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16. Abstract  <p>Vehicles form platoons at the exit point of a given traffic signal, which will disperse while they progress along the link towards the next downstream traffic signal. The platoons may disperse either more quickly or slowly depending on the actual road geometric and traffic conditions between the two adjacent intersections of interest. The adequate modeling and description of the platoon dispersion behavior ultimately affect the quality of the coordinated traffic signal timings. At present, the most widely used modeling method of platoon dispersion is the TRANSYT's macroscopic platoon dispersion model in which the determination of its major parameters is based on the empirical values. This report presents a methodology for calibrating the platoon dispersion parameters in the TRANSYT's platoon dispersion model, which is based on a statistical analysis of link travel time data rather than more traditional goodness-of-fit tests between the observed and the projected vehicles' progression patterns. Specifically, the platoon dispersion parameters are made explicit dependent variables of the average link travel time and the standard deviation of link travel times. The proposed technique is suited for applications in advanced traffic management systems (ATMS) networks where the required link travel time data could be obtained on a real-time basis. The calibration of platoon dispersion parameters using the proposed technique for the field collected data has shown that platoon dispersion parameters are indeed different, even on the same street but with different travel times. This conclusion confirms the need for calibrating platoon dispersion parameters on a link specific basis.</p>					
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**REAL-TIME CALIBRATION OF PLATOON DISPERSION  
MODEL TO OPTIMIZE THE COORDINATED TRAFFIC  
SIGNAL TIMING IN ATMS NETWORKS**

by

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Research Report SWUTC/99/472840-00044-1

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## ABSTRACT

Vehicles form platoons at the exit point of a given traffic signal, which will disperse while they progress along the link towards the next downstream traffic signal. The platoons may disperse either more quickly or slowly depending on the actual road geometric and traffic conditions between the two adjacent intersections of interest. The adequate modeling and description of the platoon dispersion behavior ultimately affect the quality of the coordinated traffic signal timings. At present, the most widely used modeling method of platoon dispersion is the TRANSYT's macroscopic platoon dispersion model in which the determination of its major parameters is based on the empirical values. This report presents a methodology for calibrating the platoon dispersion parameters in the TRANSYT's platoon dispersion model, which is based on a statistical analysis of link travel time data rather than more traditional goodness-of-fit tests between the observed and the projected vehicles' progression patterns. Specifically, the platoon dispersion parameters are made explicit dependent variables of the average link travel time and the standard deviation of link travel times. The proposed technique is suited for applications in advanced traffic management systems (ATMS) networks where the required link travel time data could be obtained on a real-time basis. The calibration of platoon dispersion parameters using the proposed technique for the field collected data has shown that platoon dispersion parameters are indeed different, even on the same street but with different travel times. This conclusion confirms the need of calibrating platoon dispersion parameters on a link specific basis.

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## EXECUTIVE SUMMARY

It has long been known that platoons, which form at the exit of a given traffic signal, do not remain intact or compact as they progress along an arterial link towards the next traffic signal. Platoons may disperse along the road either more quickly or slowly depending on the actual road geometric and traffic conditions between the two adjacent intersections of interest. In part, this dispersion of vehicle platoons occurs due to the differences in the desired speeds of the various drivers that make up the platoon. However, a large portion of the dispersion is also caused by the fact that some vehicles will experience delays while travelling along the link which are random in terms of both their occurrence and duration. The majority of these random delays along links occur when vehicles slow down for other vehicles, which are either turning off the road at a mid-block location, or attempting to enter or leave on-street parking.

The calculation of delays and stops of coordinated traffic signals by both off-line and on-line models such as the widely used TRANSYT (Robertson, 1969) and SCOOT (Hunt, et al., 1981) relies on the model's ability to accurately predict traffic flow patterns from one signal to another. The effectiveness of the coordinated signal timings depends on the accuracy of the calculated delays and stops and thus on platoon dispersion modeling. At present, one of the most commonly utilized macroscopic approaches to the modeling of the platoon dispersion process is the one developed by Robertson (1969), which was later incorporated into the TRANSYT. This approach has since also become a virtually universal standard throughout the world in other control or simulation models such as SCOOT, SATURN (Hall, et al., 1980), TRAFLO (Lieberman, et al., 1980), and INTEGRATION (Van Aerde and Yagar, 1990).

The platoon dispersion model in TRANSYT was based on the research work in U.K. by Hillier and Rothery (1967). The basic TRANSYT recursive platoon dispersion model takes the following mathematical format:

$$q_B(t+T) = Fq^A(t) + (1-F)q_B(t+T-1) \quad (E.1)$$

$$F = \frac{1}{1 + \alpha\beta t_a} \quad (E.2)$$

Where:

T is a lag time factor in seconds, which is found as  $\beta t_a$ ,

F is a smoothing factor,

$\beta$  is a dimensionless travel time factor,

$\alpha$  is a platoon dispersion factor in seconds<sup>-1</sup>, and

$t_a$  is the average travel time from the link's entry point to the tail of the queue at the link's downstream stop-line in seconds.

A successful application of the Robertson's platoon dispersion model to modeling platoon dispersion relies on the appropriate calibration of several model parameters. The empirical studies performed by the Transport and Road Research Laboratory (TRRL) in the United Kingdom suggested some default values for the platoon dispersion modeling. The work performed by PRC Engineering (Tarnoff and Parsonson, 1981) and the University of Florida (Lorick, et al., 1980) suggested a set of default values for the platoon dispersion parameters for the North American version of TRANSYT-7F. Although many research findings have indicated that the platoon dispersion parameters should be site-specific and a function of the road grades, curvature, parking, opposing flow interference, traffic volume and other sources of impedance, no methodology exists that can quantitatively calibrate the platoon dispersion parameters.

The continuing use of the default values for the platoon dispersion modeling may risk the implementation of virtually ineffective signal timing plans on roads. With the growing applications and development of the Advanced Traffic Management Systems (ATMS) throughout the world, more and more real-time control systems for coordinated traffic signals are expected to be deployed on various urban networks. Therefore, it becomes even more critical for traffic engineers to use the accurate modeling approach for determining the coordinated signal timing plans in order not to waste the resources for

investment and deployment of the advanced traffic control and management systems. The calibration of the platoon dispersion parameters is one of the central issues affecting the efficacy of the coordinated signal timings.

The objectives of this research are threefold. In the first instance, the research will examine in a great detail the underlying assumptions of the TRANSYT macroscopic platoon dispersion model. The examination will bring into question the common assumption that  $\beta$  equals 0.8 for all values of  $\alpha$ . In the second instance, the research will develop an alternate mathematical approach for calibrating the platoon dispersion parameters directly from the statistical properties of the travel time experiences of individual vehicles, which can be obtained on a real-time basis in ATMS applications. Finally, the research will collect link travel time data from selected roads and calibrate the platoon dispersion parameters using the proposed approach, thus establishing the context for using the proposed calibration approach to real world applications.

This report has made the following conclusions:

1. The original recursive TRANSYT platoon dispersion model can be expanded into the following format:

$$q_B(t) = \sum_{i=T}^{\infty} [F(1-F)^{i-T}] q^A(t-i) \quad (E.3)$$

The expression within the bracket of Equation (E.3) can be put into the following function:

$$P_r(X = i) = F(1-F)^{i-T} \quad (i = T, T+1, \dots) \quad (E.4)$$

Equation (E.4) can be considered as a probability function. If  $i$  is considered as the travel time between upstream end and downstream end of the link, Equation (E.4) takes the form of a shifted geometric distribution.

2. The analysis of the shifted geometric distribution of link travel times in Equation (E.4) results in calibration equations for three key platoon dispersion parameters  $F$ ,  $\alpha$ , and  $\beta$ .

$$\beta = \frac{1}{1 + \alpha} \quad (E.5)$$

$$\alpha = \frac{\sqrt{1 + 4\sigma^2} - 1}{2t_a + 1 - \sqrt{1 + 4\sigma^2}} \quad (E.6)$$

$$F = \frac{\sqrt{1 + 4\sigma^2} - 1}{2\sigma^2} \quad (E.7)$$

Equation (E.5) shows that the value of the travel time factor  $\beta$  should be made dependent on the value of the platoon dispersion factor  $\alpha$  in order to provide the consistency of link travel times into the geometric distributed platoon dispersion model and out of the same model, as opposed to the fixed value of 0.8, which is being used in TRANSYT at present. Equation (E.6) illustrates that the value of  $\alpha$  can be calibrated from the values of the average link travel time and the respective standard deviation. Equation (E.7) permits the calculation of the smoothing factor  $F$  directly from the standard deviation of link travel times.

3. Though the fundamental probability distributions such as the travel time geometric, travel time normal and travel speed normal distributions, are different, for a sample combination of link inflows, the dispersion of the same link inflow pattern based on different distributions results in relatively similar downstream arrival patterns.

This result shows that the particular shape of the statistical distribution that is used to represent the platoon dispersion process may not be very critical. However, the determination of the specific distribution statistics, such as the mean and the standard deviation of link travel times, may be more important.

4. A numerical example indicates that different standard deviations indeed result in completely different platoon dispersion parameters, which then result in different signal timings, delays, stops and fuel consumption. However, since the current version of TRANSYT does not permit users to input the value for  $\beta$ , it failed to verify a systematic trend for different values of the platoon dispersion parameters. In this context, it is recommended that the TRANSYT-7F input file be modified to allow users either input both  $\alpha$  and  $\beta$  values or input the standard deviation of link travel times.
  
5. It is found from a field collection of link travel time data that the links with different average link travel times and the corresponding standard deviations, even on the same street, should use completely different platoon dispersion factors, which basically contradicts the recommendations by the TRANSYT-7F Manual. Therefore, the actual link travel time statistics are more influential to the platoon dispersion parameters than simply the nature of the street. This conclusion further confirmed the need for making the platoon dispersion parameters site specific.



# CHAPTER 1

## INTRODUCTION

It has long been known that platoons, which form at the exit of a given traffic signal, do not remain intact or compact as they progress along an arterial link towards the next traffic signal. Platoons may disperse along the road either more quickly or slowly depending on the actual road geometric and traffic conditions between the two adjacent intersections of interest. In part, this dispersion of vehicle platoons occurs due to the differences in the desired speeds of the various drivers that make up the platoon. However, a large portion of the dispersion is also caused by the fact that some vehicles will experience delays while travelling along the link which are random in terms of both their occurrence and duration. The majority of these random delays along links occur when vehicles slow down for other vehicles, which are either turning off the road at a mid-block location, or attempting to enter or leave on-street parking.

The calculation of delays and stops of coordinated traffic signals by both off-line and on-line models such as the widely used TRANSYT (Robertson, 1969) and SCOOT (Hunt, et al., 1981) relies on the model's ability to accurately predict traffic flow patterns from one signal to another. The effectiveness of the coordinated signal timings depends on the accuracy of the calculated delays and stops and thus on platoon dispersion modeling. At present, one of the most commonly utilized macroscopic approaches to the modeling of the platoon dispersion process is the one developed by Robertson (1969), which was later incorporated into the TRANSYT. This approach has since also become a virtually universal standard throughout the world in other control or simulation models such as SCOOT, SATURN (Hall, et al., 1980), TRAFLO (Lieberman, et al., 1980), and INTEGRATION (Van Aerde and Yagar, 1990).

A successful application of the Robertson's platoon dispersion model to modeling platoon dispersion relies on the appropriate calibration of several model parameters. The empirical studies performed by the Transport and Road Research Laboratory (TRRL) in the United Kingdom suggested some default values for the platoon dispersion modeling.



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The continuing use of the default values for the platoon dispersion modeling may risk the implementation of virtually ineffective signal timing plans on roads. With the growing applications and development of the Advanced Traffic Management Systems (ATMS) throughout the world, more and more real-time control systems for coordinated traffic signals are expected to be deployed on various urban networks. Therefore, it becomes even more critical for traffic engineers to use the accurate modeling approach for determining the coordinated signal timing plans in order not to waste the resources for investment and deployment of the advanced traffic control and management systems. The calibration of the platoon dispersion parameters is one of the central issues affecting the efficacy of the coordinated signal timings.

### ***1-1. Vehicle Progression and Platoon Dispersion***

At a signalized traffic intersection, vehicles will stop and form the platoon behind the stop-line when the signal turns to red time. When the signal turns to green time, the held vehicle platoon will discharge from the intersection at the saturation flow rate and progress towards the downstream intersection. The platooned vehicles will disperse either quickly or slowly depending on the actual geometric and traffic conditions. Figure 1-1 illustrates the concept of the vehicles' progression and platoon dispersion. It is shown that as the vehicles depart from Intersection A and progress towards Intersection B, the headway between vehicles gradually increases. The longer the road segment is, the more dispersion the vehicles will experience.

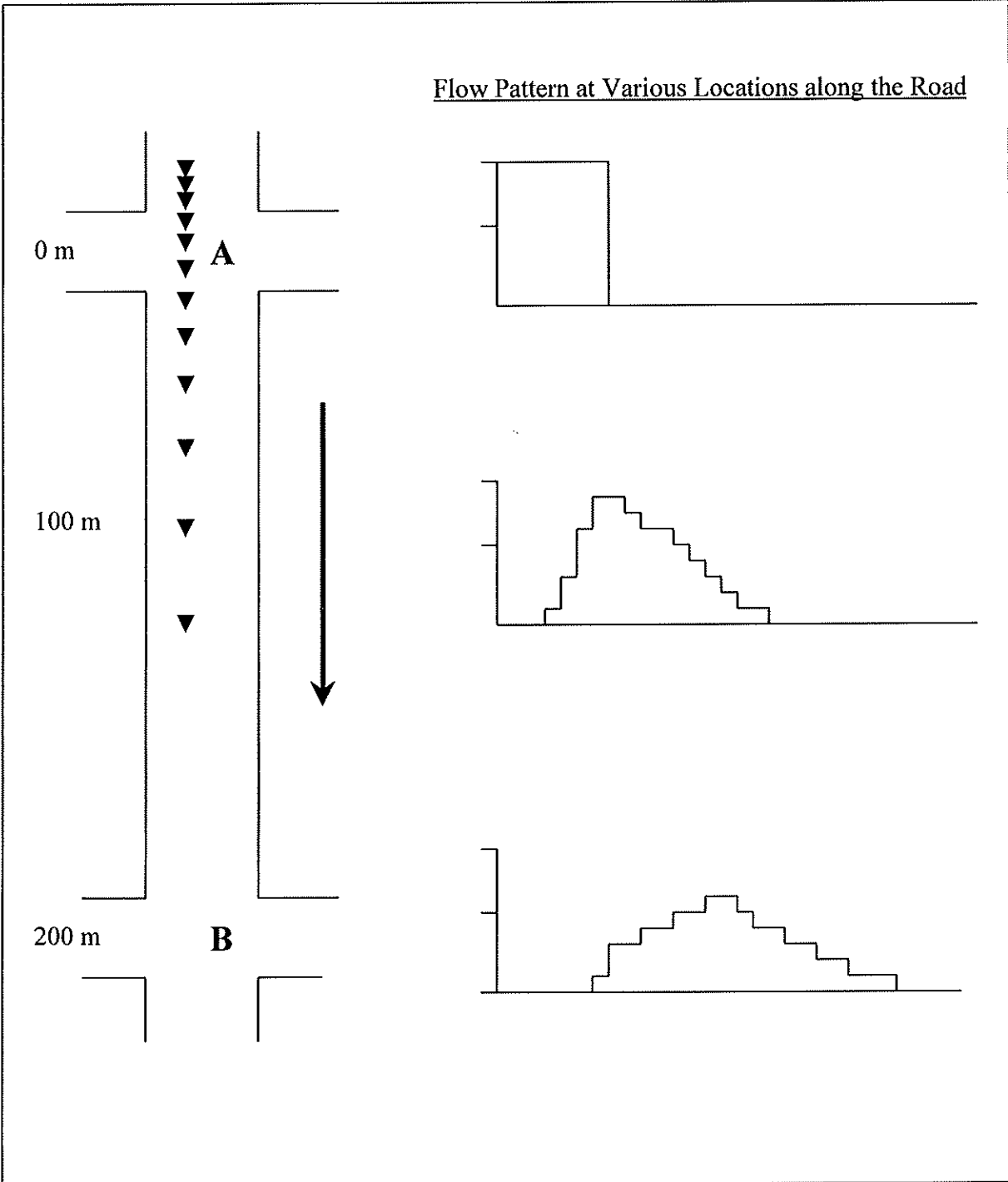


Figure 1-1: Representation of Platoon Dispersion from Intersection A to Intersection B

## Theoretical Approach to Platoon Dispersion

The phenomena of the platoon dispersion illustrated in Figure 1-1 can be described by many mathematical distribution models. With the assumption of a non-stationary Poisson traffic flow, Mine and Ohno (1970) developed the theoretical formula, which describes the platoon dispersion process as a continuous stochastic function. This formula can be expressed as the following Equation (1.1)

$$q_B(t) = \int_0^{\infty} q^A(t + \xi - s/u) g(u) du \quad (1.1)$$

Where:

$q_B(t)$  is the average arrival rate of traffic flow on the approach B at the time  $t$  ( $0 \leq t \leq c$ ) from the beginning of the effective green time in veh/sec,

$c$  is the cycle time of the signals at A and B in seconds,

$q^A(t)$  is the average departure rate of the traffic flow from the Intersection A at time  $t$  ( $0 \leq t \leq c$ ) from the beginning of the effective green time in veh/sec,

$\xi$  is the offset between A and B in seconds,

$s$  is the distance between A and B in meters,

$u$  is the moving speed of vehicles in m/sec, and

$g(u)$  is the density function of time-speed distribution for moving speed  $u$ .

The Equation (1.1) implicates that the arrival rate at Intersection B at time  $t$  is a combination of weighted contributions from all the departure flows from Intersection A, which reflect different moving speeds with different probabilities for vehicles that arrive

at Intersection B at exactly the time  $t$ . The probability distribution of the moving speeds in Equation (1.1) can be any distribution that represents on-road vehicles such as the normal distribution or geometric distribution. Equation (1.1) has been successfully applied to solving a coordinated signal timing offset problem by Yu (1988).

### TRANSYT Platoon Dispersion Model

The platoon dispersion model in TRANSYT was documented by Robertson (1969) and was based on the research work in the U.K. by Hillier and Rothery (1967). The basic TRANSYT recursive platoon dispersion model takes the following mathematical format:

$$q_B(t+T) = Fq^A(t) + (1-F)q_B(t+T-1) \quad (1.2)$$

or 
$$q_B(t) = Fq^A(t-T) + (1-F)q_B(t-1) \quad (1.3)$$

$$F = \frac{1}{1 + \alpha\beta t_a} \quad (1.4)$$

Where:

$T$  is a lag time factor in seconds, which is found as  $\beta t_a$ ,

$F$  is a smoothing factor,

$\beta$  is a dimensionless travel time factor,

$\alpha$  is a platoon dispersion factor in seconds<sup>-1</sup>, and

$t_a$  is the average travel time from the link's entry point to the tail of the queue at the link's downstream stop-line in seconds.

Equation (1.2) indicates that any arrival flow to the downstream intersection B is a weighted combination of the upstream intersection A departure flow  $T$  time ago and the arrival flow to B in the previous second. The weight on each term is a function of the

smoothing factor  $F$ , which is a function of two parameters: travel time factor and platoon dispersion factor. Therefore, it can be said that the accuracy of the prediction of the arrival flow pattern to the downstream intersection is largely influenced by the values of  $\alpha$  and  $\beta$ .

The TRANSYT manual suggests a default value of 0.8 for  $\beta$  and 0.35 for  $\alpha$  based on the empirical studies performed by the TRRL in the United Kingdom. The work performed by PRC Engineering and the University of Florida suggests using 0.5 for heavy friction roads, 0.35 for moderate friction roads and 0.25 for low friction roads in North America. The heavy friction roads represent a combination of parking, moderate to heavy turns, moderate to heavy pedestrian traffic, narrow lane width, which are typical urban CBD traffic flows. The moderate friction represents light turning traffic, light pedestrian traffic, 3.4- to 3.6-meter lanes, possibly divided, which are well-designed CBD or fringe arterial. The low friction roads represent no parking, divided, turning provisions, 3.6 meter lane width, which are suburban high-type arterials.

It should be noted that the actual roads in the real world are much more than the three types mentioned above. Thus, using only three  $\alpha$  values is not sufficient to capture the various geometric and traffic conditions. Therefore, the resulting coordinated signal timings may not be optimal. Further, many research findings have indicated that  $\alpha$  and  $\beta$  values should be correlated and site-specific.

## **1-2. Summary of Literature Review**

Since the development of the original recurrence platoon dispersion relationship in TRANSYT by Robertson, many studies have focused on the analysis and the calibration of  $\alpha$  and  $\beta$  factors. Guebert and Sparks (1989) provided a parametric sensitivity analysis to determine if the use of different values of  $\alpha$  and  $\beta$  will significantly influence the selection of the final optimized signal timing plans. Their results showed that an accurate platoon dispersion model, and therefore the calibration of accurate  $\alpha$  and  $\beta$  factors, is indeed very important in developing effective and efficient traffic signal timing plans. Baass and Lefebvre (1987) analyzed the relationship between

the platoon dispersion process and the magnitude of the link's traffic density and volume. They came to a conclusion that, if a typical curve relating service volume to the platoon dispersion factors could be defined by further study, then the platoon dispersion factors could be calculated directly from the link densities, or volumes and travel times. Manar and Baass (1996) found that the platoon dispersion increases as volumes and densities increase up to a maximum, which is attained at half the capacity. As the volumes and densities increase further, the dispersion decreases and reaches a minimum value at volumes around the maximal capacity. They subsequently proposed a mathematical model that relates the platoon dispersion factor to the traffic volumes.

McCoy, et al (1983) also indicated that the calibration of  $\alpha$  and  $\beta$  is an important requirement to the successful implementation of the TRANSYT model. They calibrated  $\alpha$  and  $\beta$  factors for two-lane streets to be  $\alpha=0.2$  and  $\beta=0.97$ , and for four-lane streets they found these factors as  $\alpha=0.15$  and  $\beta=0.97$ . In addition, they suggested that the TRANSYT program should be revised to enable the user to specify both  $\alpha$  and  $\beta$ , as opposed to requiring  $\beta$  to be fixed. El-Reedy and Ashworth (1978) analyzed the platoon dispersion process along a single carriage way in Sheffield, England. After calibrating  $\alpha$  and  $\beta$ , they found that different link travel times resulted in the selection of different  $\alpha$  and  $\beta$ , even for similar road conditions. They concluded that the constraints in the smoothing factor expression should be dependent on the observed distribution of the link travel times.

In a summary, most of the above investigations have suggested that platoon dispersion should not be generalized with the standard default parameter settings that are suggested in the TRANSYT manual; but instead, these parameters should be each time be customized to match the unique road conditions on each link. However, beyond recognizing that unique parameters need to be derived, no explicit or standardized procedure to actually determine the magnitudes of  $\alpha$  and  $\beta$  has been provided in traffic engineering books. It appears that each analyst develops and utilizes his/her own unique calibration method.

### ***1-3. Objectives of Research***

The objectives of this research are threefold. In the first instance, the research will examine in a great detail the underlying assumptions of the TRANSYT macroscopic platoon dispersion model. The examination will bring into question the common assumption that  $\beta$  equals 0.8 for all values of  $\alpha$ . In the second instance, the research will develop an alternate mathematical approach for calibrating the platoon dispersion parameters directly from the statistical properties of the travel time experiences of individual vehicles, which can be obtained on a real-time basis in ATMS applications. Finally, the research will collect link travel time data from selected roads and calibrate the platoon dispersion parameters using the proposed approach, thus establishing the context for using the proposed calibration approach in real world applications.

## CHAPTER 2

### STATISTICAL ANALYSIS OF PLATOON DISPERSION

This chapter attempts to perform the statistical analysis for the TRANSYT platoon dispersion model to provide the context for the proposed methodology for calibrating the platoon dispersion parameters based on the field observed travel time data. This chapter will also discuss the impact of different arrival distributions on the actual platoon dispersions.

#### **2-1. Analysis of TRANSYT Platoon Dispersion Logic**

The TRANSYT platoon dispersion model, which was presented in Equation (1.3), suggests that the traffic volume, which arrives during a given time interval at the downstream of a link, is a weighted combination of the arrival pattern at the downstream of the link during the previous time interval and the departure pattern from the upstream traffic signal  $T$  seconds ago. Further expansion of the recurrence platoon dispersion equation (3.1) resulted in the following form (Seddom, 1972):

$$q_B(t) = \sum_{i=T}^{\infty} [F(1-F)^{i-T}] q^A(t-i) \quad (2.1)$$

The expression within the bracket of Equation (2.1) can be put into the following function:

$$P_r(X = i) = F(1-F)^{i-T} \quad (i = T, T+1, \dots) \quad (2.2)$$

Equation (2.2) can be considered as a probability function. If  $i$  is considered as the travel time between upstream end and downstream end of the link, Equation (2.2) takes the form of a shifted geometric distribution as shown in Figure 2-1. It is shown from this figure that Equation (2.2) can be derived by shifting the original geometric distribution to its right in  $T-1$  units. The population means of the original and shifted geometric distributions are different, but their standard deviations should be the same.



It is also found by comparing Equation (2.1) with Equation (1.1) that the TRANSYT platoon dispersion model is actually a discrete version of the theoretical platoon dispersion model. In this discrete version, the travel time is assumed a shifted geometric distribution in which the distribution of speed is not given in an explicit manner.

Under the assumptions that the travel time follows the shifted geometric distribution, and that the average travel time  $t_a$  and the standard deviation of travel time  $\sigma$  are given, one can derive the expressions of  $\alpha$  and  $\beta$  as functions of average travel time and the standard deviation.

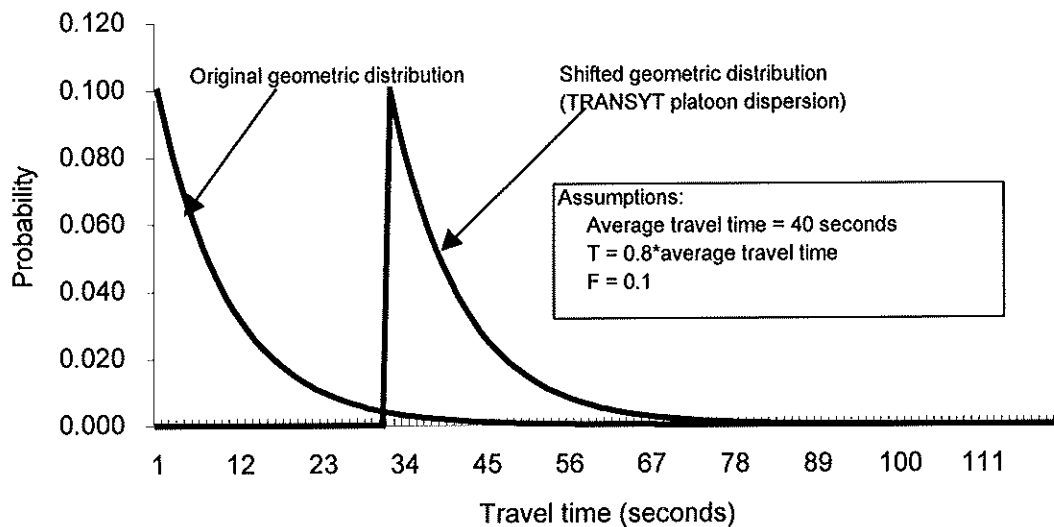


Figure 2-1: Illustration of Geometric Distribution and Shifted Geometric Distribution

Based on the definition of the geometric distribution and Equation (2.2), the mean can be expressed into the following format.

$$t_a - T + 1 = \frac{1}{F} \quad (2.3)$$

If  $F$  of Equation (1.4) is substituted into Equation (2.3), one can get

$$t_a - \beta t_a + 1 = 1 + \alpha \beta t_a \quad (2.4)$$

$$\text{Thus } \beta = \frac{1}{1 + \alpha} \text{ or } \alpha = \frac{1 - \beta}{\beta} \quad (2.5)$$

Since the standard deviations of geometric and shifted geometric distributions are equal, one gets

$$\frac{1 - F}{F^2} = \sigma^2 \quad (2.6)$$

Substituting (1.4) into (2.6), one gets

$$\alpha \beta t_a (1 + \alpha \beta t_a) = \sigma^2 \quad (2.7)$$

The solution of Equation (2.7) for the variable  $\beta$  results in

$$\beta = \frac{2t_a + 1 \pm \sqrt{1 + 4\sigma^2}}{2t_a} \quad (2.8)$$

From the Equation (2.5), since  $\alpha$  is larger than or equal to zero,  $\beta$  must be less than or equal to one. Therefore the Equation (2.8) is simplified to Equation (2.9).

$$\beta = \frac{2t_a + 1 - \sqrt{1 + 4\sigma^2}}{2t_a} \quad (2.9)$$

Substituting (2.9) into (2.5), one gets

$$\alpha = \frac{\sqrt{1 + 4\sigma^2} - 1}{2t_a + 1 - \sqrt{1 + 4\sigma^2}} \quad (2.10)$$

From Equation (2.6), one can also gets

$$F = \frac{\sqrt{1 + 4\sigma^2} - 1}{2\sigma^2} \quad (2.11)$$

Through the above development of a series of equations based on the definition of shifted probability distribution, the smoothing factor  $F$ , platoon dispersion factor  $\alpha$  and travel time factor  $\beta$  were successfully related to the vehicles' average travel time and the standard deviation of the travel time. In other words, the information about the average travel time and standard deviation would be sufficient for deriving the values of smoothing factor, platoon dispersion factor and the travel time factor.

## **2-2. Derivation of Calibration Parameters**

The derivation of Equation (2.5) suggests that the value of the travel time factor  $\beta$  should be made dependent on the value of the platoon dispersion factor  $\alpha$  in order to provide the consistency of link travel times into the geometric distributed platoon dispersion model and out of the same model. In other word, the calibration of one value of either  $\alpha$  or  $\beta$  will automatically fix the value for the other. The notion of calibrating  $\beta$  as well as  $\alpha$  has previously been discussed by Castle (1985), El-Reedy (1978) and McCoy (1983). In order to put earlier calibrated values of  $\alpha$  and  $\beta$  into perspective, a series of points have been added to Figure 2-2 in order to illustrate the range of  $\alpha$  and  $\beta$  values, which have been in various studies. While the points on this graph do not perfectly match the relationship between  $\alpha$  and  $\beta$  of Equation (2.5), the similarity in the trends appears to be more than coincidental.

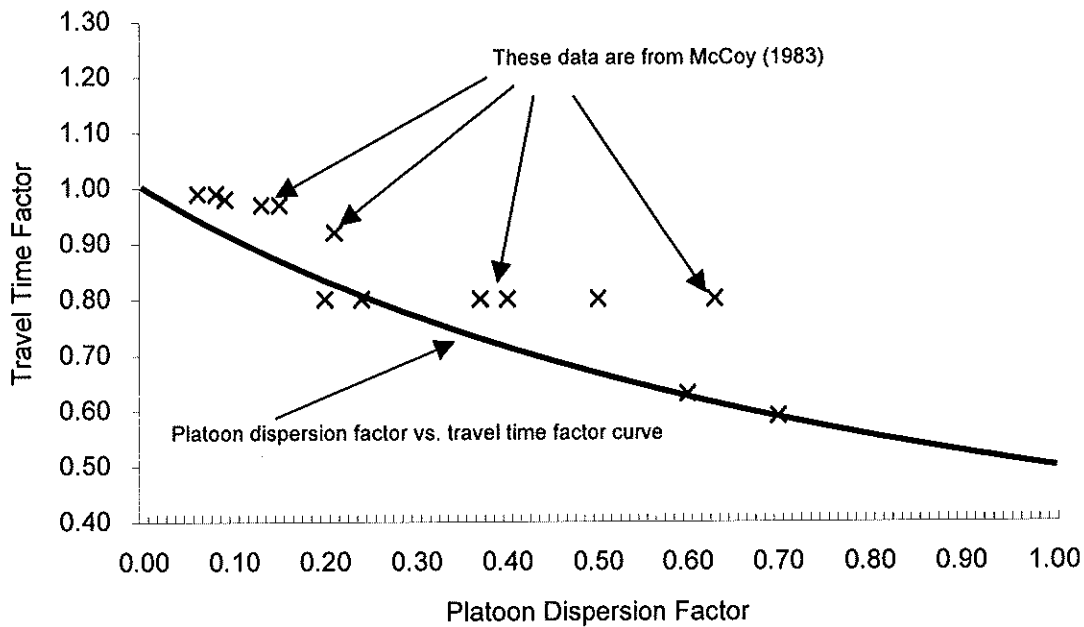


Figure 2-2: Relationship Between Platoon Dispersion Factor  $\alpha$  and Travel Time Factor  $\beta$

Equations (2.9) and (2.10) illustrate that the values of  $\alpha$  and  $\beta$  can be calibrated from the values of the average link travel time and the respective standard deviation. Therefore, if the link travel time data and its standard deviation estimate can be derived in some measures, the calibration of  $\alpha$  or  $\beta$  will be possible accordingly. A further step from Equation (2.10) is the derivation of Equation (2.11), which permits the calculation of the smoothing factor  $F$  directly from only the standard deviation of link travel times. The representation of the smoothing factor  $F$  as a function of the standard deviation has avoided the use of  $\alpha$  and  $\beta$  in the description of the platoon dispersion. Consequently, Equation (2.11) provided a direct way to relate the link travel time statistics with the smoothing factor without using any intermediate steps for calibration. Figure 2-3 illustrates the platoon dispersion factor and the smoothing factor as functions of the standard deviation of link travel times. It can be seen from the two curves on Figure 2-3 that in order to identify the platoon dispersion patterns for a real traffic network, one can attempt to determine the realistic range values of the standard deviation of link travel times instead of the traditional platoon dispersion factor. In fact, it is easier to determine

a realistic range of values for the standard deviation than for the platoon dispersion factor. It is also shown that the larger the standard deviation is, the lower the smoothing factor will be. In other words, if there are higher variations in the desired travel speeds, the vehicles will be more quickly dispersed, which is true in a real traffic network scenario.

Figure 2-4 illustrates the platoon dispersion factor and the smoothing factor as functions of the average link travel time, with 10% of the average link travel time as the value of the standard deviation. It is shown that, with the same variation degree of travel speeds, which is described in the form of the fixed percentage of the standard deviation, the larger the average travel time is, the lower the smoothing factor value is, and therefore the less likely the traffic will smoothly be transferred from the upstream to the downstream of the link. The difference in the average link travel times can be either a result of simply different link lengths or a result of different degree of link volumes with the same link length. Consequently, using link travel time statistics to calibrate the platoon dispersion parameters can capture both geometric and traffic conditions.

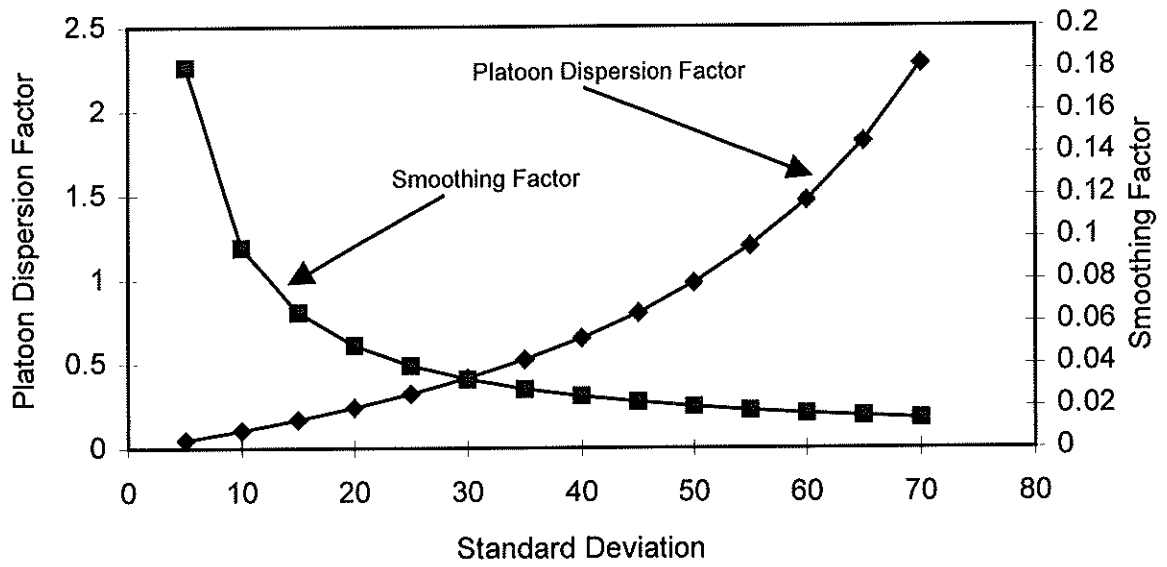


Figure 2-3: Platoon Dispersion Factor and Smoothing Factor as Functions of the Standard Deviation of Link Travel Times

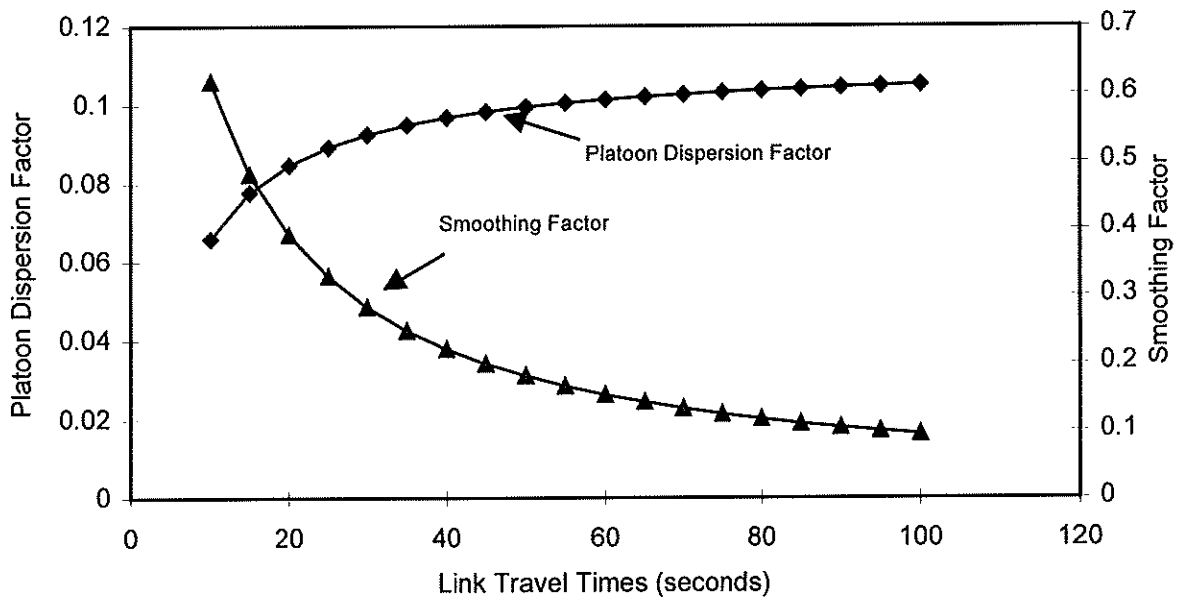


Figure 2-4: Platoon Dispersion Factor and Smoothing Factor as Functions Of Link Travel Times with 10% of the Average Link Travel Time as the Standard Deviation

From the Equation (2.7), for a given value of  $\beta=0.8$ , the standard deviation of the link travel times is a linear function of the platoon dispersion factor  $\alpha$ . This is indicated by Line A in Figure 2-5 for a link with an average travel time of 24 seconds into the platoon dispersion process. Similarly, it can also be shown that for a fixed input value of  $\beta=0.8$  and average link travel time of 24 seconds, the average link travel time resulting from a given value of platoon dispersion factor  $\alpha$  (average link travel time out of the platoon dispersion process), varies as shown by Line B in Figure 2-5.

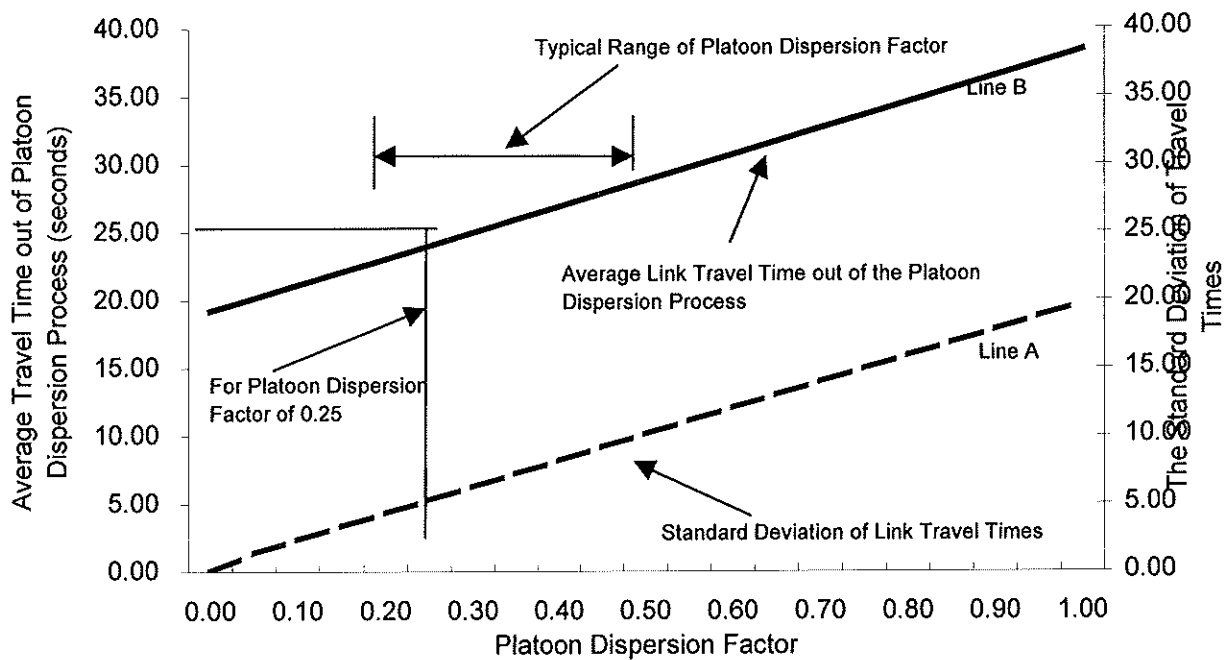


Figure 2-5: Average Link Travel Time out of the Platoon Dispersion Process and the Standard Deviation as a Function of Platoon Dispersion Factor  $\alpha$

Line A in Figure 2-5 suggests that the relationship of the standard deviation of travel times as a function of the platoon dispersion factor, can be reversed to permit the calculation of a platoon dispersion factor as a function of the standard deviation as suggested by Equation (2.10). Line B yields an interesting but important observation. For a fixed value of  $\beta=0.8$  and for a given initial average travel time of 24 seconds, the average link travel time that comes out of the platoon dispersion process varies as a function of the magnitude of the platoon dispersion factor. Specifically, only for a

platoon dispersion factor  $\alpha=0.25$  does the average travel time, which is the input into the model, result in an identical average travel time of 24 seconds, which comes out of the platoon dispersion process. Therefore, the use of Equation (2.5) is the only way to ensure the consistency between the average link travel time into the platoon dispersion model and out of the platoon dispersion model.

### 2-3. Arrival Distribution Impact on Platoon Dispersion

#### Arrival/Departure Distribution for a Given Inflow/Outflow Pulse

The TRANSYT platoon dispersion model, which was presented in Equation (1.3), suggests that the traffic volume that arrives during a given time period at the downstream of a link is a weighted combination of the arrival pattern at the downstream of the link during the previous time interval and the departure pattern from the upstream traffic signal  $T$  seconds ago. The value of the time lag factor  $T$  is found as a function of  $\beta$  times the desired average link travel time, where  $\beta$  is set to 0.8 in TRANSYT. This is illustrated graphically in Figure 2-6 for a situation in which a single inflow pulse of traffic is introduced at the upstream signal at time  $t_0$ .

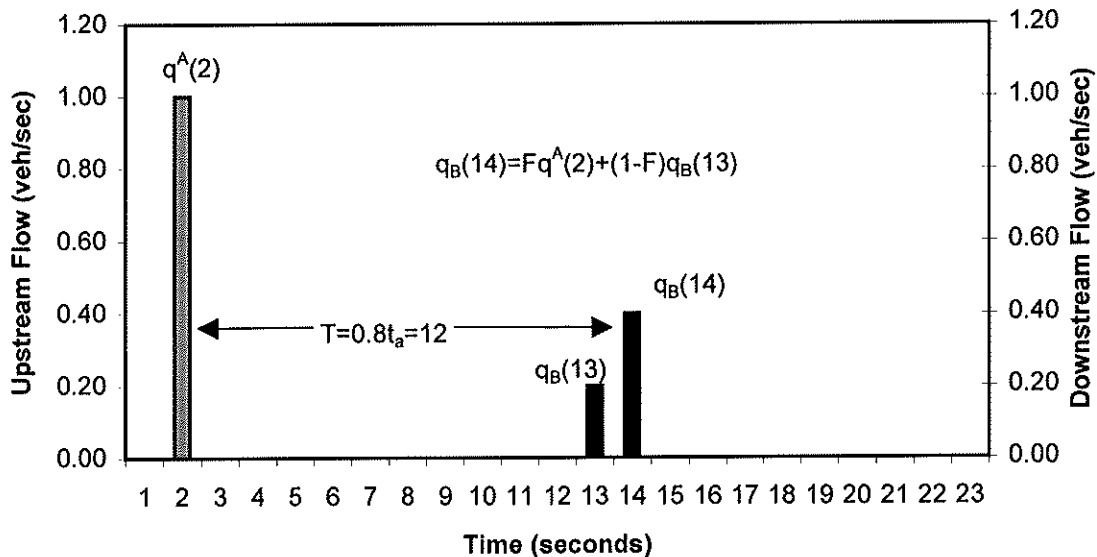


Figure 2-6: Illustration of Downstream Arrival  $Q_b(T)$  as a Combination of  $q^A(t-T)$  and  $q_b(t-1)$



Since the arrival rate during the previous time interval was also a function of the same recursive process, it can be shown that an inflow into the link results in a downstream arrival distribution, as indicated in Figure 2-7. As shown, the majority of the traffic is considered to arrive at the downstream end of the link during time interval  $T=0.8t_a$ , where  $t_a$  is the desired or measured average link travel time. A decreasingly smaller portion of the initial traffic input pulse is then assumed to arrive during any subsequent time slices, after time  $T+t_0$ , until the effect of the unit inflow at time  $t_0$  eventually vanishes to be of practical significance.

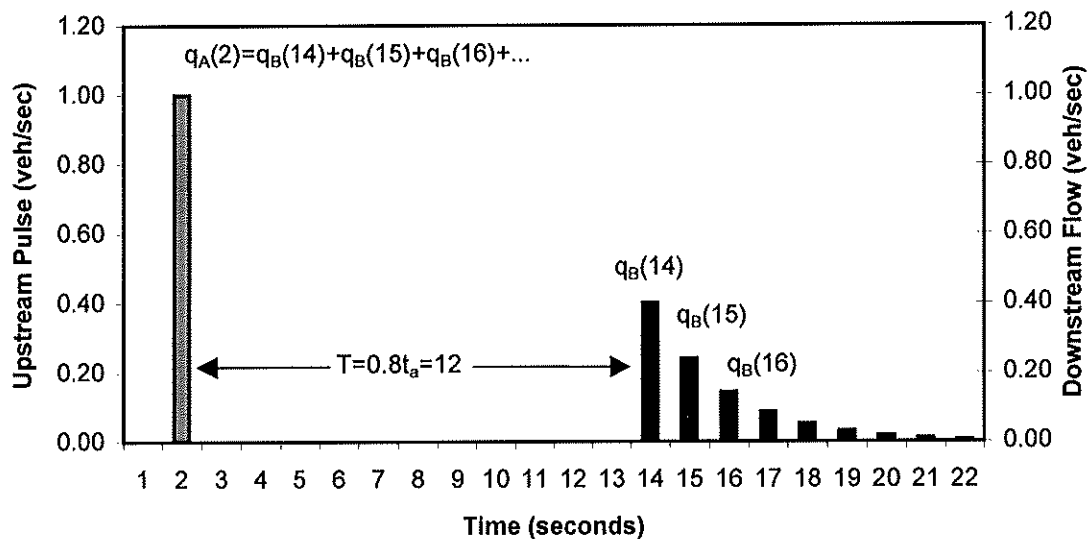


Figure 2-7: Downstream Link Arrivals due to a Unit Upstream Inflow Pulse

If the inflow is considered to represent one vehicle, one can consider the histograms of Figure 2-7 to represent the respective probabilities of when this given single vehicle is likely to arrive at the downstream link given that the travel time follows a shifted geometric distribution. Furthermore, Figure 2-8 indicates that different platoon dispersion factors translate into faster or slower decay rates of the probabilities after  $T=0.8t_a$ . It should be noted that in all cases, the histograms start at  $T=0.8t_a$ , regardless of the amount of subsequent platoon dispersion.

Figure 2-9 indicates that the problem can also be formulated in reverse. For example, a unit outflow, during a given time period at the downstream link, can be

viewed as having been accumulated from various component contributions from the link upstream inflows. These contributions were made up to  $T=0.8t_a$  seconds prior to the arrival of the unit flow at the downstream end.

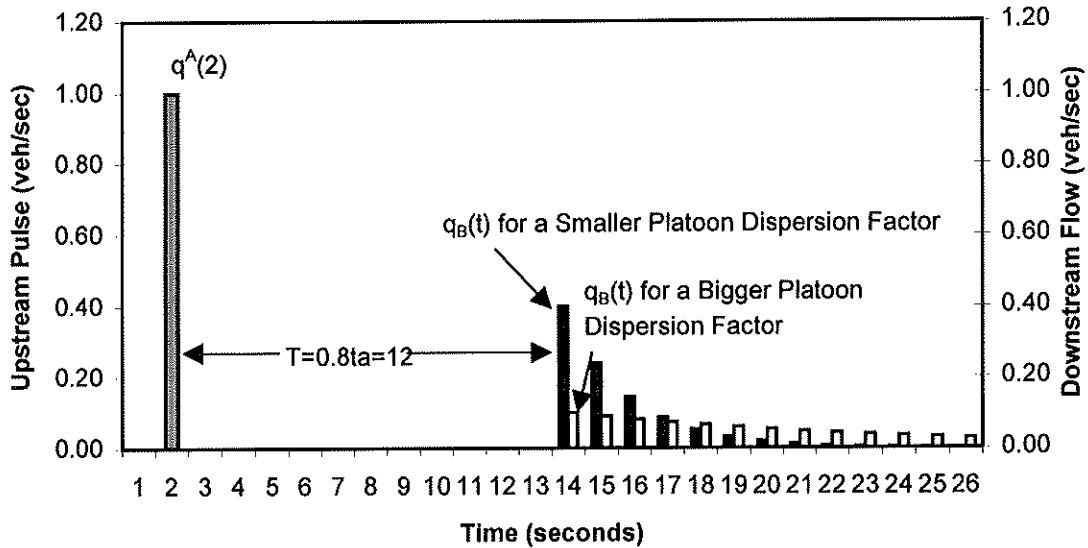


Figure 2-8: Downstream Arrivals due to a Unit Upstream Inflow Pulse for Two Different Platoon Dispersion Factor Values

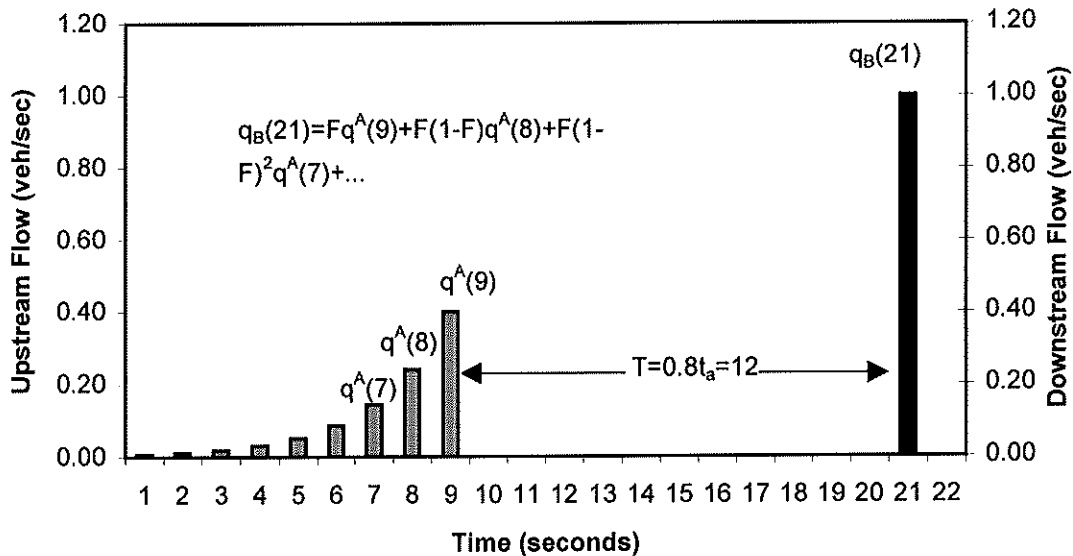


Figure 2-9: Downstream Arrivals at Time  $T=T_0=21$  due to the Upstream Inflows prior to Time  $t_0=9$

Figure 2-7 also demonstrates that the macroscopic TRANSYT platoon dispersion model is identical to the shifted geometric probability distribution, as also indicated in Section 2-1. The particular distribution considers that a large percentage of drivers travel at speeds which are actually much faster than the average, as  $T=0.8t_a$ . This implies that their speeds are up to 25% above the average speed ( $1.25=1/0.8$ ). However, some vehicles are delayed by more than  $0.2t_a$  along the link, such that their final link travel time exceeds  $t_a$ . As the probability distribution decays when  $t$  increases above  $T+t_0$ , it is implied that shorter delays are more likely to occur than longer delays.

### Link Travel Times or Speeds as a Normal Distribution

A common approach to modeling any random process is to consider the random variable in question to be normally distributed. In the platoon dispersion case, this would allow the analyst to model the platoon dispersion process by simply replicating the mean and variance of the link travel times that were observed or measured in the field. Alternatively, one could estimate a value for the latter variance indirectly based on a given TRANSYT type of platoon dispersion factor  $\alpha$ , as illustrated by Line A of Figure 2-5.

As shown previously, Equation (1.1) and Equation (2.1) have great similarity in that both equations recognize that the platoon dispersion process is based on a probability distribution. The only difference between the two equations is that while Equation (2.1) uses the shifted geometric distribution, Equation (1.1) uses a generalized form of the continuous probability distribution. If the travel time is assumed to follow the Normal distribution and its density function is given, the downstream arrival flows can then be predicted using Equation (1.1). In addition, if the travel speed is assumed to be normally distributed, the travel time probability can also be derived given the link length.

Figure 2-10 indicates that the fundamental probability distributions, for the outflow associated with a single upstream link inflow pulse, are rather different for the travel time geometric, travel time normal and travel speed normal distributions. However, Figure 2-11 indicates that for a sample combination of link inflow pulses, which

represent the shape of a typical complete platoon, the dispersion of the same link inflow pattern based on different distributions results in relatively similar downstream arrival patterns.

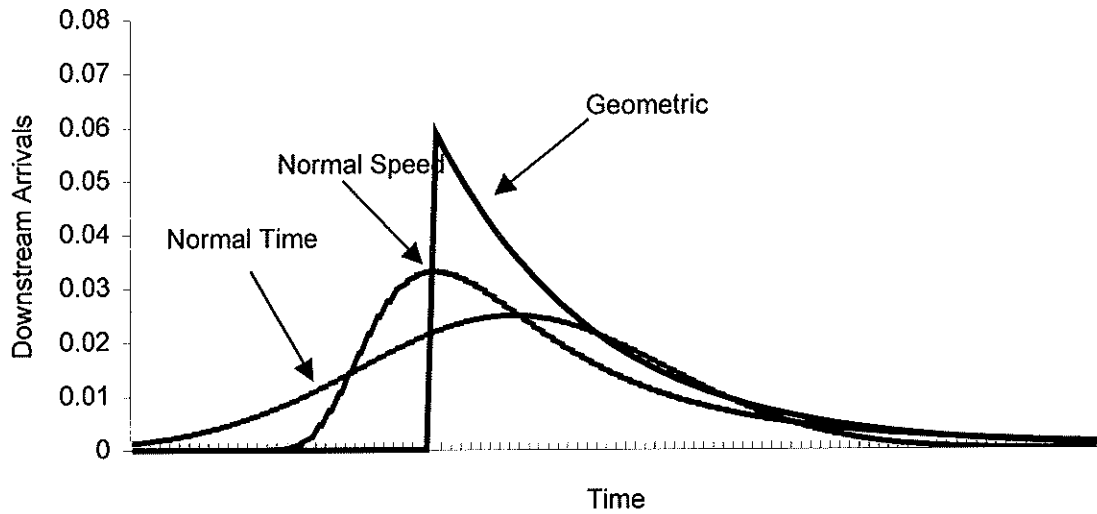


Figure 2-10: Arrival Patterns due to a Unit Upstream Inflow Pulse

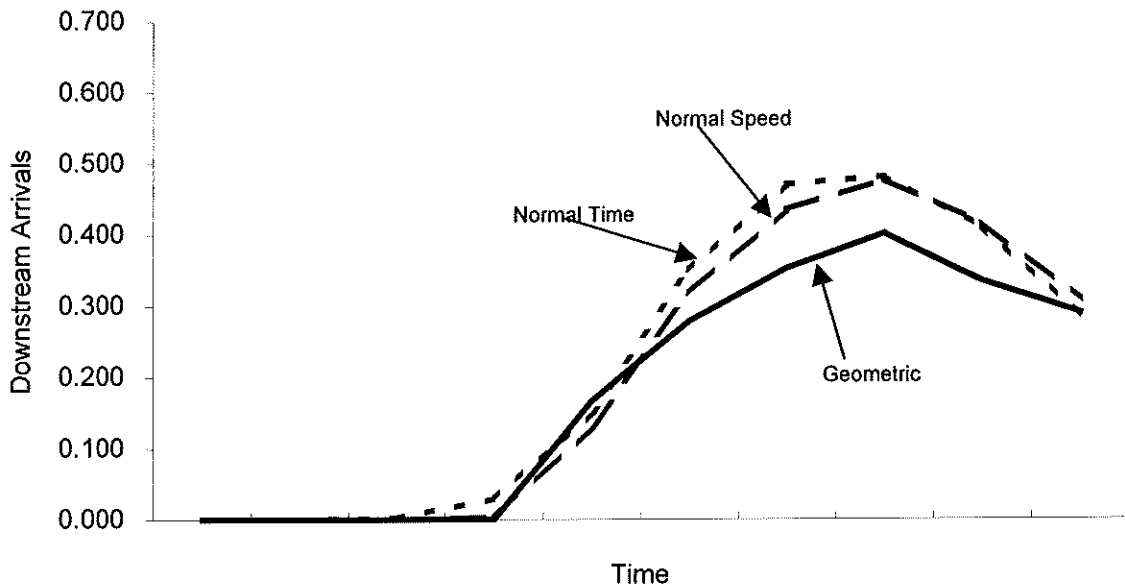


Figure 2-11: Arrival Patterns due to a Sample of Combination of Upstream Pulses

This result shows that the particular shape of the statistical distribution that is used to represent the platoon dispersion process may not be very critical. However, the determination of the specific distribution statistics, such as the mean and the standard deviation of link travel times, may be more important. This finding is significant because if multiple lanes are present in the network, the normal distribution of speeds is more realistic in representing the vehicles' progressions than the geometric distribution.

## CHAPTER 3

### CALIBRATION OF PLATOON DISPERSION IN ATMS

Chapter 2 performed the statistical analysis of the TRANSYT platoon dispersion model, which concluded that essentially the model is a form of shifted geometric distribution of link travel times. The segment also analyzed the impact of different travel time/speed distributions on the platoon dispersions. This Chapter will further develop a logic for calibrating the platoon dispersion parameters based on the results of Chapter 2.

#### 3-1. Calibration Logic in ATMS

The analysis in Section 2-1 resulted in three important equations: Equation (2.5), (2.10) and (2.11). For the purpose of discussion in this chapter, these equations are summarized and renamed as follows.

$$\beta = \frac{1}{1 + \alpha} \quad (3.1)$$

$$\alpha = \frac{\sqrt{1 + 4\sigma^2} - 1}{2t_a + 1 - \sqrt{1 + 4\sigma^2}} \quad (3.2)$$

$$F = \frac{\sqrt{1 + 4\sigma^2} - 1}{2\sigma^2} \quad (3.3)$$

As stated in Chapter 2, Equation (3.1) shows that the value of the travel time factor  $\beta$  should be made dependent on the value of the platoon dispersion factor  $\alpha$  in order to provide the consistency of link travel times into the geometric distributed platoon dispersion model and out of the same model, as opposed to the fixed value of 0.8, which is being used in TRANSYT at present. Equation (3.2) illustrates that the value of  $\alpha$  can be calibrated from the values of the average link travel time and the respective standard deviation. Equation (3.3) permits the calculation of the smoothing factor  $F$  directly from the standard deviation of link travel times.

While the original TRANSYT-7F User's Manual recommended that the values of  $\alpha$  should vary to consider specific site geometric and traffic conditions, the use of the link travel time/standard deviation for calibrating the smoothing factor can be interpreted as that all the site specific factors of grades, curvature, parking, traffic volumes and other sources of impedance will be captured by the standard deviation of link travel times.

Consider another fact with respect to the calculation of the smoothing factor. In the TRANSYT platoon dispersion model, the smoothing factor is computed based on a fixed value of the average link travel time. This is obviously unrealistic when the real-time based traffic responsive signal control strategies are applied, in which the link travel time is dependent on the actual traffic volumes on the link. If the smoothing factor is calculated based on the standard deviation of link travel times on a real-time basis, the impact of the traffic volume changes on the platoon dispersion can be easily captured.

To use Equations (3.1) through (3.3) to calibrate platoon dispersion parameters, the most important information needed are the link travel time and the standard deviation. This means that link travel time data have to be collected for every street where the signal timings are to be determined. This task is very difficult, if not impossible, considering the fact that the travel times are a function of so many real-world variables. Under an ATMS environment, however, travel times are usually available on a real-time basis. Travel times can be detected either by Automatic Vehicle Identification (AVI) techniques, inductive loop detectors, or even video image processing technology.

The availability of travel time data on a real-time basis in ATMS enables the calibration of platoon dispersion parameters based on the actual traffic conditions. This will make the signal timing settings more optimal, and thus be able to further reduce the intersection delays. In this context, the technique for calibrating the TRANSYT platoon dispersion parameters in ATMS is described by the following steps:

- Step 1. Detect the real-time link travel times of vehicles for a predetermined time period.

- Step 2. Calculate the average link travel time and its respective standard deviation.
- Step 3. Calculate the smoothing factor  $F$  using the Equation (3.3).
- Step 4. Calculate the platoon dispersion factor  $\alpha$  using the Equation (3.2).
- Step 5. Calculate the travel time factor  $\beta$  using the Equation (3.1).
- Step 6. Calculate the lag time factor  $T$  based on  $T = \beta t_a$ .
- Step 7. Substitute  $F$  and  $T$  into the platoon dispersion model to predict the platoon dispersions.

The above steps are ideally suited for applications in ATMS primarily because the required link travel time data can be derived on real-time basis. Vehicle probes, which are equipped with AVI tags, are widely used in the ATMS for collecting toll and real-time travel time data. For example, in the Houston TranStar system, many vehicles have been equipped with AVI tags and thus can serve as probes. Such vehicles can communicate with the Automatic Vehicle Detectors (AVD) on the road-side. Each vehicle provides the Traffic Management Center (TMC) with specific information, such as when vehicles enter a particular link and when vehicles reach the downstream end of the same link. The central computer can then calculate the average link travel times.

If the real-time link travel time data from ATMS are used, the platoon dispersion parameters can then be calibrated on a real-time basis and thus the traffic responsive signal control strategies can capture the vehicles' platoon dispersion behavior on the link more accurately and determine the coordinated signal timings more optimally. SCOOT (Hunt, et. al., 1981) system is a widely used real-time signal control system and has been installed in many cities in North America. The research by Gartner, et. al. (1995), however, has shown that the performance of SCOOT system may not always be superior to off-line and fixed time signal control strategies. It is expected that the adoption of the



proposed technique for calibrating platoon dispersion parameters will contribute to the improvement of a real-time traffic signal control system like SCOOT.

In addition to the ATMS and the real-time traffic signal control systems, the proposed technique is also a very effective method to calibrate the platoon dispersion parameters for an off-line traffic signal control strategy. The link travel time data for each particular link can be derived either from a direct on-site data collection or from the travel logs of those vehicles, which are equipped with an in-vehicle navigation system.

### **3-2. Recommended Revisions in TRANSYT-7F Input Files**

Although McCoy (1990) has concluded that the travel time factor  $\beta$  should be site specific based on various research findings, a fixed value of 0.8 for  $\beta$  has continuously been used by practitioners. The primary reason for this is that the TRANSYT-7F model does not permit users to set a different value for  $\beta$ . Instead, the TRANSYT-7F uses a fixed value of 0.8 internally and let users to input the value of platoon dispersion factor  $\alpha$ . In order for the TRANSYT-7F to use  $\alpha$  and  $\beta$  values that are consistent with the ones that are derived based on the proposed technique, the input files for TRANSYT-7F need to be changed.

There are several potential methods for changing the TRANSYT-7F input files. The first method is to let users input the values of both  $\alpha$  and  $\beta$ . The Card Type 39 of TRANSYT-7F permits users to input a link specific platoon dispersion factor value in the Field 2. It is suggested that an additional field is created for the travel time factor value, so that users can externally calibrate both  $\alpha$  and  $\beta$  for each link using the link travel time statistics and input them using Card Type 39.

The second method is to let users input the values of smoothing factor  $F$  and travel time factor  $\beta$ . As shown by Equation (3.3),  $F$  is only a function of the standard deviation of travel times. While  $\alpha$  is a function of both the average link travel time and the standard deviation,  $F$  is not related to the average link travel time. So users can calculate  $F$  directly from the standard deviation of link travel times instead of going

through  $\alpha$ . However,  $\beta$  is still needed in calculating the lag time factor T provided TRANSYT-7F continues to assume the geometric distribution of link travel times. To permit users to input the values of F and  $\alpha$ , TRANSYT-7F must delete its internal function in calculating F based on  $\alpha$  and  $\beta$ .

The third method of changing the TRANSYT-7F input is to permit users to input the average link travel time and the standard deviation directly. The Fields 2 and 3 in Card Type 39 can be used for this purpose. However, TRANSYT-7F has to calculate the  $\alpha$ ,  $\beta$  and F internally in its subroutines using Equations (3.1), (3.2) and (3.3). In this way, users can input their raw data of link travel times directly into the TRANSYT-7F, so that external calculations can be saved. This is the optimal solution for TRANSYT-7F to incorporate the proposed technique for calibrating the platoon dispersion factor and travel time factor.

### **3-3. Sample Size of Vehicles for Real-Time Applications**

As recommended in Sections 3-1 and 3-2, the platoon dispersion factor  $\alpha$ , travel time factor  $\beta$ , and the smoothing factor F should be calibrated based on the link travel time statistics for both fixed and real-time applications. The question, however, is the accuracy of the calibrated platoon dispersion model parameters. For real-world applications, the average link travel time and the standard deviation are calculated based on a number of link travel time sample data. Different numbers of the link travel time data used may result in different accuracies and confidence levels in the calibrated platoon dispersion parameters.

Equations (3.1) through (3.3) show that  $\alpha$ ,  $\beta$ , and F are monotonic functions of the standard deviation  $\sigma$ , given an average link travel time. The confidence limits of  $\sigma$  can be converted to the confidence limits of  $\alpha$ ,  $\beta$  and F. It is known that the confidence limits of  $\sigma$  are established based on the  $\chi^2$  (chi-squared) distribution (Crow, et. al., 1978). Given the sample size n, the confidence level  $\gamma$  and the standard deviation  $\sigma$ , the confidence limits of  $\sigma$  are described by the following expressions:

$$\left( \frac{(n-1)\sigma^2}{\chi_{\frac{\gamma}{2}, n-1}^2} \right)^{\frac{1}{2}} \quad \text{to} \quad \left( \frac{(n-1)\sigma^2}{\chi_{1-\frac{\gamma}{2}, n-1}^2} \right)^{\frac{1}{2}} \quad (3.4)$$

The values of  $\chi_{\frac{\gamma}{2}, n-1}^2$  and  $\chi_{1-\frac{\gamma}{2}, n-1}^2$  can be found from any statistics reference. For example, for a given average standard deviation of 10, the sample size of 51 and the confidence level of 5%, the calculated confidence limits of  $\sigma$  are 8.367 and 12.430. In other words, the 95% confidence interval for  $\sigma$  is [8.367, 12.430]. By assuming an average link travel time of 40 and substituting these values into Equations (3.1) through 3.3, one gets:

$$\alpha = 0.312 \text{ with a 95\% level of confidence interval} = [0.245, 0.426],$$

$$\beta = 0.762 \text{ with a 95\% level of confidence interval} = [0.701, 0.803], \text{ and}$$

$$F = 0.095 \text{ with a 95\% level of confidence interval} = [0.077, 0.113].$$

Similarly, one can determine the sample size necessary to determine the standard deviation of  $\sigma$  with  $p\%$  of its true value with confidence coefficient  $1-\gamma$ . The Figure 3-1 in the next page, which is from Crow, et. al. (1978), can be used for this purpose. For example, in estimating the precision of the link travel time, one can determine how large a sample size should be used in order to determine the standard deviation within 20% of its true value with 95% level of confidence. From Figure 3-1, it can be shown that the degrees of freedom should be 46. Consequently, since the number of degrees of freedom is one less than the sample size, the required sample size is 47 (46+1).

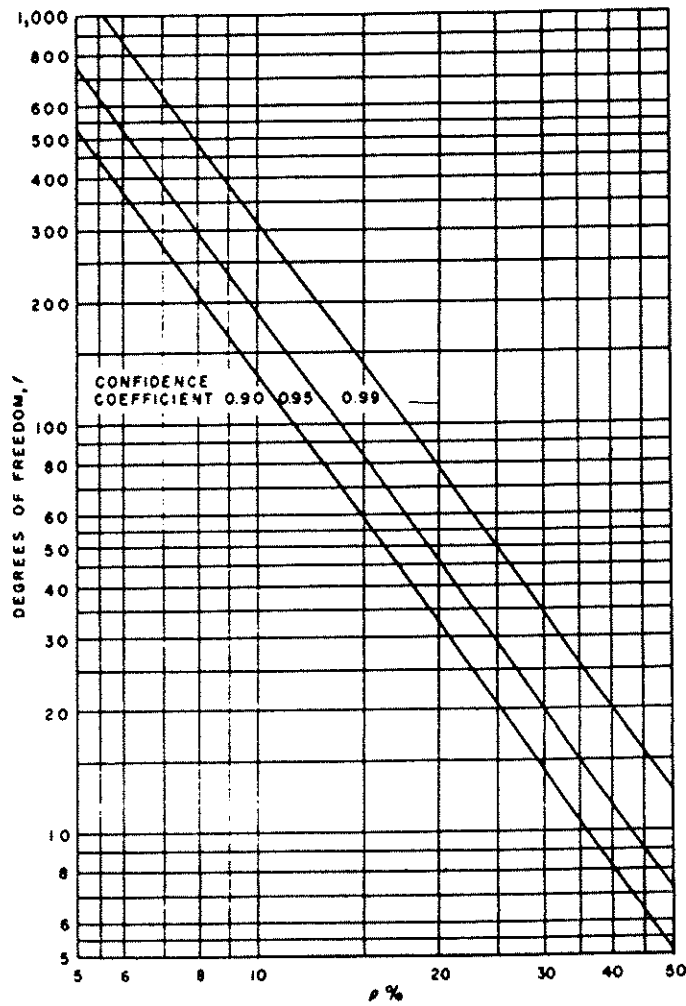


Figure 3-1: Number of Degrees of Freedom Required for Estimating the Standard Deviation within P% of its True Value, with a Prescribed Confidence Level (Source: Crow, et. al., 1978)

### 3-4. Applications in Microscopic Traffic Simulations

For the purpose of microscopic traffic simulation, it is desired that a random link travel time for an individual vehicle be generated given the platoon dispersion parameters, so that the moving of all vehicles along the link can replicate the macroscopic TRANSYT platoon dispersion behavior. Assume that a random number value  $R$ , which is in the range between 0.0 and 1.0, is first generated by any random number generating algorithm. Then, from Equation (2.2), one gets:

$$R \times F = F(1 - F)^{i-T} \quad (3.4)$$

Where  $i$  represents the link travel time. Apply LN on both sides of Equation (3.4), the following Equation (3.5) can be derived.

$$i = T + \frac{LN(R)}{LN(1 - F)} = \beta t_a + \frac{LN(R)}{LN(1 - F)} \quad (3.5)$$

Equation (3.5) means that if the random link travel times for individual vehicles in microscopic traffic simulations are generated using Equation (3.5), the resulting distribution of link travel times will be consistent with the shifted geometric distribution of the TRANSYT platoon dispersion model.

One can also consider a shifted exponential distribution as a continuous equivalent of a shifted geometric distribution. The probability distribution function of a shifted negative exponential distribution takes the following form:

$$F(X \leq i) = 1 - \exp^{-\lambda(i-\mu)} \quad (3.6)$$

Comparing Equation (3.6) and Equation (2.2), one can logically assume that  $\mu = T = \beta t_a$ . By assuming that the means of the shifted geometric distribution and the shifted exponential distribution are equal and using Equation (2.5), one can get

$\lambda = \frac{1}{(1-\beta)t_a}$ . Therefore, if a random number between 0 and 1  $R$  is generated to represent the left side of Equation (3.6), the following Equation (3.7) will be derived by substituting the  $\mu$  and  $\lambda$  into the Equation (3.6).

$$R = 1 - \exp\left(-\frac{i-\alpha t_a}{(1-\beta)t_a}\right) \quad (3.7)$$

The solution of  $i$  in Equation (3.7) is

$$i = \beta t_a + (1-\beta)t_a \text{LN}\left(\frac{1}{1-R}\right) \quad (3.8)$$

As an illustration, Figure 3-2 shows the frequency distribution of the link travel times of 500 vehicles for a given set of  $\alpha$  (0.25) and  $\beta$  (0.8) with average link travel time of 40 seconds, which are dispersed based on the Equations (3.5) and (3.8). It is shown that the random link travel times of individual vehicles that are generated based on both the discrete geometric distribution and the continuous negative exponential distribution are almost identical. This confirms that the use of the negative exponential distribution is able to replicate the TRANSYT geometric distribution.

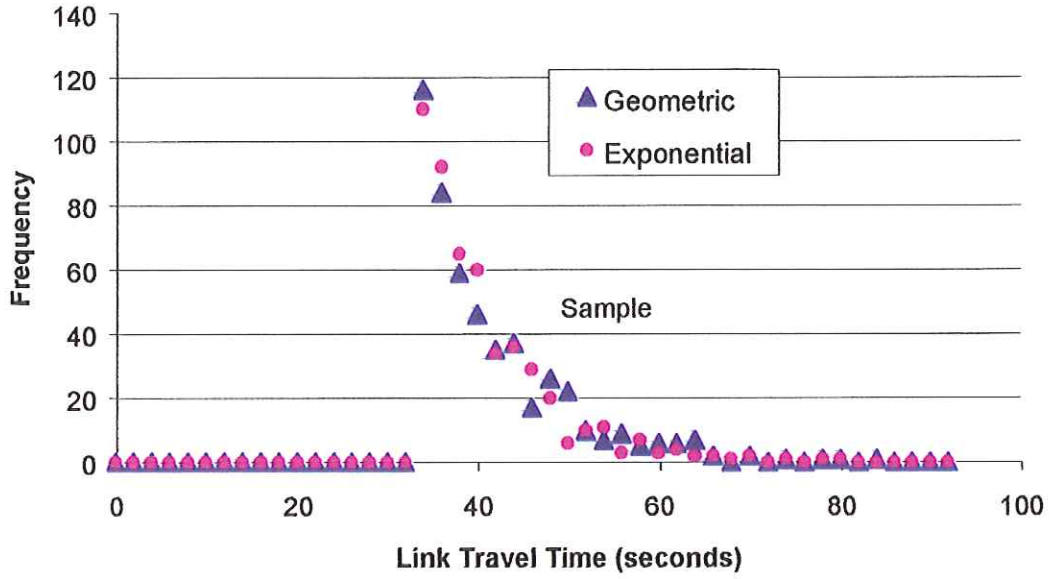


Figure 3-2: Sample Link Travel Time Distributions for Vehicles, which are Dispersed, based on a Shifted Geometric Distribution and a Shifted Negative Exponential Distribution

## CHAPTER 4

### NUMERICAL CALIBRATION AND COMPARISON

This chapter will first use some assumed link travel times to calibrate the platoon dispersion parameters, implement the TRANSYT simulation model and compare the results. Then, a field data collection effort is made to justify the need for calibrating the platoon dispersion parameters based on the proposed technique in this report.

#### ***4-1. Calibration and Comparison for TRANSYT Implementation***

Though the proposed technique for calibrating the platoon dispersion parameters in this report is ideally suited for real-time applications under ATMS, it is difficult to test its effectiveness without a real system as the test-bed. At this time, the TRANSYT is still the only available software for testing purposes.

The technique proposed in Chapter 3 for calibrating the platoon dispersion parameters indicates that all the platoon dispersion parameters are functions of the standard deviation of link travel times. Hence, the test here will emphasize on how different standard deviations of link travel times will affect calibration results and the TRANSYT implementation.

It is assumed that, in a simple scenario with a link connecting two adjacent intersections, the average link travel time is 60 seconds. Three different standard deviations of link travel times are used for the numerical test purpose. In reality, different standard deviations of link travel times may reflect different roadway and traffic conditions that impede the travel of vehicles. These conditions include the lane width, grade, curvature, traffic volume, percentage of heavy vehicles, driver population and so on. Three standard deviations are tested: 30, 20 and 10.

In the first scenario, as shown in Table 4-1, the platoon dispersion factor  $\alpha$ , the travel time factor  $\beta$  and the smoothing factor  $F$  are calibrated using the proposed calibration technique. Although these parameters are calibrated, since the current version



of TRANSYT does not permit users to input the value for  $\beta$ , the actual used parameters for  $\beta$  and F are slightly different from the calibrated when TRANSYT is implemented, as shown by the last two columns in Table 4-1. Therefore, only the calibrated value for  $\alpha$  can be externally input into the TRANSYT, which obviously cannot secure the accuracy of the platoon dispersion predictions in TRANSYT.

With this consideration in mind, the second scenario is designed. It is known that TRANSYT will only use  $\beta$  and F in its calculation of platoon dispersions. Thus, the value of  $\alpha$  is only used as an intermediate parameter for TRANSYT. Therefore, the second scenario is designed to let TRANSYT use the calibrated F value. To this end, the calibrated F value is fixed and then the  $\alpha$  value is calculated conversely using the Equation (1.4) and the 0.8 for  $\beta$ . In this way, the input  $\alpha$  value into the TRANSYT will ensure that the calibrated F value is actually used by TRANSYT.

Scenario	Link Travel Time = 60 seconds						
	$\sigma$	Calibrated Parameters			Actual Used Parameters		
		$\alpha$	$\beta$	F	$\alpha$	$\beta$	F
1	30	0.9675	0.5083	0.03278	0.9675	0.8	0.02108
	20	0.4817	0.6749	0.04877	0.4817	0.8	0.04146
	10	0.1884	0.8415	0.09513	0.1884	0.8	0.09957
2	30	0.9675	0.5083	0.03278	0.6147	0.8	0.03278
	20	0.4817	0.6749	0.04877	0.4064	0.8	0.04877
	10	0.1884	0.8415	0.09513	0.1982	0.8	0.09513

Table 4-1: Calibrated Platoon Dispersion Parameters for two Implementation Scenarios, which Contain three Different Standard Deviations of Link Travel Times

The TRANSYT-7F is implemented for the two scenarios in Table 4-1. A summary of the implementation results is tabulated in Table 4-2. It is shown from Table 4-2 that, for the standard deviation of 30 seconds, the resulting delays, stops and fuel consumption are reduced when the calibrated F value (Scenario 2) rather than the calibrated  $\alpha$  value is fixed. The fact that the offset did not change can be interpreted as

that the use of the calibrated F value results in a better prediction of platoon dispersions without affecting the optimization result of offset. For the standard deviation of 20 seconds, the offset for using the calibrated F value is different from the offset for using the calibrated  $\alpha$  value. While the delay is not improved, both stops and fuel consumption are reduced for the second scenario. For the 10 seconds of the standard deviation, the resulting offset and delay remain the same, while stops and fuel consumption are increased.

It seems from the results of Table 4-2 that there is not a systematic trend on how the results will change when the calibrated F value rather than the calibrated  $\alpha$  value is used as the input to the TRANSYT model. In fact, the TRANSYT model always fixes the value for  $\beta$  to 0.8, which causes the inaccurate calculation of the lag time factor T, which is the crucial factor to determine when the first vehicle in the platoon will arrive at the downstream end of the link. Therefore, the predictions of the platoon dispersions cannot be accurate without allowing users to change the value of  $\beta$ . The only way to solve this problem is to fundamentally change the input format of the TRANSYT as suggested in Section 3-2.

Scenario	$\sigma$	Offset (seconds)	Delay (veh- hr/hr)	Stops (veh/hr)	Fuel Consumption (lit/hr)
1	30	67	2894	3062	8272
	20	67	2891	3063	8265
	10	53	2894	2402	8257
2	30	67	2892	3055	8267
	20	63	2891	2994	8261
	10	53	2894	2412	8258

Table 4-2: TRANSYT Implementation Results for three Different Standard Deviations of Link Travel Times

## **4-2. Calibration with the Field Data**

In the two scenarios of Section 4-1, the standard deviation of link travel times was intentionally pre-assumed. However, do these values of the standard deviation reflect any real network scenarios or are they realistic values? In order to answer this question, an effort was made to collect the field link travel time data and to calculate the standard deviation for a real world situation.

For the comparison purpose, two links between two pairs of the adjacent traffic intersections are selected for the data collection in the city of Houston. Location 1 represents two intersections at Richard J.V. & Holcombe and Fannin & Holcombe, while Location 2 represents two intersections at Greenbriar Dr. & Holcombe and Kirby & Holcombe. The links of the two selected locations are located on the same street called Holcombe, which has three lanes in each direction. The link on Location 1 was measured to be 320 meters long and the link on Location 2 was found to be 560 meters. The traffic on the two links is quite heavy between 3:00 and 4:00 pm of weekdays, which was the time period when the field data were collected.

Table 4-3 lists all the collected travel time data from the two locations. The average link travel times for two links were found to be 23.66 and 40.50 seconds and their respective standard deviations were 2.22 and 4.85 seconds. Then the platoon dispersion parameters of  $\alpha$ ,  $\beta$  and  $F$  are calibrated and listed in the table. The values for the platoon dispersion factor are found to be 0.0813 and 0.1211 for two locations, both of which are different from the recommended value of 0.35 by TRANSY Manual for U.S. urban streets. The values of travel time factors are found to be 0.9248 and 0.8919, which are also different from the fixed value of 0.8, which is currently being used in TRANSYT. Finally, the values of the smoothing factor  $F$  are found to be 0.36 and 0.186, which implicates that the smoothing factors are different for different link travel times even on the same street.

The calibration results of platoon dispersion parameters indicate that in a real traffic network, platoon dispersion parameters are indeed different, even on the same

street. Therefore, they must be calibrated and made link specific for being used in predicting vehicles' progressions.

Data #	Travel Time (seconds) (Location 1)	Travel Time (seconds) (Location 2)
1	19.95	38.69
2	23.81	38.22
3	24.96	34.90
4	24.10	40.13
5	23.11	29.08
6	24.78	43.76
7	20.91	46.63
8	23.62	34.62
9	22.71	41.04
10	26.75	42.78
11	25.74	40.53
12	19.96	41.62
13	23.12	43.72
14	27.61	45.15
15	23.74	46.62
Average Travel Time $t_a$	23.66	40.50
Standard Deviation $\sigma$	2.22	4.85
Platoon Dispersion Factor $\alpha$	0.0813	0.1211
Travel Time Factor $\beta$	0.9248	0.8919
Smoothing Factor F	0.3600	0.1860

Table 4-3: The Field Collected Link Travel Time Data and the Calibrated Platoon Dispersion Parameters



## CHAPTER 5

### CONCLUSIONS AND RECOMMENDATIONS

This research analyzed the internal modeling and calibration logic of the TRANSYT macroscopic platoon dispersion model. It is found that the commonly accepted recursive TRANSYT platoon dispersion model is equivalent to a non-recursive shifted geometric probability distribution of link travel times. It is also found that the default values of platoon dispersion parameters currently used in TRANSYT result in internally inconsistent link travel times. Specifically, the mean link travel time varies with  $\alpha$  for a fixed  $\beta$  value. Therefore, the use of a fixed  $\beta=0.8$  results in that the average link travel time, which is input into the platoon dispersion model, will not always produce the same average link travel time as an output of the platoon dispersion model. Therefore, unless  $\alpha=0.25$ , the consistency between the average travel time in and out of the model cannot be maintained.

In this context, the research established a direct mathematical correspondence between the TRANSYT platoon dispersion parameters and the link travel time statistics by analyzing the equivalent shifted geometric distribution form of the original platoon dispersion model. Subsequently, a new technique for calibrating the platoon dispersion parameters was proposed. The proposed technique calibrates the values of  $\alpha$ ,  $\beta$  and  $F$  directly from the average link travel time and the standard deviation, which could practically capture all of the roadway and traffic conditions in the field.

The proposed technique for calibrating the platoon dispersion parameters is ideally suited for applications in ATMS where the required link travel time information can be collected on a real-time basis. The use of the new calibration technique will enable more accurate predictions of the platoon dispersion along the street. Therefore, the determined coordinated traffic signal timings will be more optimal and the resulting delays, fuel consumption, and vehicle emissions will be reduced.

The research found that though the shapes of different distributions of the platoon dispersion, such as shifted geometric, normal speed and normal time, are essentially different, a combination of the departure flow patterns from the upstream end of the link results in similar downstream arrival patterns for all types of distributions. It is, therefore, concluded that the type of the distribution is not critical in predicting platoon dispersions. Rather, the accurate calibration of the platoon dispersion parameters is more important.

Since the accuracy of the calibrated platoon dispersion parameters based on the real-time link travel time information is a big concern to the practitioners, the research also recommended a way of determining the confidence limits of the calibrated values. Using the chi-squared distribution, the required sample size for calibrating the platoon dispersion parameters with a given confidence level can be determined.

A numerical example indicates that different standard deviations indeed result in completely different platoon dispersion parameters, which then result in different signal timings, delays, stops and fuel consumption. However, since the current version of TRANSYT does not permit users to input the value for  $\beta$ , it failed to verify a systematic trend for different values of the platoon dispersion parameters. In this context, this report recommends that the TRANSYT-7F input file be modified to allow users either input both  $\alpha$  and  $\beta$  values or input the standard deviation of link travel times.

A field collection of link travel time data was conducted. It is found that the links with different average link travel time and the corresponding standard deviation, even on the same street, should use completely different platoon dispersion factors, which basically contradicts the recommendations by the TRANSYT-7F Manual. Therefore, the actual link travel time statistics are more influential to the platoon dispersion parameters than simply the nature of the street. This conclusion further confirmed the need for making the platoon dispersion parameters site specific.

The following recommendations are provided in order to further study of this report:

1. A comprehensive study is needed with respect to analyzing quantitative reductions of delays, stops and fuel consumption by using the proposed technique for calibrating the platoon dispersion parameters. Such a study will require changing some of the internal codes of TRANSYT to permit users the ability to adjust all of platoon dispersion parameters.
2. A real-time coordinated traffic signal control system in ATMS should be identified as the test-bed for the proposed technique. A framework should be developed to identify how the real-time link travel time data are channeled for use in calibrating the platoon dispersion parameters and how the accuracy of the calibration is ensured.





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