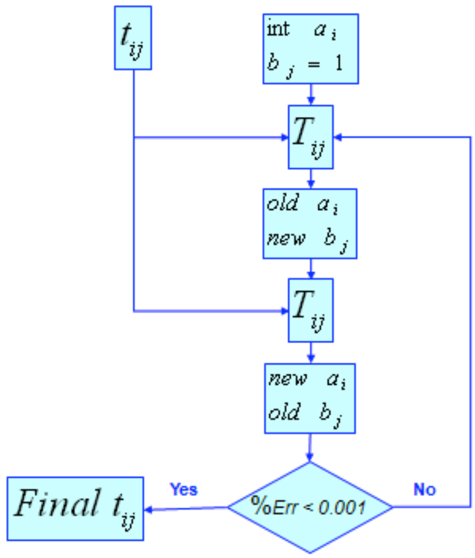

Figure 6: Schematics of the doubly constrained iteration method

m[th] Iteration: Row wise

$$a_i^m = \frac{O_{\text{target},j} * a_i^{m-1}}{O_{estimate\ j}}$$

$$b_j^m = b_j^{m-1}$$

$$\%Error_i = \sum_i \frac{\left|O_{estimate\ j} - O_{\text{target}\ j}\right|}{O_{\text{target}\ j}}$$

Int 10

Arrival (in) and Departure (out)

To:

From:	W	N	E	S	$O_{estimate}$	O_{target}	a_i
W	0	133	532	67	731	731	1.13
N	103	0	79	166	348	348	0.96
E	353	63	0	469	884	884	0.96
S	62	494	448	0	1004	1004	1.28
$D_{estimate}$	518	690	1059	702	2968	2968	IN
D_{target}	569	590	937	872	2968	2968	
b_j	1.00	1.00	1.00	1.00	OUT		

%Err 0.146

m[th] Iteration: Column wise

$$a_i^m = a_i^{m-1}$$

$$b_j^m = \frac{D_{target,j} * b_j^{m-1}}{D_{estimate\ j}}$$

$$\%Error_j = \sum_j \frac{\left|D_{estimate\ j} - D_{\text{target},j}\right|}{D_{\text{target},j}}$$

Int 10

Arrival (in) and Departure (out)

To:

From:	W	N	E	S	$O_{estimate}$	O_{target}	a_i
W	0	114	470	83	667	731	1.13
N	113	0	70	207	390	348	0.96
E	388	54	0	582	1024	884	0.96
S	68	423	396	0	887	1004	1.28
$D_{estimate}$	569	590	937	872	2968	2968	IN
D_{target}	569	590	937	872	2968	2968	
b_j	1.10	0.86	0.88	1.24	OUT		

%Err 0.1202

Figure 7: Equations for calcuate a_i,b_j and *%error*

Statistical Comparisons of Methods

By applying the SA/IB balancing technique with spreadsheet automation, engineers can run the network intersection volume balancing and derive the balanced link flows and intersection volumes very quickly. How good are the SA/IB balanced volumes, especially when they are compared with the VISUM T-Flow Fuzzy balanced volumes?

To make comparison, both the proposed SA/IB balancing technique and the T-Flow Fuzzy technique in VISUM are applied on the practical examples to balance the network wide volumes. Results are statistically analyzed. Figure 8 and Figure 9 show the regression analysis plots of both balancing methods for the two practical examples. Through visual comparison, it is easy to see that the SA/IB balancing technique shows stronger correlations between the balanced volumes and unbalanced volumes in both examples.

The statistical tests are conducted and presented in Table 1 for the two balancing techniques for both practical examples. By statistical comparison based on R-square, Root-Mean-Square-of-Errors (RMSE), Slope, and Mean Relative Error%, it is found that SA/IB technique shows better results. SA/IB technique has stronger R-Square, lower RMSE, better correlation Slope and less % of Relative Errors between balanced and unbalanced volume.

However, the statistical difference is very nominal between the techniques. Issue that is most concern is the total network volume loss. In Example 1, network total volume loss of -1358 or -3% and -1114 or -2.5% volume loss in Example 2.
The volume loss may be due to the intra-zonal trips assigned in the VISUM demand model and is a serious concern for modelers in evaluating traffic simulation results because it does not represent the worst case scenario.

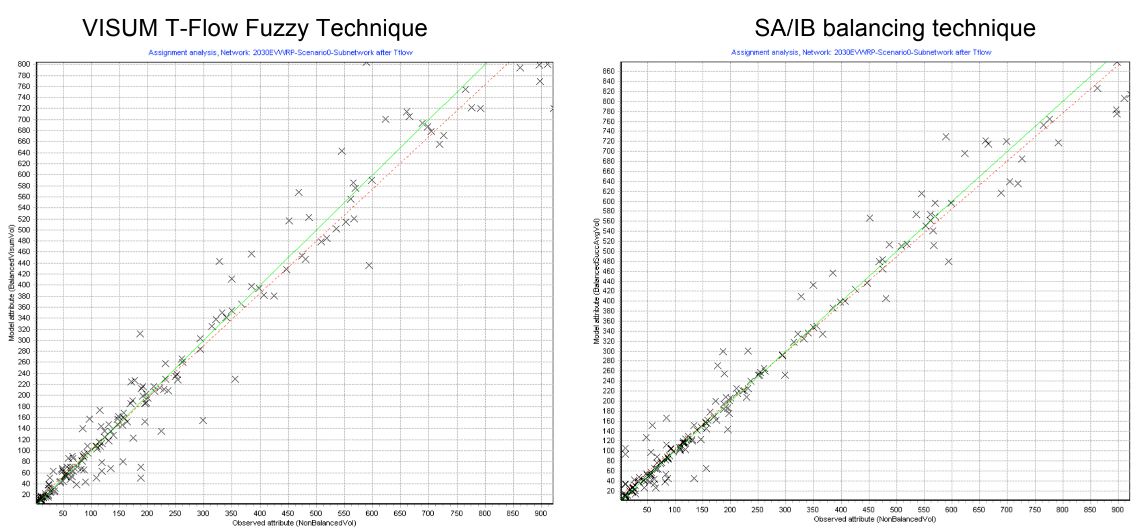

Figure 8: Example 1 Regression Scatter Plots between T-Flow Fuzzy and SA/IB

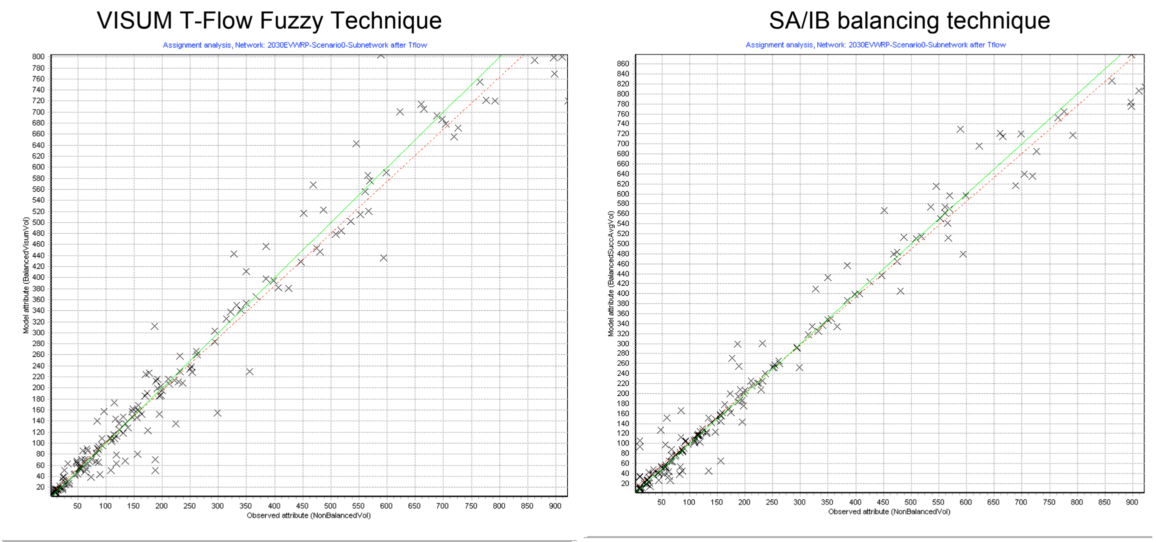

Figure 9: Example 2 Regression Scatter Plots between T-Flow Fuzzy and SA/IB

Table 1: Statistical results of Two Practical Examples by SA/IB and T-Flow Fuzzy

Tests	R^2	RMSE	Slope	Mean Rel Err%	Volume delta
T-Flow Fuzzy Ex 1	0.96	20	0.95	12	-1358 (-3.0%)
SA/IB Ex 1	0.97	17	0.96	10	4
T-Flow Fuzzy Ex 2	0.97	21	1.00	12	-1114 (-2.5%)
SA/IB Ex 2	0.99	12	0.98	7	0

Conclusion

An innovative SA/IB or SM/IB mathematical balancing technique is presented. The balanced volumes have excellent goodness of fit to the original unbalanced volumes. It's a balancing technique that can be easily automated and effectively implemented in Excel spreadsheets, and thus can save time for traffic simulation process. In the future, capacity constraint criteria will be incorporated in the balancing technique, and traffic temporal conditions can be implemented as well to reflect the dynamic traffic flows with balanced intersection volumes for more realistic and robust traffic simulation.

Acknowledgment

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References

[1] "*Advanced CORSIM Training Manual*", Minnesota Department of Transportation, January 31, 2008, http://www.dot.state.mn.us/trafficeng/modeling/corsim/final%20 corsim%20manual %209-19-09.pdf

[2] Jin Ren and David Tallent, *"Post-processing Future Intersection Turning Volumes from Traffic Counts and Planning Models,"* 2008, published on the "Proceedings of the Sixth International Conference on Traffic and Transportation Studies" by the American Society of Civil Engineering (ASCE).

[3] Mekky, A., "*Forecasting Balanced Highway Volumes Using Modeling Packages And Spreadsheets"***,** Transportation Research Board, 1996.

[4] Martin, P.T., & Bell, M.C. *"Network Programming to Derive Turning Movements from Link Flows."*, Transportation Research Record, 1992 No. 1365: 147-154.

[5] Bacharach, M., *"Bi-proportional Matrices and Input-Output Change,"* Cambridge University Press, 1970.