CALIBRATION OF TRANSYT TRAFFIC DISPERSION MODEL: ISSUES AND PROPOSED SOLUTIONS

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ABSTRACT

The paper demonstrates some inherent limitations of the TRANSYT software with regards to the calibration of the recurrence platoon dispersion model and more specifically, the modification of the travel time factor. Subsequently, the paper develops a procedure that overcomes this limitation by adjusting the average travel time in the model in order to control the value of travel time factor indirectly. Furthermore, the paper presents numerical examples in order to provide a preliminary investigation of different calibration procedures of the recurrence relationship. Although the dataset used for this purpose was generated using the INTEGRATION microscopic traffic-simulation software the procedures are general and intended for use with field data. The calibration procedure that is developed in this paper is demonstrated to produce the best results in terms of simplicity and accuracy.

INTRODUCTION

Interdependence of the neighboring signals in a traffic signalized network and proper coordination of these signals has been the subject of many studies. The interest in the subject arises from the fact that traffic signals are the most influential traffic control devices in urban and arterial networks. A well-designed traffic signal system ensures adequate traffic flow through the network, while an inefficient traffic signal system produces excessive delay, frustration, and wasted fuel.

Among the different signal coordination methods, the Road Research Laboratory (RRL) *Combination Method* (*1*) is the most widely used traffic signal coordination procedure. The combinational technique is a computer-based method that computes the set of optimum traffic signal offsets that minimizes the total delay within a network. The method utilizes the departure flow profile at each intersection to estimate the arrival platoon at the downstream signalized intersection. In modeling the movement of platoons along roadways, platoon dispersion models attempt to capture the dispersion of a platoon as it travels downstream. These models estimate vehicle arrivals at downstream locations based on an upstream vehicle departure profile and an average traffic-stream space-mean speed.

The most widely used platoon dispersion model is Robertson's (*2*) platoon dispersion model. This model has become a virtual universal standard platoon dispersion model and has been implemented in various traffic-simulation software, including TRANSYT (*2*), SCOOT (*3*), SATURN (*4*), and TRAFLO (*5*). A successful application of Robertson's platoon dispersion model requires an appropriate calibration of the model's parameters, which include the platoon dispersion factor (α) and the travel time factor (β). Specifically, Guebert and Sparks (*6*) showed that the accurate calibration of the Robertson platoon dispersion model parameters was critical in developing effective and efficient traffic signal timing plans. Despite the significant impact that platoon dispersion parameters have on the effective modeling of traffic dispersion and their subsequent impact on the selected optimum signal timings, the software's structure only allows the modeler to modify one of the two parameters that characterize traffic dispersion, namely the platoon dispersion factor. Alternatively, the software assumes that the travel time factor is fixed at 0.8.

The objectives of this paper are three-fold. First, the paper demonstrates the limitations of the TRANSYT software with regards to calibrating the platoon dispersion model. Second, the paper proposes a methodology that enables the users to calibrate the TRANSYT dispersion model effectively by providing an approach for controlling the travel time factor indirectly using the basic properties of Robertson's recurrence relationship. Third, the paper compares different calibration procedures and demonstrates the effectiveness of these calibration procedures using some example applications.

TRANSYT TRAFFIC DISPERSION MODEL

This section describes the state-of-practice TRANSYT platoon dispersion model. The calibration procedures and enhancements of the Robertson's platoon dispersion model are also described.

Robertson's Recursive Formulation

Robertson (*2*) developed an empirical recursive relationship to describe the dispersion of traffic, which forms the core of the popular TRANSYT software, commonly known as TRANSYT-7F in North America. Because of the simplicity of applying the recursive formulation, Robertson's model has become the standard platoon dispersion model and has been incorporated in a number of softwares.

The basic Robertson's recursive platoon dispersion model takes the following mathematical form:

$$q'_t = F.q_{t-T} + (1-F).q'_{t-\Delta t} \qquad [1]$$

$$F = \frac{1}{1+\alpha.\beta.T_a} \qquad [2]$$

Where:
q_{t-T} : discharging flow over a time step Δt observed at the upstream signal at time $t-T$;
q'_t : flow rate over a time step Δt arriving at the downstream signal at time t;
Δt : modeling time step duration, measured in units of time steps;
T_a : mean roadway travel time, measured in units of time steps;
T : minimum travel time on the roadway, measured in units of time steps ($T=\beta.T_a$);
α : platoon dispersion factor (unitless);
β : travel time factor (unitless); and
F : smoothing factor (time steps^{-1}).

Seddon (*7*) rewrote Equation 1 in the form

$$q'_t = \sum_{i=T}^{\infty} F.(1-F)^{i-T}.q_{t-i} \qquad [3]$$

Where:
i : the interval number for which an upstream flow is observed downstream. This integer variable ranges from T (minimum travel time) to infinity;
q_{t-i} : discharging flow over a time step Δt observed at the upstream signal at time $t-i$;
q'_t : flow rate over a time step Δt arriving at the downstream signal at time t;

Equation 3 demonstrates that the downstream traffic flow that is computed using the Robertson platoon dispersion model follows a shifted geometric series. The geometric series estimates the contribution on an upstream flow in the $(t-i)^{th}$ interval to the downstream flow in the t^{th} interval. Robertson (*2*) assumed the travel-time factor (β) to be fixed at a value of 0.8, and it has since been fixed at 0.8 in the TRANSYT software, while the platoon dispersion factor (α) was allowed to vary between 0.2 and 0.5, depending on the level of friction along the roadway. The TRANSYT-7F User's Guide (*8*) recommends that the platoon dispersion factor α vary depending on the site specific geometric and traffic conditions and provides three recommended values for three roadway conditions, namely low friction[1], moderate friction[2], and high friction[3]. The typical procedure for calibrating the platoon dispersion factor is to select the platoon dispersion factor that minimizes the sum-of-squared error between field-observed and estimated downstream flow profiles for a given upstream flow profile.

Calibration of TRANSYT's Dispersion model

Since the development of the Robertson platoon dispersion model, a number of studies have been conducted to evaluate the model parameters. Most of these studies used a best fit approach to find the appropriate values of α and β as summarized by McCoy *et al.* (*9*). These studies also demonstrated that the use of the TRANSYT-7F default platoon dispersion parameters results in significant errors in the modeling of platoon movement along roadways and thus results in inefficient traffic signal timings; however, these studies did recommend an alternative calibration procedure.

Yu and Van Aerde (*10-12*) not only demonstrated that the travel-time factor β is dependent on the platoon dispersion factor α but also developed a method for calibrating the Robertson platoon dispersion factors (α and β) directly from the statistical properties of the travel-time experiences of individual vehicles. Specifically, the authors used the basic properties of the geometric distribution of Equation 3 to derive the values of the travel time factor and platoon dispersion factor from the expected (T_a) roadway travel time and the travel-time variance (σ^2).

Rakha and Farzaneh (*13*) showed that because Yu and Van Aerde (*10-12*) considered travel times in units of seconds in the derivation of their calibration procedure, the procedure is only valid when a 1-second time step is considered. Consequently, the cyclic flow profile prediction error increases as the duration of the modeling time step increases. Rakha and Farzaneh (*13*) also provided three enhanced formulations to overcome the shortcomings of Yu and Van Aerde's calibration procedure. In this study, we use the third method since it is the simple and provides adequate accuracy. The following three equations show Rakha and Farzaneh's (*13*) third formulation:

$$\beta_n = \frac{1}{1+\alpha_n} \text{ or } \alpha_n = \frac{1-\beta_n}{\beta_n} \quad [4]$$

$$\beta_n = \frac{2T_a + n - \sqrt{n^2 + 4.\sigma^2}}{2.T_a} \quad [5]$$

$$F_n = n.\frac{\sqrt{n^2 + 4.\sigma^2} - n}{2.\sigma^2} \quad [6]$$

Where:

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[1] No parking, divided, turning provision, 12-ft lane width; suburban high-type arterial.

[2] Light-turning traffic, light-pedestrian traffic, 11 to 12 ft lanes, possibly divided; typical of well-designed CBD arterial.

[3] Combination of parking, moderate to heavy turns, moderate to heavy pedestrian traffic, narrow lane width, traffic flow typical of CBD.

β_n, F_n and α_n : model parameters for step size of n seconds,
σ : standard deviation of link travel times (s), and
T_a : mean roadway travel time (s).

Equations 4, 5, and 6 demonstrate that the values of α, β, and F are dependent on the size of the time interval.

PROBLEM DESCRIPTION

As was mentioned earlier, the successful application of Robertson's platoon dispersion model relies on the appropriate calibration of the model parameters. However, all versions of the TRANSYT software only allow for the calibration of the platoon dispersion factor and do not allow for the calibration of the travel time factor. A number of studies have attempted to quantify the impact of the platoon dispersion model parameters on the optimized signal timings. These studies have produced differing and in some instances contradicting results.

For example, McCoy *et al*. (*9*) studied two cases in the United States and found that the optimum values for α and β were different from the values provided in the TRANSYT manual. Consequently, the authors concluded that the software should be modified to enable users to specify both the α and β parameters. Similarly, Guebert and Sparks (*6*) conducted a parametric sensitivity analysis to study the effect of the calibrated platoon dispersion factors on the final optimized signal timing plan. The authors showed that the accurate calibration of the Robertson platoon dispersion model parameters is critical in developing effective and efficient traffic signal timing plans. Alternatively, Retzko and Schenk (*14*) used the TRANSYT-8 (*15*) to study the effect of the deviation of the correct value of α on the resulting optimized signal timings for three networks. The authors found that despite the changes in the platoon dispersion factor α, the optimized signal timings were not significantly affected. Consequently, the authors suggested that the use of a unique value of α provides sufficient accuracy. Contrary to the previous studies, Manar (*16*) examined the effect of the use of inappropriate platoon dispersion parameters using the TRANSYT-7F software for a road section composed of three intersections in Montreal, Canada. Manar found that the use of the recommended platoon dispersion factor of 0.25 incurred 65,250 CND per year in additional user costs as a result of the resulting inefficient signal timings.

Consequently, as part of this study, an attempt was made to quantify the effect of the recursive platoon dispersion model parameter values on the traffic performance at traffic signals by conducting a sensitivity analysis using data generated by the INTEGRATION software (*17*). The INTEGRATION model represents the movement of individual vehicles at a 1 hertz resolution, based on a steady-state car-following relationship for each link and driver/vehicle specific acceleration and deceleration constraints. A detailed description of the model calibration procedures is beyond the scope of this paper but is described in detail in the literature (*18-19*). In terms of platoon dispersion behavior, Rakha and Farzaneh (*13*) showed that INTEGRATION's traffic dispersion modeling is consistent with the field observed data demonstrating the validity of the software for modeling traffic dispersion.

The configuration that is used in this study consists of a three-lane arterial of 1-km length with a pre-timed traffic signal on the entrance link. Vehicles departing from the upstream traffic signal were monitored as they traveled downstream along the roadway. Specifically, six loop detectors were placed on the roadway. The first loop detector was located immediately upstream of the signalized intersection, while the other five detectors were located downstream of the signalized intersection at a spacing of 200 meters. The loop detectors gathered data at 3-second intervals. Figure 1 depicts the network layout, while Table 1 summarizes the roadway and network characteristics of the three cases that were simulated.

For each case, the simulation run continued for 1200 seconds and consisted of seventeen distinct platoons of vehicles that departed from the upstream traffic signal. All the vehicles were passenger cars. Travel-time variability was captured through the use of a normally distributed function about the steady-state car-following model. The user has control over the level of randomness by specifying a Coefficient of Variation (CV) for the desired level of randomness. All simulated vehicles were set as probes to record their individual travel times in computing the travel time mean and variance for the calibration of the α_n and β_n parameters using Equations 4 through 6. All the required procedures (data retrieving, platoon dispersion modeling, optimal offset search, and delay calculation) were implemented within MATLAB 6.0.

The value of the platoon dispersion factor α_n was varied between 0.25 and 0.50 at increments of 0.05. Similarly, the travel time factor β_n was varied between 0.70 and 0.95 at increments of 0.05. Using Equations 1 and 2, the traffic flow profile at each downstream check point was calculated for each pair of α_n and β_n combination. To study the effect of the analysis step size on the results, three step sizes were selected for the prediction phase: 1, 3, and 6 seconds. It must be noted that these step sizes were only used for flow prediction purposes, while the delay estimation was conducted using a step size of 1 second.

In computing the optimum offset, all downstream virtual signals[4] were assumed to operate at a common cycle length and the signal timing plan of the upstream traffic signal. The optimum offset for each virtual downstream traffic signal was computed using the projected downstream flow profile using a simple hill-climbing search algorithm. The search algorithm minimized a performance index (PI) function, which was a weighted combination of vehicle delay and stops, as follows:

$$d_i^t = d_i + KC_i \qquad [7]$$

Where
d_i^t : the total delay for i-th intersection (veh-s/lane),
d_i : the average delay for i-th intersection (veh-s/lane),
C : the number of vehicles stopped behind i-th intersection, and
K : stop penalty factor (s/stop), normally 4 (s/stop).

A 4-second/stop equivalency was selected in order to be consistent with the TRANSYT-7F manual. The optimum offset for each α_n and β_n combination was then applied to the arrival flow profile to compute the total delay and number of vehicle stops using deterministic queuing theory. Since the final results are qualitatively the same for all investigated cases, only the results for the first case are presented in Figures 2 through 7.

Figures 2, 4, and 6 demonstrate the variation in the PI associated with different values of the travel time factor β_n for step sizes of 1, 3, and 6 seconds, respectively. Alternatively, Figures 3, 5, and 7 illustrate the variation in the PI as a function of the platoon dispersion factor α_n. A comparison of the two sets of figures clearly demonstrates that the variation in the PI is significantly higher in the case of β_n than for α_n values. Furthermore, the effect of

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[4] Virtual signals are considered at different locations for delay and offset calculation purposes.

β_n increases as the distance of travel increases (600, 800, and 1000 m), while α_n has a minimum impact on the PI. Alternatively, as the travel distance decreases the impact of α_n on the PI increases while the impact of β_n on the PI decreases; however, the impact of β_n remains higher for most cases. This phenomenon is attributed to the fact that for shorter distances the dispersion is minimal and vehicle platoons typically remain intact; therefore, with a sub-optimal offset most of the vehicles can discharge during the green phase. On the other hand, as vehicles travel farther downstream, vehicle platoons disperse significantly and thus the start time of the green phase becomes critical.

Furthermore, a comparison of the results was conducted for different temporal step sizes including step sizes of 1, 3, and 6 seconds. The results demonstrate that the PI is more sensitive to the variation in α_n and β_n values than to the modeling step size; however, the overall trends appear to be similar. In our case, since the original data were collected at 3-second intervals and then disaggregated to 1-second data, the difference between the results for 1-second and 3-second time step sizes is not significant; however, the results for a 6-second step size shows more variation in comparison to the 1 and 3 second step sizes. Overall, the results indicate that the PI is more sensitive to β_n than α_n.

In conclusion, the findings of this sensitivity analysis can be summarized as follows:

1- Proper calibration of the recursive platoon dispersion model is important to achieve and maintain a good signal timing plan.

2- The PI is more sensitive to the value of the travel time factor β_n than the platoon dispersion factor α_n and thus the calibration of β_n is more critical than the calibration of α_n.

3- The importance of calibrating β_n is more significant for larger signal spacing distances.

4- Using a unique value of α_n provides a reasonable accuracy as was suggested by Retzko and Schenk (*14*).

Considering these conclusions and recognizing that the current versions of the TRANSYT software do not allow the user to vary the travel time factor β_n from its set value of 0.8, it becomes a challenge to calibrate the TRANSYT software. Although a number of researchers (*9 & 16*) have suggested that the TRANSYT software should be revised to allow users to control the value of the travel time factor, these recommendations have not been addressed. Consequently, we are offering a solution that does not require modifications to the code, as is described in the following section.

PROPOSED SOLUTION

The problem with calibration of the TRANSYT software arises from the fact that the software uses a fixed value for the travel time factor and only provides the user with control over the platoon dispersion factor which was demonstrated earlier in the paper to have a smaller impact on estimating the optimum signal timing plan.

The first step in addressing this problem is to analyze Robertson's formulation and its elements. The objective is to maintain the level of prediction error as produced by the optimum α and β parameters. Equation 3 demonstrates that the model has two main factors, namely the minimum travel time ($T=\beta.T_a$) and the smoothing factor F which is equal to $1/(1+\alpha.\beta.T_a)$ (Equation 2). Consequently, based on Equation 3, if the values of T and F are held constant, the model will produce identical dispersion behavior.

Assume that for a certain link α' and β' are the optimum dispersion and travel time factors that result in a good timing plan and that α and β are the corresponding TRANSYT input parameters. The α' and β' parameters can be calibrated using the Rakha and Farzaneh (*13*) calibration procedure (Equations 4 through 6) or through the use of a best fit approach. Recognizing that the TRANSYT travel time parameter is equal to 0.8 and utilizing Equations 2 and 3 with α' and β', we predict the *correct*[5] downstream flow profile. In order to produce identical downstream profiles using TRANSYT's parameters (α and β), the following equalities must be satisfied;

$$\beta.T_a = 0.8T_a = \beta'.T'_a \qquad [8]$$

$$\alpha.\beta.T_a = 0.8\alpha.T_a = \alpha'.\beta'.T'_a \qquad [9]$$

Where
T_a : user coded average travel time in TRANSYT (s), and
T'_a : observed average travel time (s).

If we ensure that $\alpha = \alpha'$ then maintaining $0.8T_a$ to equal $\beta'.T'_a$ the model provides an estimate of the average travel time that is coded in the TRANSYT software in order to produce an identical downstream profile as produced by the α' and β' parameters. The value of the average travel time T_a can be calculated as follows

$$T_a = \frac{\beta'.T'_a}{0.8} = 1.25\beta' T'_a. \qquad [10]$$

Equation 10 demonstrates that by altering the average travel time that is input into the TRANSYT software, the model users can indirectly control the value of travel time factor. It should be noted that the link specific platoon dispersion factor can be modified using the link specific platoon dispersion card, as described in the TRANSYT-7F manual (*8*).

A legitimate concern about the use of Equation 10 may be that by altering the average link travel time the results of the software may be adversely affected. In addressing this concern it should be noted that Equation 10 guarantees that the TRANSYT software produces the desired downstream flow profile. Consequently, the vehicle delay and stop estimates would be correct given that all computations are based on the arrival cyclic profile. However, it should be noted that by applying Equation 10 the total travel time estimates would be altered since TRANSYT uses the user-defined average link travel time to estimate the total network travel time. Consequently, this parameter should be used with caution.

NUMERICAL EXAMPLE OF CALIBRATION METHODS

This section attempts to provide a preliminary investigation of different calibration procedures. This effort serves two purposes: first, it explains different choices that users have to calibrate TRANSYT's platoon dispersion model and second, it provides a preliminary validity analysis for each of the methods.

The data used for this purpose is the dataset that was generated and used in the problem description section. Seven different calibration methods were considered and applied to the data, as summarized in Table 2. Five of the seven calibration approaches use the state-of-practice best-fit technique to calibrate the α and β parameters while the sixth

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[5] A predicted traffic-flow profile that gives a signal timing close enough to the optimum timing plan obtained from the observed traffic flow.

approach uses the Rakha and Farzaneh approach to calibrate the model parameters (Equation 4 through 6), and the final approach considers the TRANSYT-7F default parameters. The average travel time for the Rakha and Farzaneh formulation was estimated based on simulated probe travel time experiences generated by the INTEGRATION software. Alternatively, the average travel time for the remainder scenarios was calculated as the distance between the centers of gravity of the area under the upstream and downstream flow profiles, as is commonly done in practice.

The vehicle delay and stop estimates were made using deterministic queuing theory. As was the case earlier, three time-step sizes were considered, namely 1, 3, and 6 seconds. These time steps were used to predict the downstream flow profile in searching for the optimum platoon dispersion parameters using the best-fit technique. Two different flow profiles were used for the 1-second analysis. The first profile was generated by disaggregating the 3-second flow profile and the second profile was generated by disaggregating the 6-second flow profile. Furthermore, for the best-fit approaches, two methods were utilized to estimate the optimum platoon dispersion parameters. The first method minimized the error for all seventeen platoons simultaneously while the second approach minimized the error considering a single randomly selected cyclic profile.

Since the final results are similar for all three cases that were analyzed, only the results of the first case are illustrated in Figure 8. Figure 8 clearly demonstrates that none of the calibration methods guarantees that the derived calibrated parameters result in minimum delay[6] for all traffic and roadway instances. Furthermore, Table 3 demonstrates that methods that use a fixed value of the travel time parameter (β = 0.8) (methods M4, M5, and M7) tend to produce greater delay estimates on average compared to the other methods. Second, methods that use the best-fit approach (methods M1, M3, and M6) tend to produce the least delay estimates of all three methods. Finally, on average, the Rakha and Farzaneh calibration method (method M2) provided better timing plans than the fixed travel time parameter methods (β = 0.8).

In comparing different calibration methods two factors play key roles: the accuracy and efficiency of the method and the simplicity and applicability of the method to different roadway and traffic conditions. As described above, the best fit methods tend to yield better results in terms of precision and efficiency; however the use of such methods requires extensive data collection that deems them unpractical. In contrast, the formulation proposed by Rakha and Farzaneh (*13*) provides adequate precision and efficiency, and at the same time is easy to apply, which makes it the best candidate for practical use. The ease of application arises from the fact that it only requires tracking a sample of vehicles to estimate the travel time mean and variance.

Figure 8 also demonstrates that for most of the cases the resulting delay estimates are similar whether a single or multiple platoons are considered. These results are encouraging because it indicates that for most situations observation of a single platoon provides adequate accuracy. Furthermore, Figure 8 also illustrates that in general a 6-second step size results in the highest delay. This issue implies that better resolution (smaller step sizes) provides better efficiency in terms of delay.

The literatures suggest that calibrating the platoon dispersion parameters by minimizing the deviation between the estimated and observed downstream profiles would result in estimating the optimum signal-timing plan. In contrast, we found that approximately 30

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[6] This is the delay calculated by applying the offset derived from the predicted downstream flow profile.

percent of our investigated cases (217 out of 712 cases) did not result in the optimum signal timings. The reason of this finding is the fact that the vehicle travel time distribution is not necessarily a shifted geometric distribution as is assumed in the platoon dispersion model. In contrast, studies have shown that the distribution of vehicle travel times is more consistent with a normal, lognormal or a gamma distribution rather than a geometric distribution (*20-21*).

CONCLUSION

The paper demonstrates the importance of calibrating the recurrence platoon dispersion model. The paper clearly demonstrates that the value of the travel time factor β is critical in estimating appropriate signal-timing plans. Alternatively, the paper demonstrates that the value of the platoon dispersion factor α does not significantly affect the estimated downstream cyclic flow profile; therefore, a unique value of α provides the necessary precision. Unfortunately, the TRANSYT software allows the user to calibrate the platoon dispersion factor but does not allow the user to calibrate the travel time factor. In an attempt to address this shortcoming, the paper proposes a formulation (Equation 10) using the basic properties of the recurrence relationship to enable the user to control the travel time factor indirectly by altering the link average travel time.

Finally, the paper presents some numerical examples to demonstrate the effectiveness of different calibration methods of the recurrence platoon dispersion model. Although the dataset used for this purpose was generated using the INTEGRATION microscopic traffic-simulation software the procedures are general and intended for use with field data. It is anticipated that the implementation of the proposed formulations can enhance the accuracy of the traffic dispersion model within the TRANSYT software and thus produce better signal timings.

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Table 1: Characteristics of simulated roadways

Link Characteristic	**Case 1**	**Case 2**	**Case 3**
Roadway length (m)	1000	1000	1000
Free-flow speed (km/h)	50	60	40
Speed-at-capacity (km/h)	35	45	32
Capacity (veh/h/lane)	1800	1800	1800
Jam density (veh/km/lane)	100	100	100
Number of lanes	3	3	3
Number of loop detectors	6	6	6
Speed coefficient of variation (percent)	15	20	20
Entering headway distribution (% Random)	100	100	100
Total Simulation Time (s)	1200	1200	1200
Cycle Length (s)	60	60	60
Effective Green Time (s)	35	35	35

Table 2: Definition of different calibration Methods for TRANSYT's platoon dispersion model

Method	**Definition**
M1	Best fit, varying average travel time and standard deviation of travel times, separately for each downstream intersection
M2	Rakha and Farzaneh method, separately for each downstream intersection
M3	Best fit, varying α and β, separately for each downstream intersection
M4	Best fit, considering $\beta = 0.8$ and varying α separately for each downstream intersection
M5	TRANSYT's default values, $\alpha = 0.35$ and $\beta = 0.8$
M6	Best fit, varying α and β, for all downstream intersections collectively
M7	Best fit, considering $\beta = 0.8$ and varying α, all downstream intersections collectively

Table 3: Results of the preliminary analysis of calibration methods

Factor	**Method**						
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**
Percent sample with least extra delay	45.0	30.0	30.8	27.5	20.8	35.8	22.5
Percent sample with largest extra delay	13.3	24.2	15.8	26.7	31.7	30.8	31.7
Maximum extra delay (percent)	17.3	74.9	32.6	46.1	68.8	32.6	46.1
Minimum extra delay (percent)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

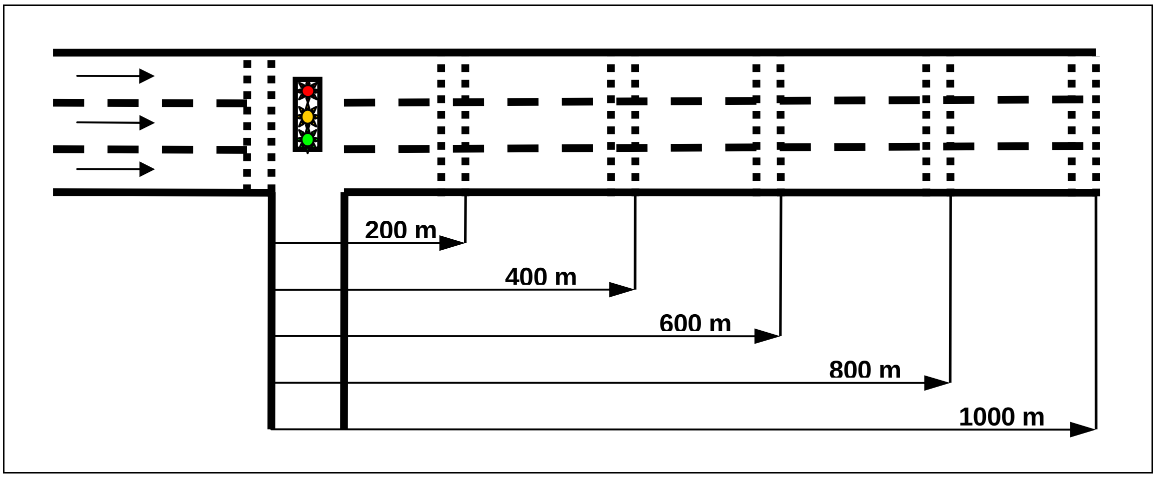


Figure 1: Simulated network configuration

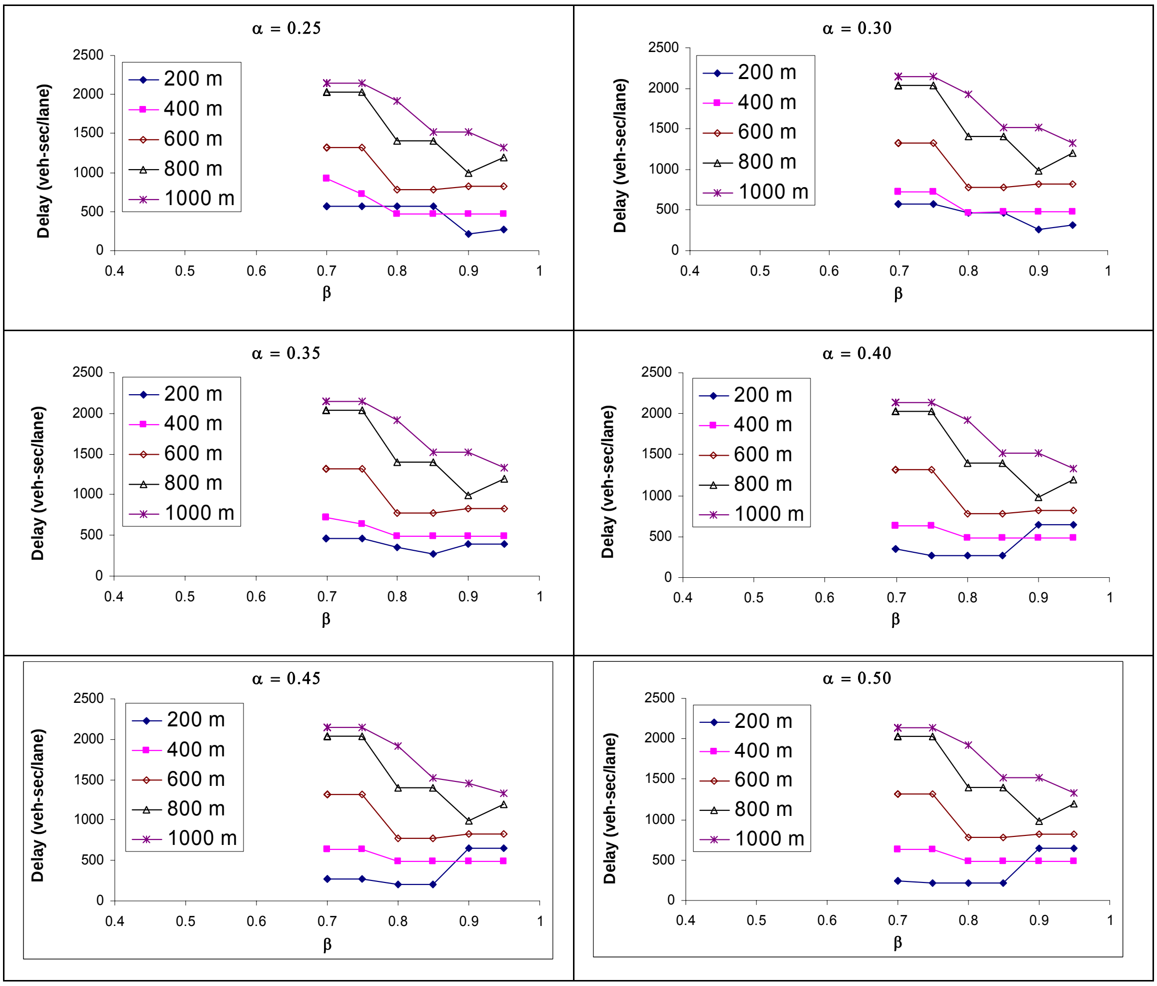


Figure 2: Variation of total delay as function of travel time factor using 6-second step size (first case)

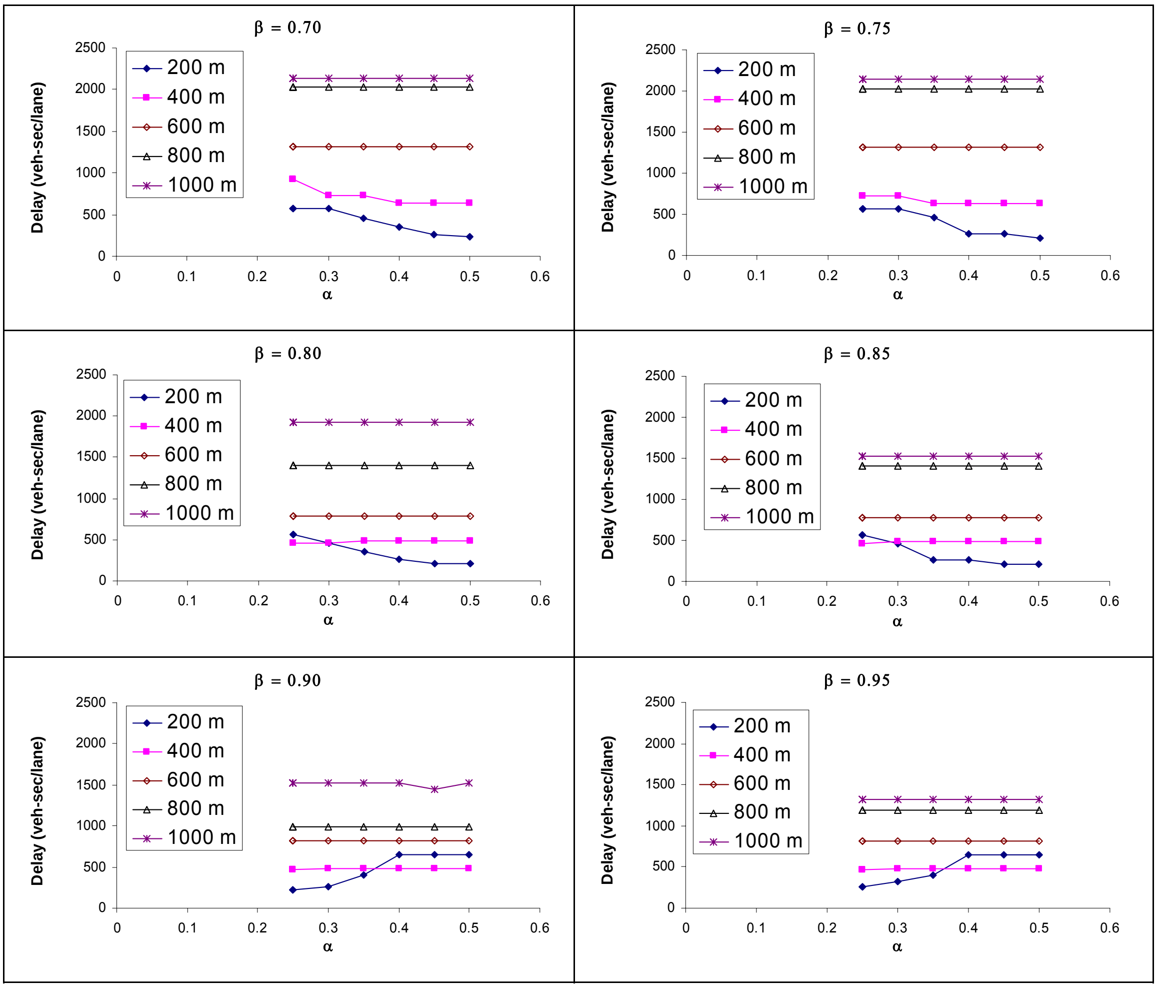


Figure 3: Variation of total delay as function of platoon dispersion factor using 6-second step size (first case)

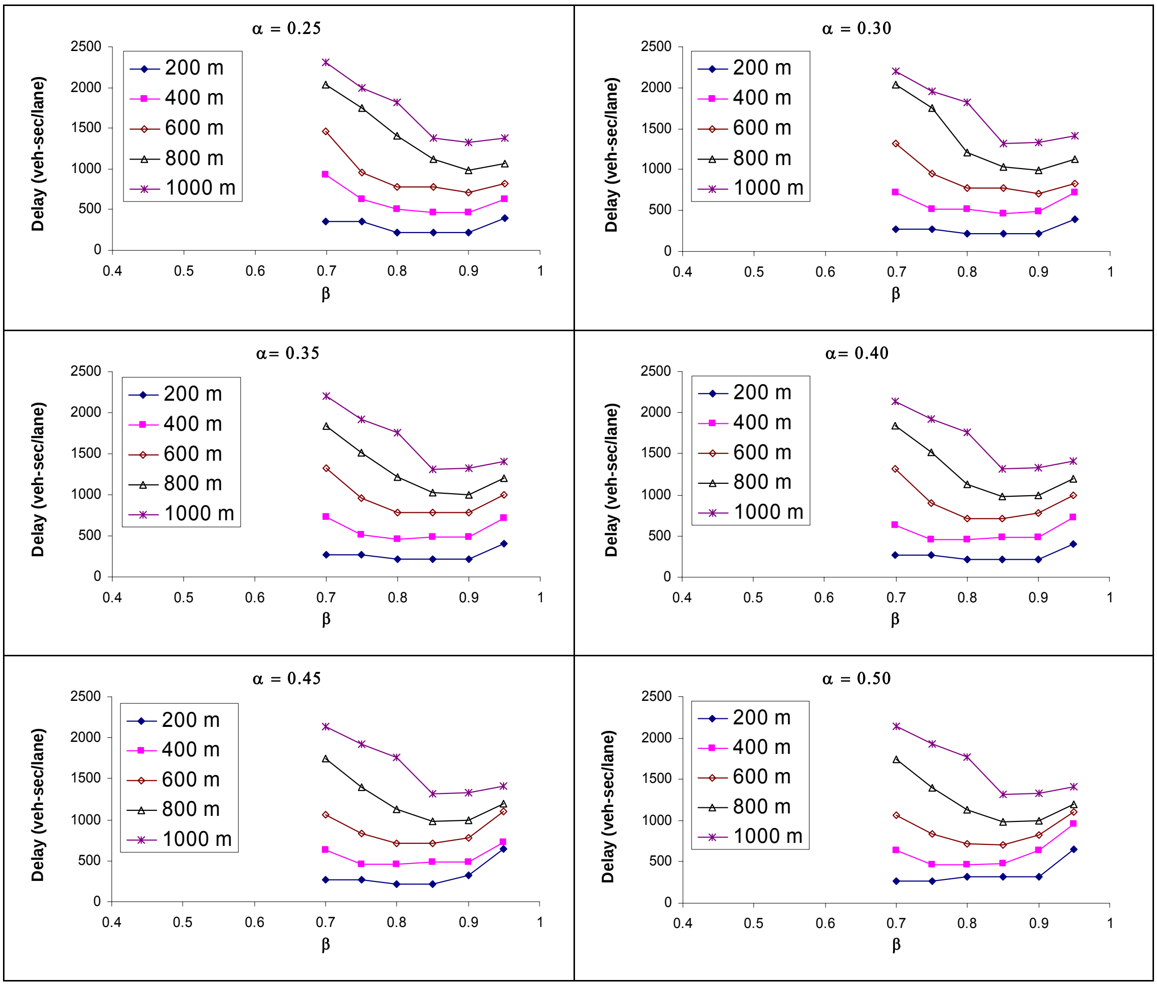


Figure 4: Variation of total delay as function of travel time factor using 3-second step size (first case)

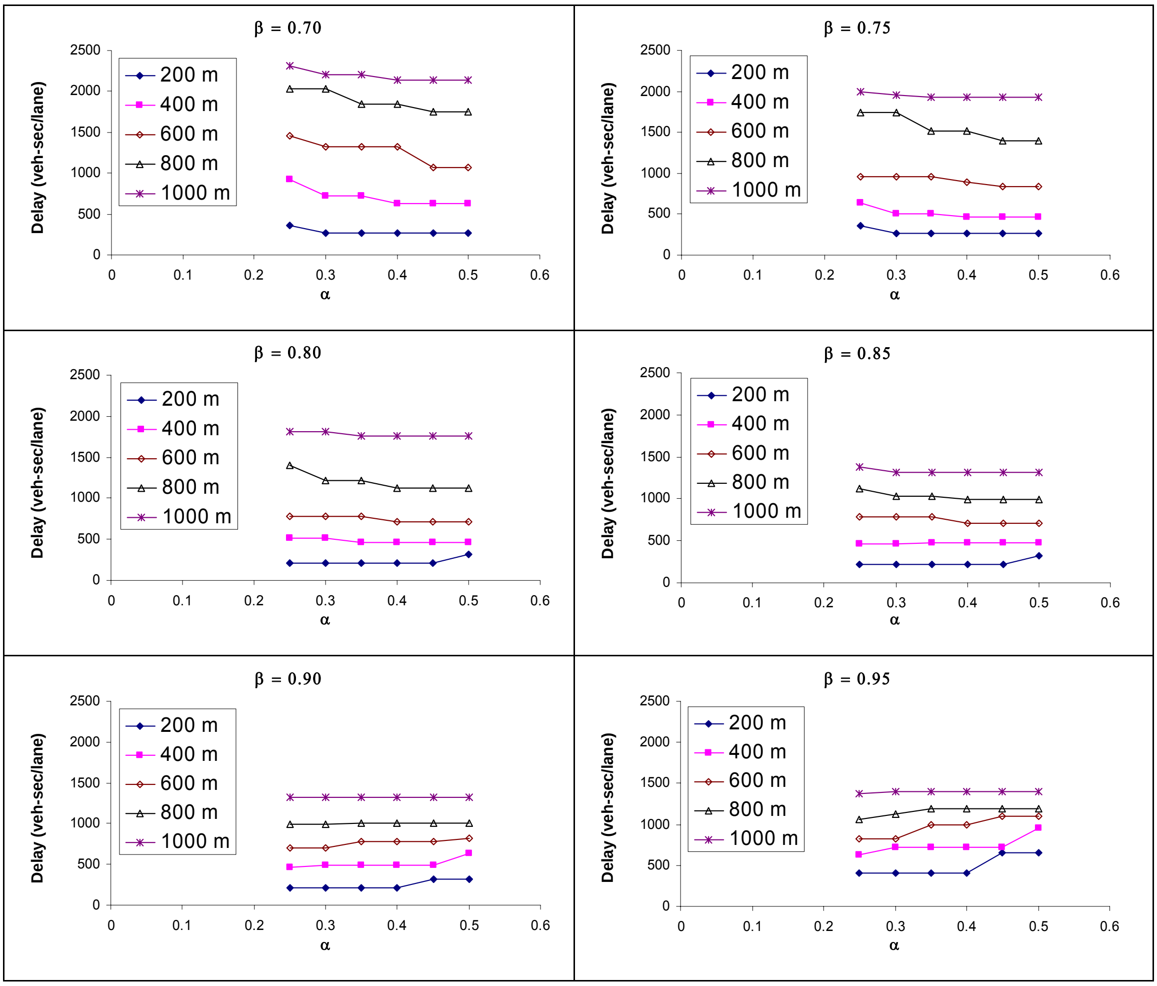


Figure 5: Variation of total delay as function of platoon dispersion factor using 3-second step size (first case)

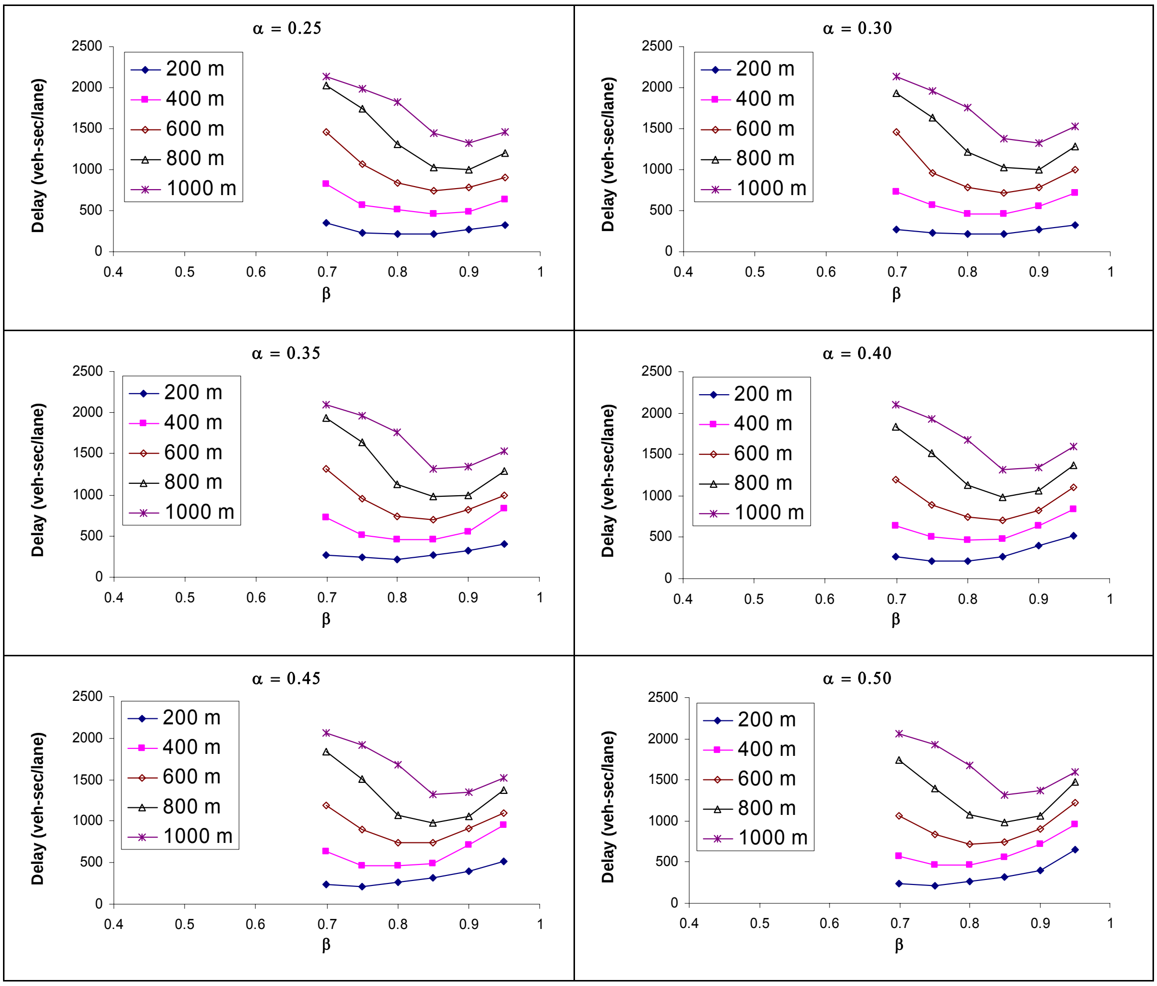


Figure 6: Variation of total delay as function of travel time factor using 1-second step size (first case)

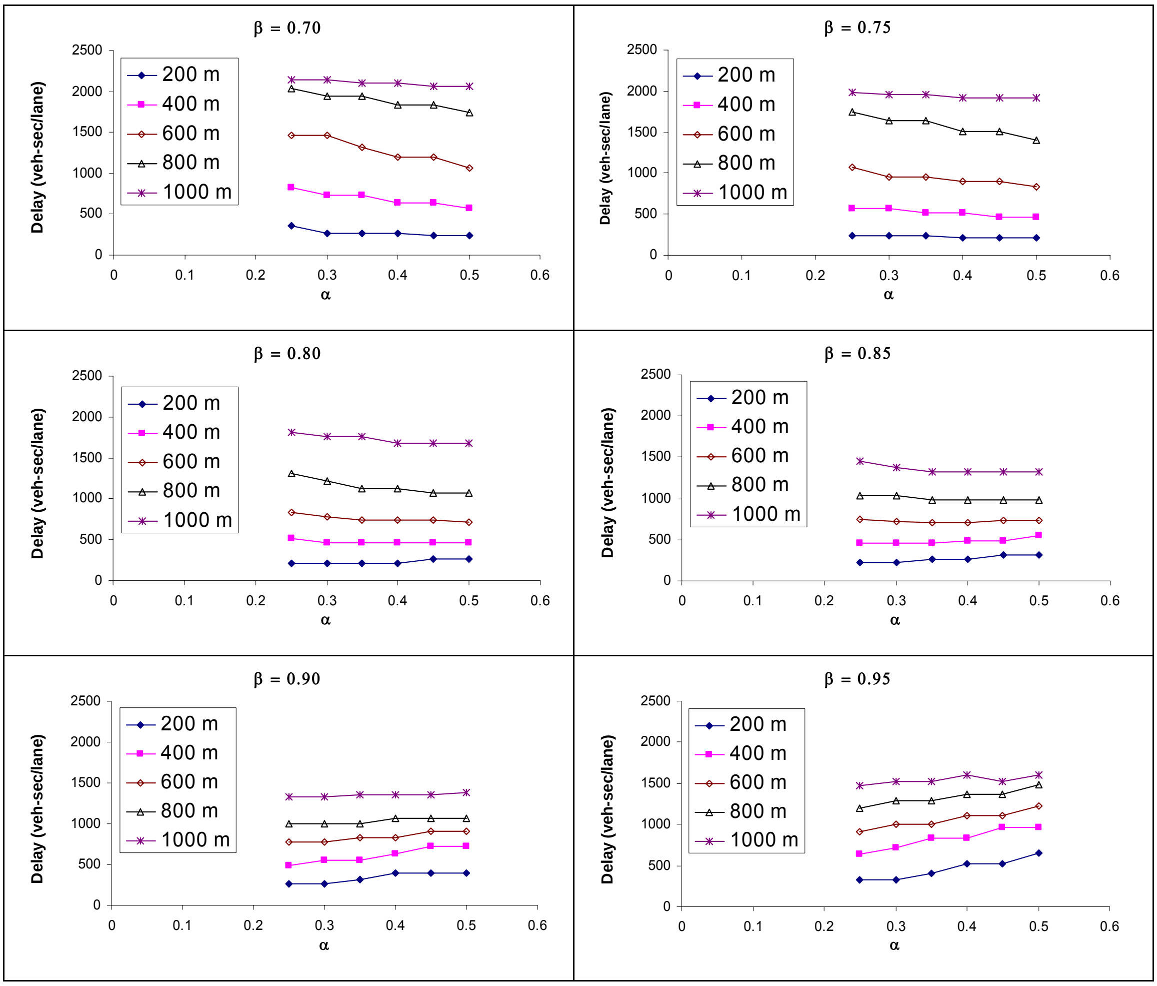
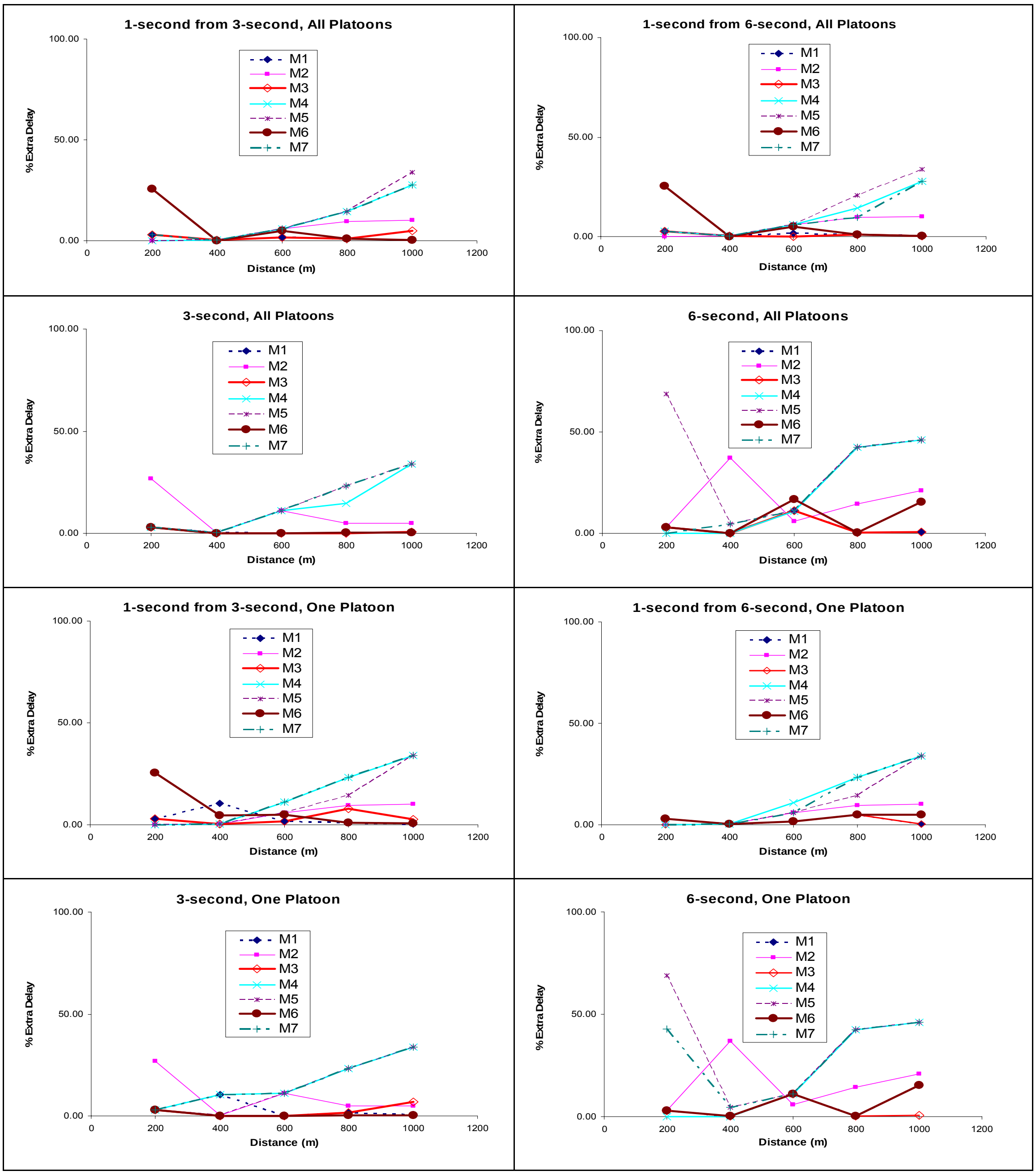


Figure 7: Variation of total delay as function of platoon dispersion factor using 1-second step size (first case)



1-second from 3-second, All Platoons

1-second from 6-second, All Platoons

3-second, All Platoons

6-second, All Platoons

1-second from 3-second, One Platoon

1-second from 6-second, One Platoon

3-second, One Platoon

6-second, One Platoon

Figure 8: Percent of extra delay caused by different calibration methods (first case)