

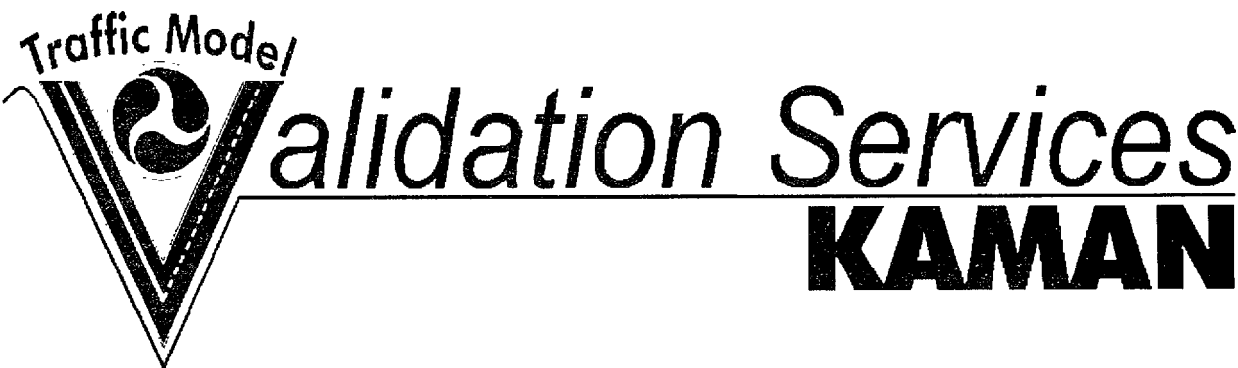


# **A Compendium of Traffic Model Validation Documentation and Recommendations**

*Phase I, Tasks A-H*

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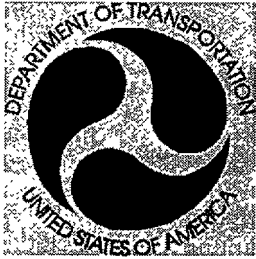
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# A Compendium of Traffic Model Validation Documentation and Recommendations

## *Phase I, Tasks A-H*

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### Forward

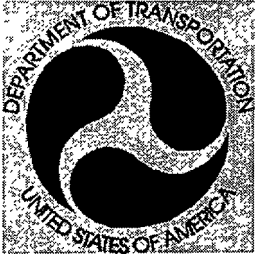
The intent of this report is to consolidate the documentation delivered to FHWA for the Databases for Assessment of Operation Tests and Traffic Models contract. The contents are arranged by tabs corresponding to the statement of work tasks listed below. The titles of the contents of each tab and the corresponding task(s) they address are listed below.

<b>Tab 1</b>	Traffic Model Validation and Data Requirements	Tasks A & B
<b>Tab 2</b>	Data Inventory Working Paper	Task C
<b>Tab 3</b>	Data Acquisition for Traffic Model Validation	Task D & E
<b>Tab 4</b>	Traffic Model Validation Methodology	Task G
<b>Tab 5</b>	Database Management System, Vendor Recommendations and Preliminary Design	Task F
<b>Tab 6</b>	Preliminary Work Plan	Task H

Task H is addressed by the recommendations that are included in each of the white papers. A specific section is not devoted to addressing them, since the suggested implementation of the recommendations culminated in the preliminary work plan tasks

Some introductory remarks are required to understand the rationale used in the white papers provided in this compendium. Several months into this project, it became clear to Kaman and FHWA that validation and calibration of the TRAF family of codes in their present form was not going to be a fruitful exercise nor an efficient use of resources. This is because the traffic codes have been developed and modified primarily to permit macroscopic evaluations of traffic flow. Thus the models simulate general trends in the traffic patterns, not absolutes. In addition, the implementation of the code has not been well documented to permit easy access to the traffic parameters under study. Since validation and calibration is performed on a microscopic level, comparisons between the actual measurements and simulation results can be done only at a very coarse level to obtain correlation between the two.

As a result, FHWA and Kaman traffic engineers agreed that a small-scale traffic simulation testbed was required. This testbed will be used to explore various traffic models and to mature the validation and calibration methods. Another advantage of the testbed is that there will be an in-depth understanding of the source code and full control of the implemented traffic parameters so direct comparisons to collected traffic data can be made. The testbed will also permit various models to be compared in a controlled environment to assist in recommending enhancements to the models in the TRAF codes. The incompatibility of the TRAF simulations to the collected test data and the need for a calibrated testbed are themes that flow throughout the white papers and congeal in the implementation of the Small-Scale Traffic Simulation Testbed tasks outlined in the work plan located in tab 6. In addition, the Validation Services



# A Compendium of Traffic Model Validation Documentation and Recommendations

## *Phase I, Tasks A-H*

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System for Traffic tasks will develop a pilot database management system to permit users not only to access the data collected at selected sites, but to access the models developed under the Small-Scale Traffic Simulation Testbed.



# A Compendium of Traffic Model Validation Documentation and Recommendations

*Phase I, Tasks A-H*

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***Prepared by:***

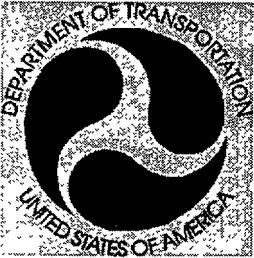
Kaman Sciences Corporation  
PO Box 7463  
Colorado Springs, CO 80933

***Authors:***

Larry E. Owen, PI  
Gary Brock  
Scott Mastbrook  
Rick Pavlik  
Lei Rao  
Charlie Stallard  
Srinivasa Sunkari  
Yunlong Zhang

***Prepared For:***

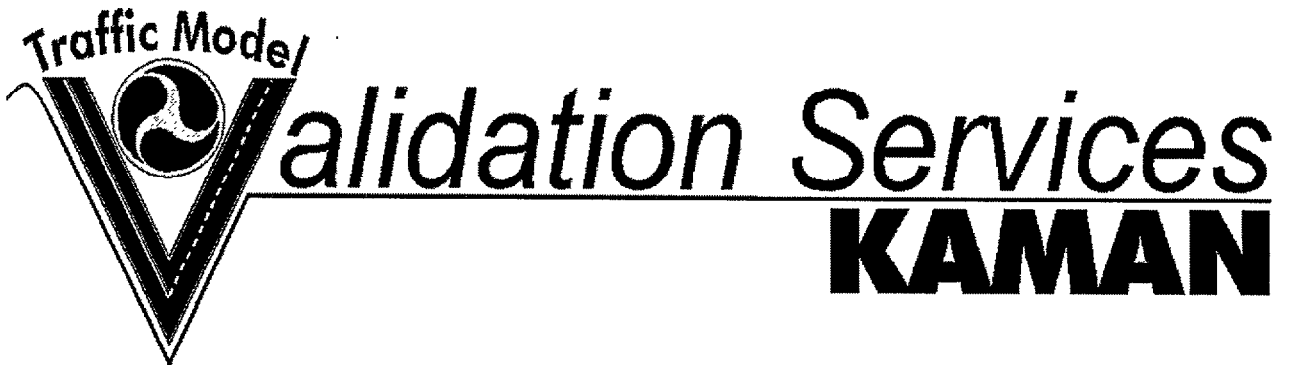
US Department of Transportation  
Federal Highway Administration  
IST Division, HSR-10  
6300 Georgetown Pike  
McLean VA 22101

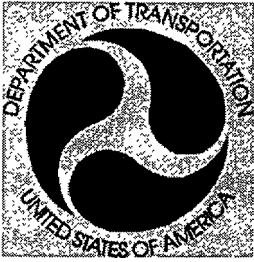


# Data Requirements for Traffic Model Validation

*Tasks A & B*

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# Data Requirements for Traffic Model Validation

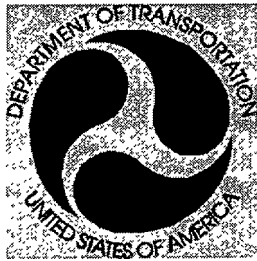
## *Task A & B*

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### **Forward**

Traffic models are widely and very successfully used by traffic professionals for optimization, planning and analysis. As these models expand in scope and complexity to meet the diversity of applications, validity continues to be an issue with users and decision makers. Often, the documentation, methodology or extent of the validation efforts are insufficient to establish a high confidence level in model results. Part of the difficulty with validation is suitable and accessible data to complete the process. To address these issues, the Federal Highway Administration has sponsored this research effort to identify the most effective procedures for validating certain components of the TRAF family. In conjunction with this effort, a database will be developed to satisfy the data requirements of this program.

A basic overview of validation is included in Section 1. Section 2 identifies and defines important traffic model and validation concepts, model-specific characterizations are contained in Section 3, and a description of preparatory activities for validation studies is contained in Section 4.



# Data Requirements for Traffic Model Validation

*Task A & B*

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*Prepared by:*

Kaman Sciences Corporation  
PO Box 7463  
Colorado Springs, CO 80933

Authors:

Larry E. Owen, PI  
Greg Krueger  
Scott Mastbrook  
Lei Rao  
Srinivasa Sunkari

Dr. James Williams, University of Texas, Arlington

*Prepared For:*

US Department of Transportation  
Federal Highway Administration  
IVHS Research Division, HSR-11  
6300 Georgetown Pike  
McLean VA 22101

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# Section 1. Introduction

The overall program scope and objectives of this inquiry are described below. This inquiry addresses the many facets of the validation process, therefore, a brief overview of traffic model validation is included in the introduction. This study emphasizes traffic flow models as opposed to other categories and components of traffic models. Traffic flow models generally consist of vehicle and driver performance and response models.

## ***Overall Program Scope and Objectives***

The objectives of the FHWA program are summarized as follows:

- Establish procedures and determine data requirements for validation and calibration (V&C) of traffic models.
- Determine the availability and utility of data from operational tests and other sources to support this V&C process.
- Develop a comprehensive database for model validation, calibration and assessment of ITS Services.
- Validate and calibrate selected critical functions of the TRAF family of models.

It should be emphasized that **the scope of this program only extends to the validation and calibration of selected critical functions of the TRAF family**. The reference to other traffic models is only for the purposes of extending the potential utility of program information, and to identify and implement unifying principles. A model's inclusion or exclusion does not constitute an endorsement or lack of endorsement by the FHWA.

## ***Utilization of the Inquiry Results***

In response to the objectives of this program, this inquiry will collect perspectives on traffic model development and V&C from knowledgeable developers and researchers. This information will **be** used to:

- Identify and synthesize of data requirements.
- Define state-of-the-practice V&C methods.
- Assess applicability of existing data.
- Establish guidelines for future data collection or augment certain future operational tests.
- Guide the design of a Database Management System (DBMS) to contain and make available existing and future applicable data.

## **Organization of This Inquiry**

The content of this document is organized into five main sections:

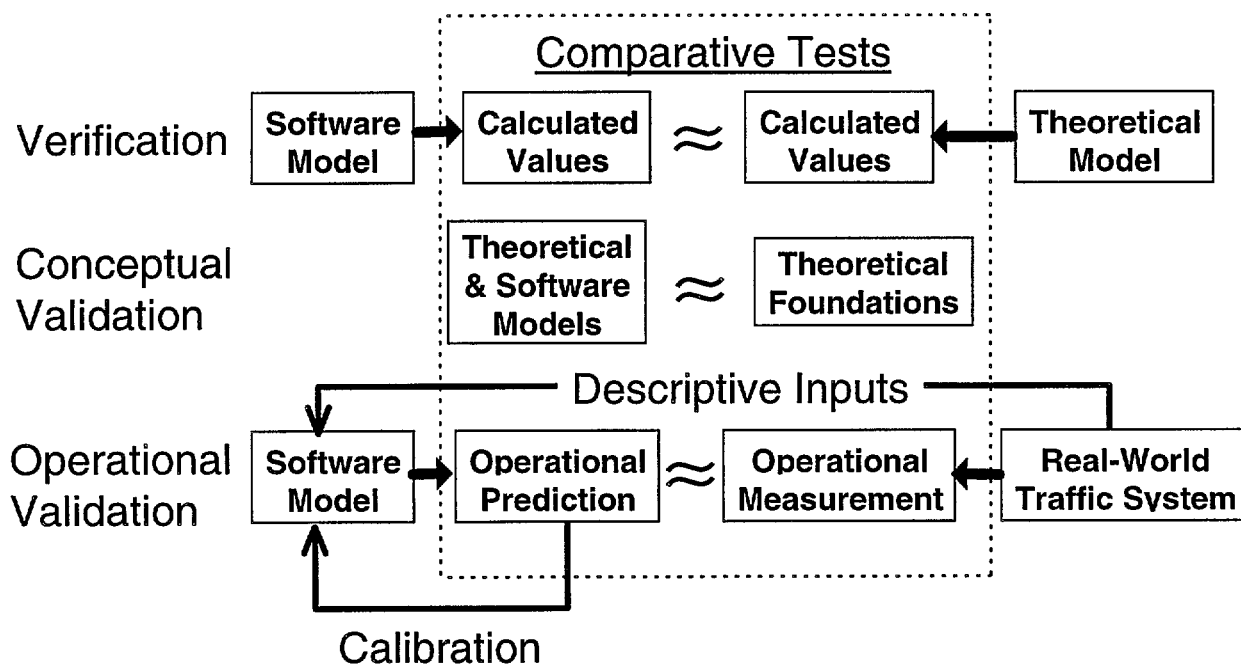
- Section 1 is an introduction to the program and inquiry objectives including a brief introduction to model validation.

- Section 2 introduces and defines concepts that are important to the study.
- Section 3 contains characterizations of various traffic models primarily for the purpose of identifying data requirements and significant traffic flow components.
- Section 4 contains specific illustrations of the preparatory efforts leading up to data collection and, validation and calibration.

### ***A Brief Overview of Model Validation***

Verification and validation are the traditional methods to assure model correctness. Each of these methods consists of comparative tests that measure model consistency with a benchmark as shown in Figure 1-1. Verification consists of evaluating calculated values from the software model compared to the corresponding values from the theoretical model. Validation is divided into two aspects: conceptual and operational. Conceptual validation is a process of assessing the theoretical and software models against sound and accepted theoretical foundations. The operational validation process consists of comparisons between model operational predictions and measured real-world system operational behavior.

The models discussed in this document have, at some point and to varying degrees, been verified and validated. In addition, these models continue to be verified and validated, albeit in an unsystematic and inconsistent manner, by developers and users. The objective of this study is to formulate a systematic validation process for application to the TRAF family.



***Figure 1-1 Traditional Methods to Assure Model Accuracy***

For the most part, this study will concentrate on the validation processes. This should not be interpreted as underestimating the benefits of verification procedures. However, rigorous verification requires exhaustive parametric studies comparing theoretical results with values from the software manifestation of each independent component. In the case of the TRAF family, like many mature models, numerous modifications have been made solely to the

existing software models. In addition, verification does not measure the relative merits of the theoretical model. Therefore, verification, in this case, is somewhat intractable and of limited value. Many of the same verification objectives can be accomplished through conceptual validation as described below.

The objective of the validation process is to build a body of evidence so that users and decision makers can use to judge the adequacy of a model. As indicated in Table I-I, the traffic model validation process consists of two parts: an evaluation of a model's conceptual representation and an evaluation of the behavioral prediction relative to corresponding real-world systems. The methods proposed to accomplish each aspect are also indicated in Table I-I. The implementation of these methods, in turn, requires specific information and data, as shown in the table.

**Conceptual Validation**

Conceptual validation is inherently less quantitative than operational validation. The primary focus of conceptual validation is on the underlying traffic flow theory. Conceptual validation is not necessarily a precursor to operational validation. Rather, conceptual validation is a concurrent and reoccurring process that takes place in conjunction with operational validation as described below. Conceptual validation may be prompted by inconclusive operational validation results.

The primary method for conceptual validation is the model walkthrough. A walkthrough involves a small group of qualified individuals who carefully review and revisit the model's logic and documentation. This group may also contrast existing logic with alternative methods as well as review the basic structure of the model. By observing computerized animation, the operation of the model can be confirmed.

Conceptual validation requires the identification of the model's underlying theory, usually described in the model's documentation, supporting academic literature, comparisons with alternative approaches, and the source code of the model itself. The criteria for conceptual validation are qualitative assessments of a model's theoretical underpinnings, and its implementation, evaluated in the light of sound and accepted theoretical methods.

**Operational Validation**

The primary methods of the operational validation process measure the consistency of model prediction compared to operational data from a real-world system. These comparative measures are usually derived from statistical techniques such as chi-square tests. When the model prediction conflicts with reasonable expectations during the course of operational validation, anomalous behavior is also identified and investigated. The identification of anomalous behavior is primarily accomplished through computerized animation showing the movement of vehicles through the traffic facilities. The model validation process also looks for

**Table 1-1 Validation Methodology and Information Requirements**

Validation	Primary Methods	Information Requirements
Conceptual	<ul style="list-style-type: none"> <li>• Model Walkthroughs</li> <li>• Contrast with Alternative Methods</li> <li>• Computerized Animation</li> </ul>	<ul style="list-style-type: none"> <li>• Software</li> <li>• Documentation/References</li> <li>• Criteria</li> </ul>
Operational	<ul style="list-style-type: none"> <li>• Comparative Tests</li> <li>• Computerized Animation</li> <li>• Symptom Generation</li> </ul>	<ul style="list-style-type: none"> <li>• Real-World Descriptive and Behavioral Data</li> <li>• Criteria</li> </ul>

instances where the model recreates difficulties that arise in the real-world or reproduces known results. Operational validation is, therefore, an empirical process, rather than a theoretical proof of the model's underlying paradigm.

Data requirements for operational validation consist of descriptive and operational data from the actual system. The nature of traffic models requires that certain real-world system descriptive parameters be converted and used as input to the model. Examples of descriptive parameters include geometric layouts, control system operation, and traffic volumes. Other parameters, such as travel time, are computed to describe the operational behavior of the real-world traffic system. The operational parameters are used for validation purposes

Operational validation criteria could include threshold values on the quantitative measures of consistency between model results and real-world data. A model is never an absolutely accurate translation of the real-world system. Therefore, realistic criteria for validation must always be less than a one-to-one correspondence to the real-world system. Also, a universal criterion is difficult to formulate. In addition, criteria are a function of the types of data collected and methods of comparison. For these reasons, the criteria development will be an evolutionary process that develops as the study progresses.

## Section 2. Concepts Related to Traffic Model Validation

This section identifies and defines a set of concepts that are important to the description and execution of the validation process. In addition, these concepts form the basis for the eventual synthesis of traffic modeling information into a database management system. In most cases, the definition of a term is taken from established technical or traffic engineering references. When an existing definition is insufficient or ambiguous, a working definition is formulated and tailored for the purposes of this study.

### **Definition 2-1 A Traffic System**

A 'system that consists of the following facilities and interacting elements:

- Roadways.
- Controls. (The combination of roadways and controls is generally referred to as facilities)
- Vehicles.
- Road Users.

### **Traffic Systems and Traffic Models**

Elements of a traffic system are analyzed using models of the system elements identified in Figure 2-1. Figure 2-1 establishes a boundary that divides the world into two regimes: the real world and the synthetic world. Models exist in the synthetic world and consist of approximations and representations of corresponding real-world elements. Models, if they are sufficiently accurate, enable analysis and experimentation to be performed without the expense and risk of trial-and-error in the real-world.

### **Definition 2-2 Model**

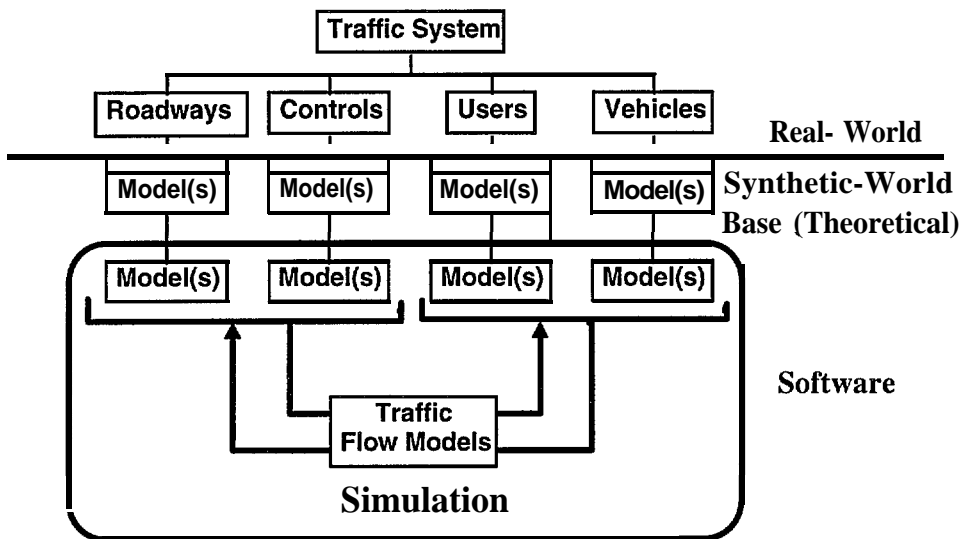
<sup>2</sup>An approximation, representation, or idealization of selected aspects of the structure, behavior, operation, or other characteristics of a real-world process, concept or system. **Note:** Models may have other models as components.

A model is typically formulated at a theoretical or base level. There are different types of base-level models as defined below (all except **theoretical** and **combination** taken from Reference 2):

- **Mathematical Model** - symbols and relationships
  - **Empirical** - derived from observation, experiment, or experience
  - **Working Definition of Theoretical** - derived from mathematical/physical principles
  - **Working Definition of Combination** - Empirical/Theoretical
- **Graphical Model** - diagrams

- e.g. street layouts
- **Tabular Model** - tabular form
  - e.g. fuel consumption tables
- **Narrative Model** - expressed in words
  - rules-of-thumb

When the term “model” is used, it does not necessarily imply computer software. In fact, for verification purposes, it is important to distinguish between the base and software models.



**Figure 2-1 Transitions from Real-World to Base Model, from Theoretical Model to Traffic Software Mode/**

### **Traffic Model Paradigms**

Historically, the traffic engineering community generally recognizes three types of traffic software models classified by their corresponding application:

- Traffic Signal Optimization.
- Traffic Assignment.
- Traffic Simulation.

Off-line models for signal optimization generally fall into two categories: 1) maximization of some desirable utility, such as bandwidth, and 2) minimization of delay, stops or other measures of disutility. Traffic assignment models compute the paths of vehicles through a

network typically by minimizing travel time from trip origin to destination. Note that both of these applications involve minimax solutions (searching, linear/non-linear programming algorithms) which usually limits the fidelity of the traffic flow models

The categories listed above overlap to some degree. A signal optimization or traffic assignment model can or cannot be classified as a simulation (discussed below). Signal optimization or traffic assignment models that are not simulations are generally referred to as simply analytical models

This study's emphasis is on simulations and their corresponding traffic flow components independent of whether the application is signal optimization, assignment or evaluation. Signal optimization and traffic assignment models must either contain significant traffic flow component models or depend heavily on basic assumptions about traffic flow. Validation and calibration, in the context of this study, refers to traffic flow aspects and does not extend to other components of signal optimization and traffic assignment.

When the term simulation is used here, the implication is "traffic system" simulation. A simulation must embody models of all traffic system elements as indicated in Figure 2-1. From a V&C perspective, the most significant components associated with simulations are traffic flow models to calculate the movement of vehicles and users through the facilities

TRANSYT-7F is an example of the most basic type of simulation. In TRANSYT-7F, platoon dispersion is characterized by an empirically-based macroscopic model. Models, such as PASSER-II, that characterize traffic flow by mostly scalar values such as average link speed and saturation flow rate, typically would not be categorized as simulations.

### **Traffic System Simulations**

Traffic simulations consist of component models for each of the system elements. Since the purpose of simulation is to predict the dynamic nature of the system, component models must exist to quantify the performance and response of vehicles and users (drivers and pedestrians) to control and roadways. Certain analytical techniques are employed within the traffic flow models. These constructs are characterized by contrasting perspectives and identify the type of logic used.

#### ***Definition 2-3 Working Definition of Traffic System Simulation***

A software model for conducting experiments using controlled inputs that explicitly reflect a given traffic system for the purpose of predicting the system's dynamic operational behavior due to existing or modified conditions. Such a model must have substantive component models of all traffic system elements and traffic flow as indicated in Figure 2-1.

There are certain common features of all traffic system simulations considered here. These common features include:

- **Symbolic** (as opposed to iconic) simulations capture the properties of the real system in mathematical and/or symbolic form that are, in turn, converted to software.
- **Dynamic** (as opposed to static) simulations describe the behavior of the traffic system through time.



### ***Discrete and Continuous***

Since the models considered here are dynamic, the simulation must have a mechanism to change the state of objects within the system. These mechanisms are categorized by either continuous, discrete or combined. These concepts are defined below.

#### ***Definition 2-4 Simulation Constructs Related to State Changes***

**Discrete** - A model that describes changes in system status only at isolated points in time.

**Continuous** - A model where changes to the system are described as a continuously occurring phenomena.

**Combined** - A model that represents some parts of the system as continuous and some parts as discrete.

### ***Microscopic and Macroscopic***

Macroscopic and microscopic are the most fundamental constructs of traffic flow modeling. Macroscopic and microscopic perspectives<sup>3</sup> are often employed with respect each of the three fundamental traffic parameters: speed, flow and density. Recent trends in model categorization have also identified mesoscopic modeling that combines aspects of both macroscopic and microscopic modeling (see the description of DYNASMART in Section 4 below).

#### ***Definition 2-5 Simulation Constructs Related to Scale***

**Microscopic Modeling** - A model that continuously or discretely predicts the state of individual vehicles; microscopic measures are individual vehicle speeds and locations

**Macroscopic Modeling** - Models that aggregate the description of traffic flow; macroscopic measures are speed, flow and density.

**Mesoscopic Modeling** - Models that have aspects of both of the above; analogous to combined discrete and continuous.

### ***Stochastic and Deterministic***

Because many factors associated with traffic flow are generally regarded as random processes, stochastic techniques are often used to represent real-world systems. Stochastic models have

#### ***Definition 2-6 Simulation Constructs Related to Random Variation***

**Stochastic Modeling** - <sup>2</sup>A model in which the results are determined by using one or more random variables to represent uncertainty about a process or in which a given input will produce an output according to some statistical distribution; stochastic methods are usually associated with microscopic modeling.

**Deterministic Modeling** - <sup>2</sup>A model in which the results are determined through known relationships among the states and events, and in which a given input will always produce the same output; deterministic methods are usually associated with macroscopic models.

the disadvantage of requiring a knowledge of the distributions and many replications to adequately sample the statistical distributions associated with traffic behavior.

Deterministic models, contrasted with stochastic, give aggregated or average values for performance or response. Thus, deterministic models do not require replications. The issue with deterministic models is how well they represent the variations in real-world behavior.

## ***Facility Descriptions***

The type of traffic facility has an important influence on the type of traffic flow modeling. There are two standard types of facilities as defined below.

### ***Definition 2-7 Facility Descriptions***

**Uninterrupted Flow** - <sup>4</sup>A category of traffic facilities having no fixed causes of delay or interruption external to the traffic stream; examples of such facilities include freeways and unsignalized sections of multilane and two-lane rural highways

**Interrupted Flow** - <sup>4</sup>A category of traffic facilities having traffic signals, STOP signs, or other fixed causes of periodic delay or interruption to the traffic stream; examples include intersections and arterials.

## ***Validation and Calibration (V&C)***

The overview of the operational validation process contained in Section 1 describes the necessity of real-world data. This real-world data must contain both descriptive and at least one component of operational data known (measured) with precision. With this data, the model can be executed and the model prediction compared to the real-world operational data. In an attempt to improve this comparison, iterative steps can be taken to modify some input variables

### ***Definition 2-8 Working Definition of Calibration***

Calibration is the iterative procedure of modifying certain vehicle or user (driver or pedestrian) performance or response input parameters during operational validation with the objective of improving the consistency between model prediction and observed real-world system operational data; calibratable parameters usually have some known range of uncertainty.

whose precise values are unknown. These steps are referred to as calibration.

Calibration is the implicit recognition that not all parameters can or will be known or measured with precision, but whose values are bounded or distributed in some reasonably established manner. Additionally, only specific parameters are available for calibration purposes (see Section 4 for model-specific identification of such parameters). For example, adjusting any descriptive traffic input parameter, such as volumes, to achieve a better comparison to real-world traffic flow data is usually inappropriate. Adjusting input parameters beyond either physical or common-sense limits just to obtain a better comparison is also unacceptable for validation purposes. Calibration also carries the connotation of small scale changes or refinements to a limited set of default input values. Calibration requires engineering judgment, therefore, the set of parameters that can be calibrated effectively is also dependent upon the degree of user sophistication and experience with the model.

## **Relationship Between Model and Intended Application**

Overlaying the other considerations described in this section is the relationship between the application scenario and the complexity of the model. For example, practitioners would rarely use a stochastic, microscopic model to routinely assess basic intersection capacity. Neither would thoughtful practitioners use a macroscopic, deterministic model to assess reactions of the road-user population to very subtle changes in control.

Going beyond this basic balance between model complexity and the required output detail is the application of one given model in situations requiring different levels of output detail. For example, some users will use microscopic models to measure subtle effects in a large network, where they are interested in the network-wide comparison of before and after performance. These same users might also use microscopic models in small networks to assess the effects of control changes on a particular traffic stream, or even on a particular class of users within that traffic stream (such as buses). Both applications may justify the use of a detailed microscopic simulation, either because of the subtlety of the effects being evaluated or because of the required output resolution. These applications require much different levels of calibration.

The technique needed to assure the model's accuracy on an aggregate level will be much different than the technique required to assure accuracy at the detailed level. Likewise, the data required to support aggregate-level calibration will be very different from the data needed to support detailed-level calibration.

From a practical standpoint, aggregate-level calibration will be most often applied in large network situations, where the resources required for detailed-level calibration are not usually available. Likewise, situations requiring highly detailed output will usually be formulated as small networks to control the cost of performing the simulation.

In the discussions that follow, the potential applications are divided into categories based on output detail. The categories are network, link/node and vehicle.

## **Stages of V&C**

A validation stage identifies a combination of facility geometrical extent and degree of complexity in traffic flow conditions. The concept of a validation stage is important for two reasons: 1) the various stages identify the progression of the V&C process, and 2) increasing stages impose basic limitations on the data collection and reduction that can be accomplished.

Table 2-2 shows five different levels of V&C as a function of facility extent and the degree of traffic flow complexity. Section 5 contains illustrations and discussion of a Stage 1 V&C process for interrupted and uninterrupted flow.

**Table 2-2 Stages of the V&C Process**

<b>V&amp;C Stage</b>	<b>Interrupted Flow</b>	<b>Uninterrupted Flow</b>
<b>0</b>	Sign controlled isolated intersection	Free flow conditions
1	Single Link, signal controlled at each end	Representative Segment with on and off ramps
2	Arterial or Small Grid	Lane drop or closure (Bottleneck)
3	Network	Freeway Density contour map
4	Combinations of Interrupted and Uninterrupted Facilities	

Even at the lower stages of V&C, several factors influence the complexity. For example at Stage 1 of interrupted flow shown in Figure 4-1, the following traffic flow parameters increase the complexity of the V&C process and data collection:

- Traffic volume
- Sources and sinks
- Link length
- Distribution of turning movements
- Vehicle types
- Hills, curves
- Number of lanes
- Driver types

The validation process starts at a low level of facility extent with a minimum of complexity. This is discussed in more detail in the section that follows.

## Section 3. Model-Specific Characterizations and Data Requirements

This section briefly describes the characteristics of various models, their data requirements in the form of a matrix, and any significant traffic flow components. The data requirements matrix basically categorizes the input and output data. The input data can be of two types: Descriptive data and Modifiable data. Descriptive data are, in general, non-calibratable and essential to the representation of specific site characteristics and conditions. Examples of descriptive data are number of intersections, link lengths, and traffic volumes among others. Modifiable data are inputs that can be changed, at the discretion of the user, to better match the local conditions. Examples of modifiable input data are number of sneakers, phase loss time, and average speeds

Modifiable data are not optional inputs. Rather, the user must decide either to accept the default values or change the parameter to a value that better reflects local conditions. A change in input value is usually based on actual field site information or expert guidance (sources of expert guidance are individuals, “rules-of-thumb”, handbooks, manuals, etc.). The user who does not have access to such information accepts the default values.

With the introduction of operational characteristics measured at the referent field site (corresponding to model predictions), tuning model input parameters so that model prediction better matches this information can be attempted. There are two levels of calibrated data: Basic and Advanced. Basic calibration data contains most of the Modifiable input data. Some of the input data which will not have a significant impact on calibration may be left out. For example in PASSER-II, ideal saturation flow rate was not carried over to the Basic Calibration Data category. The power user, who makes a significant effort to accurately calibrate the model through extensive data collection, usually employs advanced calibration parameters. The input data in this category will be a subset of the input data in the previous category. For example while PASSER-II does not contain any input data which can be extensively calibrated, TRANSYT-7F contains the platoon dispersion factor which can be calibrated in greater detail.

Input data are also being categorized by the scale of the model’s applications and the intended output resolution, as discussed in the previous section. First, input data can be required on a network or arterial wide basis. Examples of aggregate data are number of intersections and number of sneakers in PASSER-II and PI definition and Network-wide loss time in TRANSYT-7F. Next, data can be input on a link or node (intersection) level. In general, input requirements are concentrated at this level. Examples of link/node input data are volumes, link lengths, saturation flow rates, and speeds. Finally, data can be input which will impact individual vehicles. Data at this level will mostly be required for microscopic traffic models.

### ***PASSER-II Characterization and Data Requirements***

‘PASSER II is a computer program that can assist traffic engineers in the analysis of individual signalized operations as well as optimization of coordinated arterial street systems. PASSER is an acronym for Progression Analysis Signal System Evaluation Routine and was developed by the Texas Transportation Institute at Texas A&M University for the Texas Department of Transportation

PASSER II maximizes the bandwidth for the major arterial by adjusting the phasing sequences and offsets of the coordinated phases. It does not consider any progression along the cross-street. It then finds an optimum cycle length that maximizes arterial bandwidth and then

minimizes system delay based on that bandwidth. PASSER II features include provisions for actuated and pretimed control, an engineer's assistant key to compute saturation flow rate using the Highway Capacity Manual (HCM) methodology, and the capability of modeling permitted left turns. PASSER II can be used as an evaluation as well as an optimization program.

### **Significant Traffic Flow Components**

PASSER II models all types of left-turn treatments, i.e., protected, permitted, and protected-permitted operations. The computation of phase capacity for protected mode of operation is done by estimating the saturation flow rates for left turn movement in a protected mode which is very simple to measure in the field. The capacity for permitted operation is obtained by computing the saturation flow rate which depends on traffic demand for the opposing through movement, the acceptable gap, and discharge headway. For computing the capacity of protected-permitted operation, PASSER II computes the capacity of the protected and permitted portion of the phase separately and estimates the total capacity of the left-turn phase. The model used by PASSER II uses a number of variables and can be calibrated to better suit local conditions.

### **Data Requirements Matrix**

PASSER II contains little data that can be calibrated extensively (Table 3-I). It is also a macroscopic model. The model does not require any data that is vehicle or driver specific. Hence, the matrix does not contain any Advanced *calibration* data or detailed individual Vehicle data.

### ***PASSER-IV Characterization and Data Requirements***

PASSER IV is also developed at the Texas Transportation Institute for the Texas Department of Transportation and is currently the only practical network based program that can optimize and derive an optimum bandwidth solution for coordinated networks. The program can currently optimize up to twenty arterials and thirty five intersections. PASSER IV is being modified to increase the number of arterials and intersections it can optimize.

PASSER IV can be used for one-way streets, single arterials, and multi-arterial closed loop networks. The user can define the priorities for progression for various arterials as well as the direction of traffic along the arterial. The user can even allow the program to pick the weights for the progression based on traffic volumes.

PASSER IV provides one global and two heuristic optimization procedures. The program picks an optimum cycle length based on the range of given cycle length and the weight given to cycle length minimization. The user can also generate a desired number of solutions. The advantage of having multiple solutions generated is that one of those solutions could be more easily implemented than the others without compromising the optimization process.

**Table 3-1 PASSER-II Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	<i>Descriptive data (non-calibratable)</i>	<ul style="list-style-type: none"> <li>• #of intersections</li> <li>• Cycle length range</li> </ul>	<ul style="list-style-type: none"> <li>• Traffic volumes</li> <li>• Lane configuration</li> <li>• Link lengths</li> <li>• Phase patterns</li> </ul>	N/A
	<i>Modifiable data (Calibra table)</i>	<ul style="list-style-type: none"> <li>• # of sneakers</li> <li>• Phase loss time</li> <li>• Ideal saturation flow rate</li> </ul>	<ul style="list-style-type: none"> <li>• Saturation flow rate</li> <li>• Speeds</li> <li>• Queue clearances</li> <li>• Offsets</li> <li>• Minimum phase times</li> </ul>	N/A
	<i>Basic calibration data</i>	<ul style="list-style-type: none"> <li>• # of sneakers</li> <li>• Phase loss time</li> </ul>	<ul style="list-style-type: none"> <li>• Saturation flow rate</li> <li>• Speeds</li> <li>• Queue clearances</li> <li>• Offsets</li> </ul>	N/A
	<i>Advanced Calibration data</i>	N/A	N/A	N/A
Output		<ul style="list-style-type: none"> <li>• Bandwidth</li> <li>• Efficiency</li> <li>• Attainability</li> <li>• Avg. Int. delay</li> <li>• Total system delay, stops, and fuel consumption</li> <li>• Total number of vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• V/C ratio</li> <li>• Int. Delay (secs/veh)</li> <li>• Queue (veh/lane)</li> <li>• Stops (stops/hr)</li> <li>• Fuel consumption (gal/hr)</li> </ul>	N/A

**Significant Traffic Flow Components**

PASSER IV can model protected and permitted mode of left-turn treatment. The user can also allow PASSER IV to vary the speed on various links to have better progression along the arterial. Apart from these minor models, PASSER IV does not appear to have any significant sub-models which can be calibrated.

**Data Requirements Matrix**

Similar to PASSER II, PASSER IV also does not require any data which can be calibrated extensively as shown in Table 3-2. It is also a macroscopic model. The model does not require any data which is vehicle or driver specific. Hence, the matrix does not contain any Advanced calibration or Vehicle data.

**TRANSYT-7F Characterization and Data Requirements**

<sup>7</sup>TRANSYT-7F is a traffic simulation and signal timing optimization program. It is one of the most comprehensive tools for traffic signal timing and analysis for two dimensional networks. TRANSYT is macroscopic in nature. However, TRANSYT simulates traffic flow in small time increments, so that it's representation of traffic is more advanced than other macroscopic models. One of the most significant features of TRANSYT is it's platoon dispersion algorithm that simulates the dispersion of a platoon of vehicles as they travel downstream.

**Table 3-2 PASSER-IV Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	<i>Descriptive data (non-calibratable)</i>	<ul style="list-style-type: none"> <li>• # of arterials and intersections</li> <li>• Cycle length range</li> </ul>	<ul style="list-style-type: none"> <li>• Node identification number</li> <li>• Direction of NEMA 2 movement</li> <li>• A-Direction on cross-street</li> <li>• Link length</li> <li>• Volumes</li> <li>• Lane assignment</li> </ul>	N/A
	<i>Modifiable data (Calibratable)</i>	<ul style="list-style-type: none"> <li>• System wide loss time</li> <li>• Arterial and directional priority</li> <li>• Avg. speeds, speed range, allowable speedchange</li> </ul>	<ul style="list-style-type: none"> <li>• Saturation flow rates</li> <li>• Lost time</li> <li>• Link speed and speed variation</li> <li>• Queue clearances</li> <li>• Minimum phase times</li> </ul>	N/A
	<i>Basic Calibration data</i>	<ul style="list-style-type: none"> <li>•</li> </ul>	<ul style="list-style-type: none"> <li>• Saturation flow rates</li> <li>• Lost time</li> <li>• Link speed and speed variation</li> <li>• Queue clearances</li> </ul>	N/A
	<i>Advanced Calibration data</i>	N/A	N/A	N/A
output		<ul style="list-style-type: none"> <li>• Bandwidth</li> <li>• Efficiency</li> <li>• Attainability</li> </ul>	<ul style="list-style-type: none"> <li>• Link travel time (secs)</li> <li>• Average speed (mph)</li> <li>• Intersection stopped and approach delay (secs/veh)</li> <li>• V/C ratio</li> </ul>	N/A

**Significant Traffic Flow Components**

The simulation model used by TRANSYT can be described in two steps. As vehicles are discharged from a queue at the stop-line after the signal indication turns green, the model first accounts for the start up lost time of the vehicles. Then the discharge slowly starts and the rate of discharge increases until it reaches a point known as *saturation flow rate*. TRANSYT models the discharge in small time increments and develops a “flow profile” histogram.

As traffic moves downstream, the initially tight platoon formed from the departing queue tends to disperse the farther downstream it travels. This is because drivers tend to increase their



space headway as they increase their speeds for safety reasons TRANSYT models the platoon dispersion phenomenon as the platoon travels downstream.

The major elements of the signal optimization process are number of phases, phase sequence, cycle length, interval and phase lengths (splits), and offsets. TRANSYT requires the number of phases, phase sequence, and a range of cycle lengths as inputs to the model. The model can then optimize signal timings, generate splits, offsets, and select an appropriate cycle length.

TRANSYT uses an objective function called the performance index (PI) in the optimization process. The PI is a linear combination of delay, stops, fuel consumption, maximum back of queue, and/or excess operating cost. The PI can also take into account progression opportunities (PROS) and assign weights to it to obtain better optimization results.

TRANSYT uses a gradient search technique to optimize splits and offsets. The process is also called the hill-climbing technique. Signal timings with various splits and offsets are simulated and the timings with the smallest PI are selected. Then the cycle length is also selected using the same logic Various cycle lengths are simulated and the one with the best value of PI is selected.

As mentioned earlier, one of the most important sub-models of TRANSYT is the platoon dispersion model. The user manual describes a recurrence equation to model the predicted flow rate. The recurrence relationship adjusts the profile of platoon flow by removing density from the leading edge of the platoon and applying it to the trailing edge. Two parameters are used to calibrate the recurrence relationship. One value is a shift parameter, known as beta, which adjusts the position of the downstream flow profile in time. Beta is fixed within TRANSYT. The other parameter is called the platoon dispersion factor (PDF) which controls the degree of dispersion, and therefore is related to the friction of the roadway. The PDF can be changed either for the entire network (Card Type 10) or for each link (Card Type 39). The PDF depends on various friction factors like parking, turns, pedestrian traffic, lane width, and the area. The default value of the PDF in CT 10 is 35. However, platoon dispersion is a very important factor in the traffic flow modeling in TRANSYT and PDF should be input after careful examination of local conditions.

### **Data Requirements Matrix**

Data requirements for TRANSYT-7F (Table 3-3) are also on a similar scale as the PASSER programs. However, TRANSYT-7F has the platoon dispersion factor which can be calibrated extensively. Hence, the platoon dispersion factor is the only input which can be classified as Advanced calibration data.

**Table 3-3 TRANSYT-7F Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	<i>Descriptive data (non-calibratable)</i>	<ul style="list-style-type: none"> <li>• # of intersections</li> <li>• Cycle length range and increment</li> <li>• PI definition</li> </ul>	<ul style="list-style-type: none"> <li>• Volumes</li> <li>• Lane configuration</li> <li>• Link lengths</li> <li>• Phase pattern</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>
	<i>Modifiable data (Calibratable)</i>	<ul style="list-style-type: none"> <li>• Network-wide loss time</li> <li>• Network-wide stop penalty</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• Saturation flow rate</li> <li>• Offsets</li> <li>• Minimum phase times</li> <li>• Link flow rates</li> <li>• Platoon dispersion factor</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>
	<i>Basic Calibration data</i>	<ul style="list-style-type: none"> <li>• N / A</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• Saturation flow rate</li> <li>• Offsets</li> <li>• Platoon dispersion factor</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>
	<i>Advanced Calibration data</i>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>	<ul style="list-style-type: none"> <li>• Platoon dispersion factor</li> </ul>	<ul style="list-style-type: none"> <li>• N / A</li> </ul>
output		<ul style="list-style-type: none"> <li>• stops</li> <li>• Delay (secs/veh)</li> <li>• Fuel consumption (gal.)</li> <li>• Emissions</li> </ul>	<ul style="list-style-type: none"> <li>• stops</li> <li>• Delay</li> <li>• Fuel consumption</li> <li>• Emissions</li> <li>• Queue length</li> <li>• Saturation</li> <li>• Flow profiles</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>

### **INTEGRATION (Release 2) Characterization and Data Requirements**

\*INTEGRATION is a fully microscopic simulation model that tracks the lateral as well as longitudinal movements of individual vehicles to the resolution of a deci-second. The model can consider virtually continuous time-varying traffic demands, routings, link capacities, and traffic control, without the need to pre-define an explicit common time-slice duration between these processes. INTEGRATION also permits the density of traffic to vary continuously along a link and, thus, demonstrating the dispersion of a platoon as it traverses the link.

#### **Significant Traffic Flow Components**

The INTEGRATION model uses some basic traffic flow fundamentals. Once vehicles enter the link at the designated time, the vehicle selects the appropriate lane on the link based on the maximum available space headway to the vehicle downstream of it. Based on a link-specific microscopic car following relationship, the vehicle then computes its desired speed. The microscopic car following relationship for each link is, however, calibrated to yield the aggregate macroscopic speed-flow attributes of that particular link. The vehicle then updates its speed and space headway every deci-second based on its current speed and headway. The

macroscopic calibration of the car-following relationship ensures that vehicles will traverse each link in a manner consistent with that link's desired free speed, speed at capacity, and capacity and jam density.

The vehicle then uses a lane-changing model to change lanes. Lane-changing maneuvers can be either discretionary or mandatory. Discretionary lane changes occur if adequate headway is available in the adjacent lanes and the vehicle has a better chance of attaining link desired speed. Mandatory lane changing is a function of the system geometry. The model also uses a model to facilitate link-to-link lane transitions based on the number of available lanes downstream, adequate distance headway, and conflicting opposing flow.

Finally the model uses the internal routing logic to determine the next link for each vehicle on a link. The logic used can be either static and deterministic, or dynamic and stochastic.

Among the above-mentioned models, the microscopic car-following model and the macroscopic speed-flow-density relationships are link specific and appear to be most important. These models need to be calibrated precisely to suit local conditions.

### **Data Requirements Matrix**

INTEGRATION is a microscopic simulation model. The model has some significant sub-models which can be calibrated extensively (Table 3-4). Hence, some Advanced calibration data are available. Since the model is also microscopic in nature, some data are also required at the Vehicle level.

**Table 3-4 INTEGRATION Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	<i>Descriptive data (non-calibratable)</i>	<ul style="list-style-type: none"> <li>• #of nodes</li> <li>• Scale of coordinates and node coordinates</li> <li>• Node ID and type</li> <li>• Macro-zone cluster number</li> <li>• # of links</li> <li>• # of signals and signal plans</li> <li>• # of OD pairs</li> </ul>	<ul style="list-style-type: none"> <li>• Link scale factors</li> <li>• Link and adjacent nodes ID</li> <li>• Link length</li> <li>• Number of lanes</li> <li>• Initial cycle length</li> <li>• Cycle length range for internal optimization for each intersection</li> <li>• Phase splits and sequence</li> <li>• OD scaling factors</li> <li>• OD departure rate</li> <li>• Lanes blocked by incident</li> <li>• Incident duration</li> <li>• Rate of internal optimization</li> </ul>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>
	<i>Modifiable data (Calibratable)</i>	<ul style="list-style-type: none"> <li>• N/A</li> </ul>	<ul style="list-style-type: none"> <li>• Free speed and speed at capacity in links</li> <li>• Link saturation flow rate</li> <li>• Link jam density</li> <li>• Signal offset</li> <li>• Effective lost time</li> <li>• Passenger car equivalency</li> <li>• Vehicle departure headways</li> </ul>	<ul style="list-style-type: none"> <li>• Link vehicle speed variability</li> <li>• Traffic stream composition</li> </ul>
	<i>Advanced Calibration data</i>	<ul style="list-style-type: none"> <li>• N / A</li> </ul>	<ul style="list-style-type: none"> <li>• Free speed and speed at capacity in links</li> <li>• Link jam density</li> </ul>	<ul style="list-style-type: none"> <li>• Link vehicle speed variability</li> <li>• Traffic stream composition</li> </ul>
output		<ul style="list-style-type: none"> <li>• Total link travel time</li> <li>• Total network travel</li> <li>• Average network speed</li> <li>• Total network stops</li> <li>• Avg. network stops</li> <li>• Incident duration</li> <li>• Fuel consumption</li> <li>• Emissions - HC, CO, NO</li> </ul>	<ul style="list-style-type: none"> <li>• Signal timing optimization results</li> <li>• Min., avg., and max. trip times for all vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Min., avg., and max. trip times by vehicle type</li> <li>• Min., avg., and max. trip times by OD pair</li> </ul>

## ***DYNASMART Characterization and Data Requirements***

<sup>9</sup>DYNASMART is a network-assignment simulation modeling framework designed to assign time-varying traffic demands and model the corresponding dynamic traffic patterns to evaluate overall network performance of Advanced Traveler Information System (ATIS) and/or Advanced Traffic Management System (ATMS). DYNASMART is developed by the Center for Transportation Research, University of Texas at Austin and is primarily a descriptive analysis tool for the evaluation of information supply strategies, traffic control measures and dynamic traffic assignment (DTA) rules.

DYNASMART is designed to meet functional requirements set forth by FHWA for ATIS/ATMS applications, including representation of several user classes corresponding to different information availability and different behavioral rules, the capability to model disruptions due to incidents and other occurrences, and the capability to simulate a wide range of traffic control measures for both intersections and freeways.

### **Significant Traffic Flow Components**

DYNASMART uses established macroscopic traffic flow relationships to quantify interactions among vehicles and model the flow of vehicles through a network. However, whereas macroscopic simulation models do not keep track of individual vehicles, DYNASMART also employs the concept of macro-particles and moves vehicles individually or in packets; therefore, it has the capability to keep a record of the locations and itineraries of the individual vehicle.

The approach adopted in DYNASMART integrates traffic flow models, path processing methodologies, behavioral rules and information supply strategies into a single simulation-assignment framework. The simulation component consists of two primary modules: link movement and node transfer. Given the input data including time-dependent OD matrices, network representation, link characteristics and control parameters, the simulation component takes a time-dependent loading pattern and processes the movement of vehicles on links, as well as the transfers between links according to specified control parameters. These transfers are based on the instructions from the path processing and user behavior components, which determine individual path decision of each user in the network. The output of DYNASMART includes a wide range of output measures of effectiveness, which are link, node, and vehicle specific.

As an advanced evaluation tool of ATIS/ATMS, DYNASMART provides a flexible framework for modeling the performance of a traffic network and describing the evolution of mixed traffic flows in the network for a given time-dependent pattern of origin-destination trip desires under a given real-time information supply strategy.

## Data Requirements Matrix

DYNASMART is a microscopic network assignment simulation model. The significance in the data requirement matrix (Table 3-5, Table 3-6 and Table 3-7) for DYNASMART is the amount of data that is required at the Advanced level. Unlike the models introduced earlier, DYNASMART requires a significant amount of non-calibratable data as well as calibratable data at the Advanced level.

**Table 3-5 DYNASMART Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	Descriptive data (non-calibratable)	<ul style="list-style-type: none"> <li>• #of nodes</li> <li>• # of links</li> <li>• # of demand zones</li> <li>• Maximum simulation length</li> <li>• K factor for K-shortest path.</li> </ul>	<ul style="list-style-type: none"> <li>• Link and adjacent nodes ID</li> <li>• Link length</li> <li>• Link functional type</li> <li>• Movement definition for each link</li> <li>• Number of lanes</li> <li>• OD demand</li> <li>• Demand zone ID</li> <li>• Correlation between demand zone ID and network node ID</li> <li>• Signal control type</li> <li>• Cycle length</li> <li>• # of VMS</li> <li>• # of detectors of ramp control</li> <li>• % of HOV</li> <li>• Ramp detector ID and adjacent node ID</li> <li>• VMS ID number</li> <li>• VMS type</li> <li>• VMS location</li> <li>• # of incidents</li> <li>• Incident link ID</li> <li>• Bus ID</li> <li>• Average dwell time for bus</li> </ul>	<ul style="list-style-type: none"> <li>• Start time of incident</li> <li>• End time of incident</li> <li>• Severity of incident</li> <li>• Start time of each bus operation</li> <li>• # of nodes in bus route and the sequence of nodes</li> </ul>

**Table 3-6 DYNASMART Data Requirements Matrix (Continued)**

	Modifiable data (Calibratable)	N/A	<ul style="list-style-type: none"> <li>• Link maximum velocity</li> <li>• Saturation flow rate</li> <li>• Relative indifference band</li> <li>• Threshold bound</li> <li>• A loading factor for demand generation</li> <li>• Index for initial routes</li> <li>• Classification for multiple user classes</li> <li>• Green time allocation</li> <li>• Ramp parameter</li> <li>• Operational index for bus</li> </ul>	<ul style="list-style-type: none"> <li>• Fraction of compliant vehicles</li> <li>• VMS speed reduction factor</li> <li>• % of diverted vehicles by VMS</li> </ul>
	Basic Calibration data	N/A	<ul style="list-style-type: none"> <li>• Link maximum velocity</li> <li>• Saturation flow rate</li> <li>• Relative indifference band</li> <li>• Threshold bound</li> <li>• A loading factor for demand generation</li> <li>• Classification for multiple user classes</li> <li>• Green time allocation</li> <li>• Ramp parameter</li> <li>• Operational index for bus</li> </ul>	<ul style="list-style-type: none"> <li>• Fraction of compliant vehicles</li> <li>• VMS speed reduction factor</li> <li>• % of diverted vehicles by VMS</li> </ul>
	Advanced Calibration data	N/A	N/A	<ul style="list-style-type: none"> <li>• Fraction of compliant vehicles</li> </ul>

**Table 3-7 DYNASmart Data Requirements Matrix (Continued)**

output		<ul style="list-style-type: none"> <li>• Total and average trip times</li> <li>• Total and average entry queue times</li> <li>• Total and average stop times</li> <li>• Total and average trip distance</li> </ul>	<ul style="list-style-type: none"> <li>• Record of ramp-metering for each controlled ramp (if requested)</li> <li>• Record of signal operation (if requested)</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicle trajectory (if requested)</li> </ul>
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**TRAF Models**

<sup>10</sup>TRAF is an integrated software system that consists of the following component models:

- **NETSIM**, a microscopic stochastic simulation model of urban traffic
- **FRESIM**, a microscopic stochastic simulation model of freeway traffic
- **NETFLO 1** (Level 1), a detailed macroscopic simulation model of urban traffic
- **NETFLO 2** (Level 2), a less detailed macroscopic simulation model of urban traffic
- **FREFLO**, a macroscopic simulation model of freeway traffic

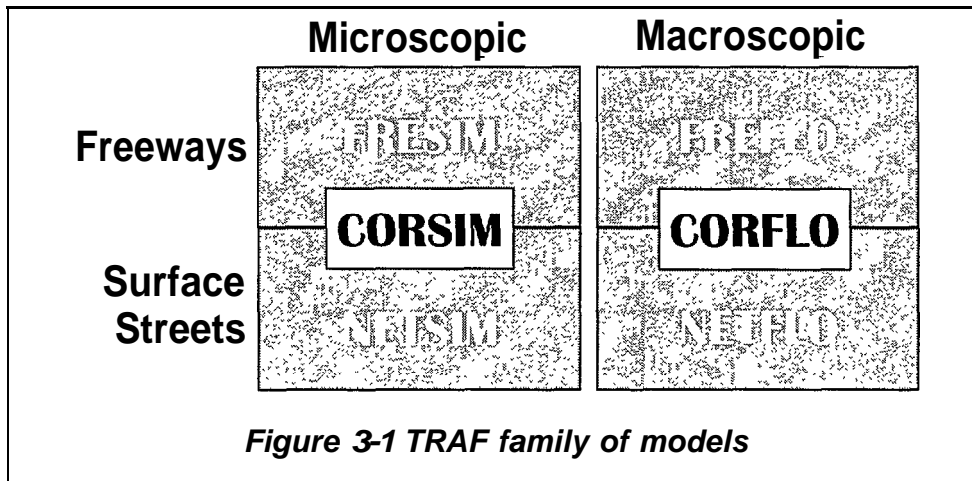
The naming system for these models is based on a combination of prefixes and suffixes and is depicted in Figure 3-1. The prefixes NET and FRE indicate a surface street network and a freeway network, respectively, and the suffixes SIM and FLO indicate microscopic simulation and macroscopic simulation, respectively. The combination of NETSIM and FRESIM is named CORSIM, for corridor-microscopic simulation. The NETFLO 1, NETFLO 2, and FREFLO models are distributed as a group for use in analyzing transportation corridors, and the group is named CORFLO, for corridor-macroscopic simulation. Only the microscopic components are discussed below.

**NETSIM Characterization and Data Requirements**

NETSIM was originally developed under the “Urban Traffic Control Systems” (UTCS-1) Project in the early 1970’s. This program evolved under the direction of FHWA and was later renamed NETSIM (NETwork SIMulator). NETSIM uses a link-node representation to describe the topology of the traffic facilities. Links are one-directional segments of streets and nodes are usually the intersection of two or more links. Once the user has a geometric picture of the network, it should be translated to the appropriate form needed by NETSIM input file. Links are defined in terms of their upstream and downstream nodes. For entry and exit links to the network, dummy nodes are placed between the entry and exit and the internal nodes. Statistics can thus be collected on the traffic entering and exiting the network. The internal links and nodes in the network should be defined by the user. The street length, number of lanes on the street, channelization of the lanes, and free-flow speeds on the streets are among the various inputs as described below in the data requirements section.



## Significant Traffic Flow Componentis



### Gap Acceptance Model

The gap acceptance model determines if a vehicle may proceed through an intersection. The logic is based upon the critical gap, the available gap, and the conflict point. The conflict point is the distance from the stop line to the point in the intersection where the subject and the opposing vehicle will conflict if they started to move through the intersection at the same time. The critical gap is the time that the opposing vehicle will reach the conflict point. The available gap is the time which the subject vehicle can move to the receiving link and is computed from a random distribution. If the available gap is less than the critical gap the vehicle is permitted to move through the intersection.

### Lane Changing Model

The lane changing model determines motivation and possibility for a driver to change lanes. It determines the motivation for a driver to change lanes through a point system based on the goal of the vehicle. There may be one or more candidate lanes that the vehicle could be in based on its goal. The lane change may be mandatory if the vehicle needs to be in a turn lane. On the other hand, a lane change would be discretionary if the vehicle could improve its speed in another lane. The feasibility of the maneuver is then computed based on the risk factor, and the speeds and positions of vehicles. If a lane change is desired and feasible then it is performed in the next time step.

### Car-following Model

The car-following model generates a vehicle's response to the actions of the vehicle in front of it. The vehicles space themselves at some distance such that they can avoid a collision in the event that emergency braking is needed. Many car following models have been used for different applications. The one used in NETSIM is the Pitt car-following model. The goal of the model is to allow enough space so the vehicle may be able to stop with emergency braking without a collision in the event the lead vehicle stops suddenly.

**Data Requirements Matrix**

The NETSIM descriptive input data requirements are concentrated in the Link/Node area as shown in Table 3-8 and Table 3-9. Since NETSIM is a microscopic model, an extensive set of inputs are available for calibration,

**Table 3-8 NETSIM Data Requirements Matrix**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
Input	<i>Descriptive data (non-calibratable)</i>	Pedestrian movements	<ul style="list-style-type: none"> <li>• Lane channelization</li> <li>• Length of turn pockets</li> <li>• Number of through lanes</li> <li>• Traffic control measures</li> <li>• Phase pattern</li> <li>• Phase times</li> <li>• Entry volumes</li> <li>• Turning percentages</li> <li>• Link Length</li> <li>• Link grade</li> <li>• Source/Sink links</li> <li>• Bus stop locations</li> <li>• Mean bus dwell time</li> <li>• Bus paths and routes</li> <li>• Conditional turning movements</li> <li>• O/D data</li> <li>• Lane alignment</li> <li>• Detector location</li> </ul>	N/A
	<i>Modifiable data (calibratable)</i>	<ul style="list-style-type: none"> <li>• Free flow speed</li> <li>• Queue discharge rate</li> <li>• Minimum phase time</li> </ul>	<ul style="list-style-type: none"> <li>• Bus flow rates</li> <li>• Off sets</li> <li>• Yield point</li> <li>• Force-off point</li> </ul>	<ul style="list-style-type: none"> <li>• Mean start-up lost time</li> <li>• Mean queue discharge rate</li> </ul>

**Table 3-9 NETSIM Data Requirements Matrix (Continued)**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
	<i>Advanced Calibration data</i>	<ul style="list-style-type: none"> <li>• Parking activity of street</li> </ul>	<ul style="list-style-type: none"> <li>• Link environmental rates</li> <li>• Left turn jumper probabilities</li> <li>• Free-flow speeds</li> <li>• Short term events</li> <li>• Link distributions for queue discharge headways and start-up lost time</li> </ul>	<ul style="list-style-type: none"> <li>• Length of vehicle types</li> <li>• Max. accel. Rate</li> <li>• Max. speed</li> <li>• % of vehicle types</li> <li>• Avg. number of passengers in vehicle type</li> <li>• Network environmental rates</li> <li>• Max. turning speeds</li> <li>• Lane-switching acceptable lag</li> <li>• Acceptable gap at stop signs</li> <li>• Amber phase response</li> <li>• Left-turn gap</li> </ul>

**FRESIM Characterization and Data Requirements**

FRESIM is the microscopic element of CORSIM for freeway traffic simulation. It also uses the node-link representation to model the geometry of the roadway system. The geometry of the freeway portion of CORSIM is slightly more involved than for urban streets since on-ramps and off-ramps are modeled as well.

**Significant Traffic Flow Components**

**Car-Following model**

FRESIM also employs the Pitt car-following model. Some of the parameters used to calibrate this model include the driver sensitivity, the length of the leading vehicle, the acceleration capabilities of the vehicles, the lag, and the maximum emergency deceleration.

**Lane Changing Model**

The lane changing model in FRESIM is slightly more developed than the one employed by NETSIM. In FRESIM there are three specific reasons for vehicles to perform a lane changing maneuver: mandatory lane change, discretionary lane change, and random lane change. A lane change is considered mandatory if one of the following criteria applies:

- The vehicle is in an acceleration lane and must merge with traffic

- The vehicle needs to merge into a deceleration lane to exit the freeway
- The vehicle is traveling on a lane that will be dropped further downstream
- The vehicle is traveling on a lane that is blocked by an incident downstream
- If a lane change is not mandatory then a discretionary lane change may be made based on motivation, advantage, and urgency.

Each of these terms is based on specific information about the traffic flow, calibration parameters, and statistical distributions. If a mandatory or discretionary lane change has not been set then the vehicle may make a random lane change based on a threshold set by the user. Once a lane change has been set, then the feasibility of the lane change is determined based on the acceptable leading and trailing gaps. These gaps are based on driver sensitivity, vehicle performance factors, and risk factors

### ***Data Requirements Matrix***

The FRESIM data requirements matrix is shown in Table 3-10. Again, the descriptive inputs are concentrated in the Link/Node area.

**Table 3-10 FRESIM Data Requirements Matrix**

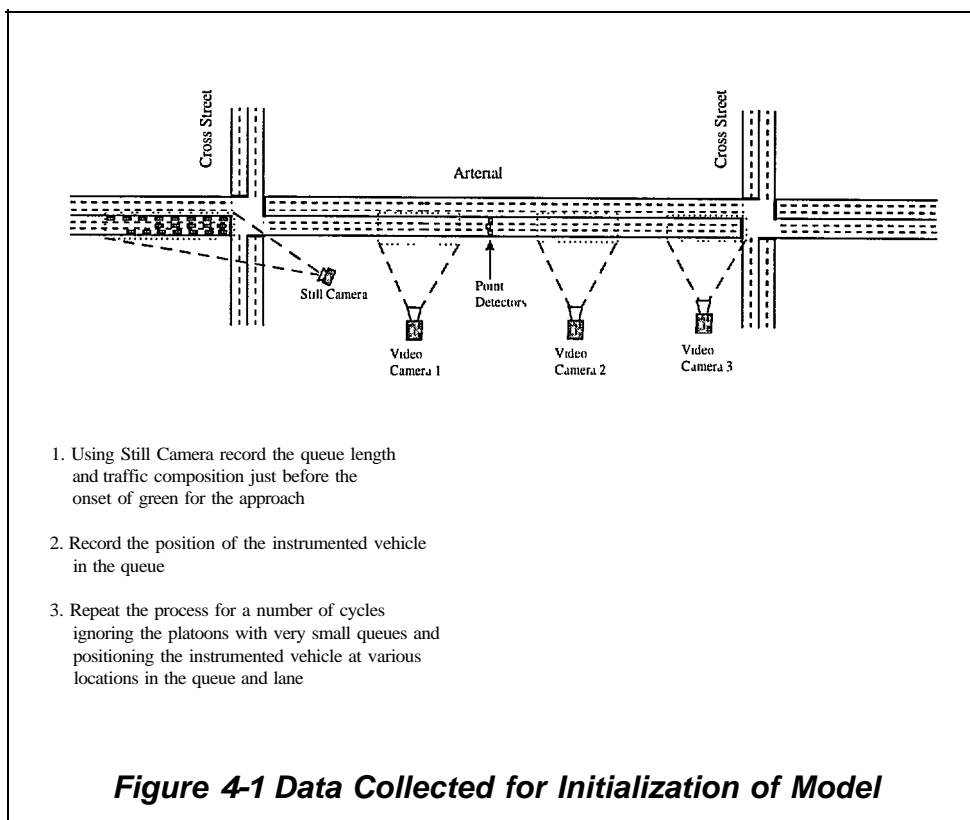
		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle</b>
<b>Input</b>	<i>Descriptive data (non-calibratable)</i>	N/A	<ul style="list-style-type: none"> <li>• Link geometry</li> <li>• Number of lanes</li> <li>• Length of lanes and accel/decel lanes</li> <li>• Lane drops/adds</li> <li>• Grades</li> <li>• Superelevations</li> <li>• Curve Radii</li> <li>• Pavement characteristics</li> <li>• Turning movement volumes</li> <li>• Input volumes</li> <li>• % Trucks</li> <li>• Detector locations</li> <li>• Incident Specifications</li> </ul>	N/A
	<i>Basic Calibration Data</i>	<ul style="list-style-type: none"> <li>• Pavement friction factors</li> <li>• Maximum non-emergency deceleration</li> </ul>	<ul style="list-style-type: none"> <li>• Free flow speed</li> <li>• O/D data</li> <li>* Warning sign locations</li> <li>• Ramp metering parameters</li> </ul>	<ul style="list-style-type: none"> <li>• Truck Bias</li> </ul>
	<i>Advanced Calibration Data</i>	<ul style="list-style-type: none"> <li>• Driver following sensitivity</li> <li>• Percent of drivers yielding to lane-changers</li> <li>• Accel./Decel. lags</li> </ul>	<ul style="list-style-type: none"> <li>• Start-up Delay (Queue discharge rate)</li> </ul>	<ul style="list-style-type: none"> <li>• Veh. accel/decel rates</li> <li>* Veh. sizes</li> <li>• Fleet composition</li> </ul>
<b>Output</b>		N/A	<ul style="list-style-type: none"> <li>• Total vehicle throughput</li> <li>• Density</li> <li>• Average and point speeds</li> <li>• Fuel consumption</li> <li>• Emissions</li> <li>• Number of lane changes</li> </ul>	<ul style="list-style-type: none"> <li>• Total travel time</li> <li>• Total delay time</li> <li>• Average network speed</li> <li>• Fuel consumption</li> <li>• Emissions</li> </ul>

## Section 4. Preparatory Activities for Pilot V&C Efforts

The objective of this section is to demonstrate many of the critical functions in preparation for V&C. Operational validation and calibration requires the existence of real-world data both to provide descriptive inputs as well as operational measures of system performance for calibration purposes. The discussion below describes the scenario, data requirements, data collection and reduction, and approach to V&C. The two illustrations, one for interrupted and uninterrupted flow respectively, describe preparations for pilot studies. These examples are based on Stage 1 geometry at a relatively low degree of traffic flow complexity as discussed in Section 2 above. The concept is to minimize the number of calibratable parameters and model input uncertainties through either direct measurement or scenario simplification. The perspective for these cases is fundamentally microscopic and is intended for NETSIM and FRESIM applications respectively.

### *Interrupted Flow Illustration*

A very simple case of interrupted flow (Stage 1) is chosen. Figure 4-1 describes the geometry of the Stage 1 Interrupted flow case. This scenario is selected to validate a traffic model's prediction of vehicles discharged from an upstream node, the pattern of those vehicles as they traverse the link (platoon dispersion), and their progression or stoppage at a downstream node.



The study will be conducted under conditions conducive to observe reasonable levels of platoon dispersion. The geometry of the link is the most important issue. The link length should be long enough (at least 0.5 to 1 mile) to allow platoon dispersion. Very short link lengths will not allow the platoons to disperse. The volumes on the arterial approaches should be high enough

to form queues of reasonable length but not too high as very high volumes may not allow the platoon discharged to disperse freely. In this simple case, a link with minimum sources and sinks will be chosen to minimize complications. Finally, a site will be chosen based on the ease of data collection

### **Data Requirements**

The geometry of the two intersections and the link will be measured. The signal control information (cycle lengths, splits, phasing sequences, etc.) will be obtained from field observations as well as from the traffic engineer's office. The traffic conditions like volumes will be observed and recorded to be input into the simulation model.

The calibrated inputs are then observed. These include start up loss time, discharge headway which in turn will give saturation flow rates, sneakers, and heavy vehicles or buses.

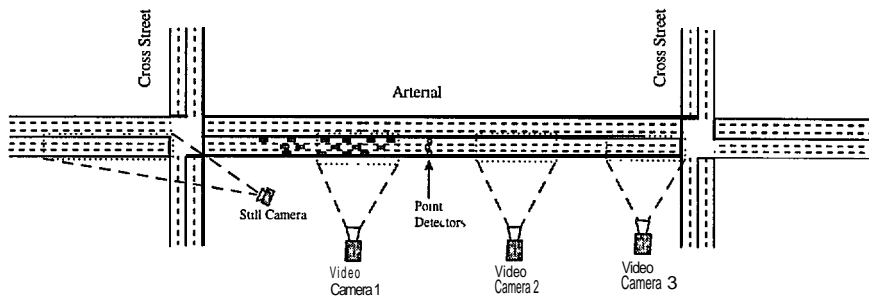
Finally, some validation parameters will be observed. They include travel time of either random vehicles and/or instrumented vehicles in the platoon, the lane changing behavior of the drivers, and the platoon dispersion phenomenon. These parameters will assist in the calibration of the simulation model. Results and recommendations of some research conducted in 1985 to study platoon dispersion" will be used to conduct this exercise.

### **Data Collection and Reduction**

The buildup of the queue at the upstream intersection will be observed and recorded. The queue length (number of vehicles as well as the length of the roadway occupied) and the traffic composition of the queue will be recorded. This will be done in a snap shot manner i.e., an instant before the signal turns green, the number of vehicles in the queue in each lane and the traffic composition will be observed. A still camera will be used to record this data as shown in Figure 4-1. At a later time, the startup loss time, discharge headway, and the number of sneakers will be observed at the upstream intersection.

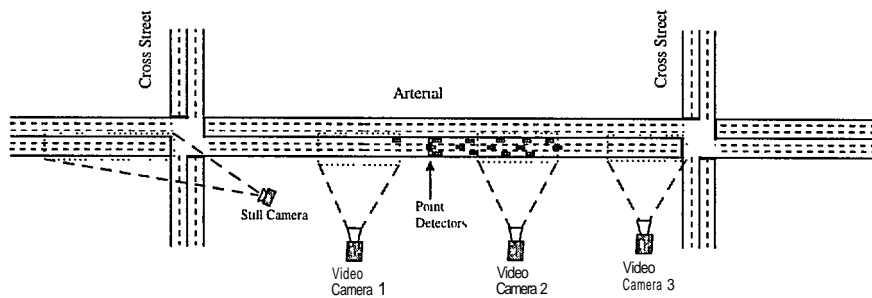
The platoon will be observed at a minimum of one suitable point between the two intersections to observe the dispersion of platoon. Dispersion of platoon can be measured by observing the increase in space headways of the vehicles in the platoon. The simplest way to observe the space headway is to video tape a section of the roadway at the desired location. If it is possible, a camera will be located overlooking the roadway from a tall building. If the camera is placed beside the roadway, the camera should cover about 200 to 300 feet of the roadway with the view perpendicular to the direction of traffic. One or two video cameras will be positioned as shown in Figure 4-2 and Figure 4-3 (Video Camera 1 and Video Camera 2) and the progress of the platoon recorded. Some point detectors also may be used either along with the video cameras or instead of a video camera. These point detectors should be able to provide headway data.

Finally the arrival of the platoon at the downstream intersection will be recorded by a video camera as shown in Figure 4-4 (Video Camera 3). The data collected from the still camera and video cameras will be used to track individual vehicles from the upstream intersection to the downstream intersection and hence the travel time of each vehicle will be deduced. It will also be possible to find out the destination of each of the individual vehicles to accurately simulate the progress of the platoon in a simulation model like CORSIM.



1. Using video tape from Camera 1, observe the space headway as traffic passes through its field of view
2. Repeat the process for all the cycles that had considerable queues

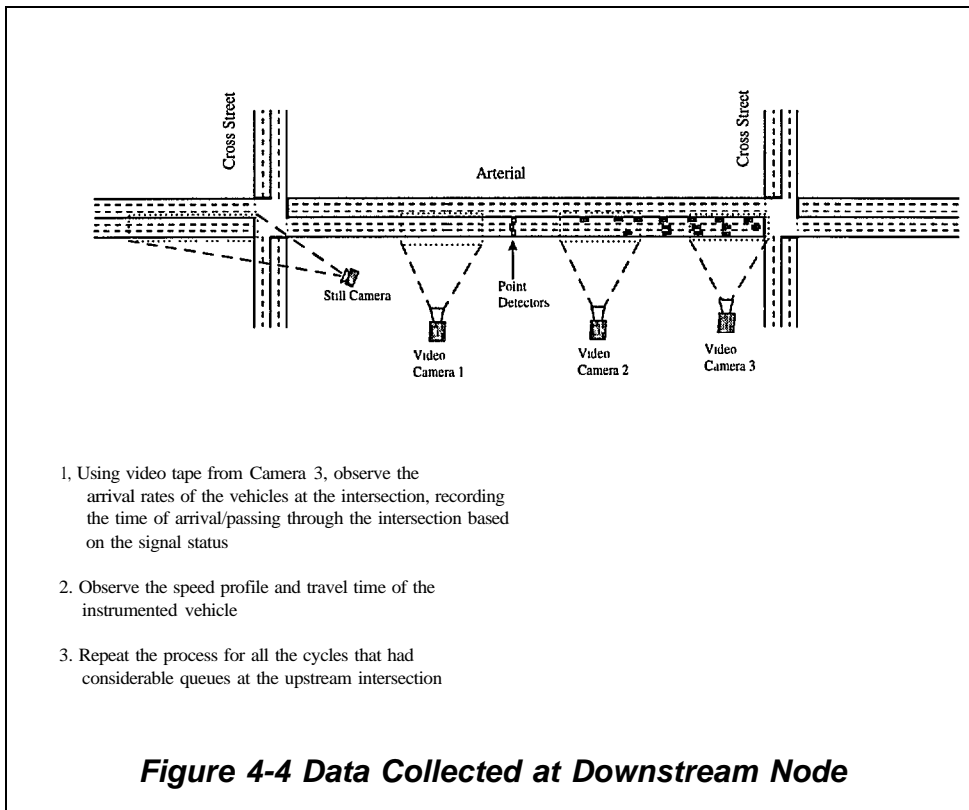
**Figure 4-2 Data Collected at Ear/y Mid-Block**



1. Using video tape from Camera 2, observe the space headway as traffic passes through its field of view
2. If Camera 2 is not available, use Point detectors to obtain, speed and time headways of all vehicles
3. Repeat the process for all the cycles that had considerable queues

**Figure 4-3 Data Collected at Mid-Block**





The video tape will be played back with two lines marked on a TV screen representing a known distance along the roadway. Time headways are measured for all the vehicles as they cross each of these two lines. Since the distance on the roadway between these two lines is known, the speed of individual vehicles can be calculated and the space headways can be computed. Such a process can be repeated at 2 to 3 locations to get an idea of the status of the platoon as it progresses along a link. Similarly, the arrival pattern of the vehicles at the downstream intersection will be also recorded along with the signal status. Thus the travel time of each of the vehicles in the platoon will also be obtained.

This exercise demonstrates the dispersion of the platoon on a link and gives a distribution of the travel time of all the vehicles in the platoon. By identifying the position of a vehicle in the platoon at the upstream intersection, we can thus determine the effect of position on the travel time of individual vehicles. This process will be repeated for a number of platoons. Collecting data from a number of platoons will minimize any significant differences in composition of the platoon with respect to vehicle types, driver types, and position in queues.

### Concepts of Validation

Each selected platoon will then be simulated and calibrated to reflect the field observations as close as possible. The model would initially be modified to artificially impose the actual real-world queue content including lane occupancy and vehicle type. In addition, the signal timing (start of green at the upstream and start of red at the downstream node) would be imposed. The typical user does not normally have this kind of access and control over the inputs. However, exercising this kind of control improves the capability to more closely replicate the real-world situation.

At a later stage, the validation returns to the normal user mode. This kind of data collection and control does not eliminate all uncertainties, however. The driver type occupying each vehicle will be unknown. The objective is to record platoon dispersion as accurately as possible and

simulate it in a model like CORSIM. The simulation will be calibrated and repeated until it accurately represents the field observations in the field.

### **Factors influencing the dispersion of a platoon (lane changing) along an arterial.**

<b>Definition of platoon dispersion:</b> Increase in longitudinal separation (space and time headway) as well as lateral separation (more lane changing).
---

1. Volume  
At very low traffic volumes, a distinct platoon is usually not formed. Hence, very little turbulence or lane changing maneuvers are observed. An increase in volume tends to increase the lane changing activity in the traffic stream. However, a significant increase in the volume also inhibits lane changing. Hence, a slight increase in volume along with other factors mentioned below can be used to model platoon dispersion.
2. Distance to the downstream link  
A very short link distance (1 500 feet) inhibits free lane changing and platoon dispersion.
3. Link speed distribution  
The higher the range of speeds in the speed distribution along the link, the greater the likelihood of an increase in the lane changing activity and increased dispersion of a platoon.
4. Commercial developments and mid-block driveways  
Any traffic generators as well as sinks in the link will affect the traffic flow between the two nodes. The absence of left turn and right turn lanes will disrupt the smooth flow of traffic. Sources and sinks will increase traffic turbulence.
5. Vehicle type mix  
The mix of vehicles will affect the smooth flow of traffic. A large number of heavy vehicles will tend to slow the traffic stream due to their slower acceleration rates. The large size of the vehicles will also induce the smaller vehicles behind them to switch lanes.
6. Area type (driver type)  
In urban areas, drivers tend to be more aggressive. They tend to change lanes more often than in rural areas. Also the range of speeds tends to be higher in urban areas compared to rural areas.
7. Turning percentage at the start up intersection as well as downstream intersection  
Higher turning percentages at the start up intersection will tend to create unequal distribution of queues at the intersection. Vehicles in these queues when discharged will tend to create an equilibrium of vehicles in each lane by changing lanes. Similarly high turning percentage of vehicles at the downstream intersection will increase the lane changing activity in two ways. First the vehicles will change lanes to get into the proper lanes to make their turning movements. Second, if the turning vehicles either do not have an exclusive turning lane or if the queue of the turning vehicles backs up into the through lanes, the through vehicles will tend to change lanes to try to create equal sized queues by changing lanes.

These factors tend to have an impact on the platoon dispersion phenomenon on a link. While some of these factors impact platoon dispersion phenomenon by increasing the headway, others influence it by lane changing behavior.

## ***Uninterrupted Flow Illustration***

In the uninterrupted flow situation, the Stage 1 case is different because the traffic is not broken up into distinct platoons, but is continuous along the freeway. As platoon dispersion is the major factor in the interrupted flow case, freeway turbulence is the major factor in the uninterrupted flow case. Freeway turbulence can be defined as the changing speeds, densities, and flows over a section of freeway due to a mixture of factors. Some of the factors affecting freeway turbulence include on-ramp flows, off-ramp flows, road geometry, driver's gap acceptance, driver's attitudes, vehicle types, weaving vehicles, number of lanes, lane widths, changing conditions, time of day, incidents, and others. In light of the V&C complexity levels chosen, a simple case of freeway turbulence can be observed in a simple section with a single entrance and exit. This segment with the idea data collection conditions is shown in Figure 4-5. The reasoning for selecting a simple section for Stage 1 V&C is to minimize the complications of larger systems and focus on a few of the most basic factors

### **Data Requirements**

The data requirements matrix in Section 3 described sets of parameters for different stages of calibration. Some of these parameters are difficult to study particularly if there are other major influences such as incidents or complex geometries. These particular parameters are abstract but need to be carefully calibrated to assure accurate performance of the model. The parameters to be looked at in the stage 1 V&C are: driver aggressiveness, acceleration/deceleration lags, lane change maneuver times, car following sensitivity distributions, and vehicle performance indexes

### **Data Collection & Reduction**

A site involving the most ideal conditions for studying freeway turbulence is selected based on a number of criteria depicted in Figure 4-5. The objective of the study is to record the progress of vehicles into, through, and out of the weaving section. Due to the continuous nature of uninterrupted flow, criteria must be given describing the proper platoon headway and length. An adequate space between an upstream vehicle and downstream vehicle must be chosen to insure that vehicles actions recorded upstream are in free flow and not affected by downstream vehicles. Under low to medium flow conditions, a headway of 500 feet would be reasonable. The length of the platoon can only be taken as far as the camera can effectively see, which is approximately 1500 feet.

The turbulence is measured by observing the platoon and ramp flows through the weaving section. The turbulence is measured by several factors including:

- Change in vehicle headways
- Change in vehicle speeds
- Lane changes

The change in vehicle headways and speeds can be observed with the timed detector output in conjunction with timed video tape of the section. Specifically, the headways and speeds will be recorded at a point approximately 500 feet downstream of the end of the on-ramp and at 500 feet downstream of the off-ramp. Origin and destination information about each vehicle is also recorded along with the total number of lane changes.

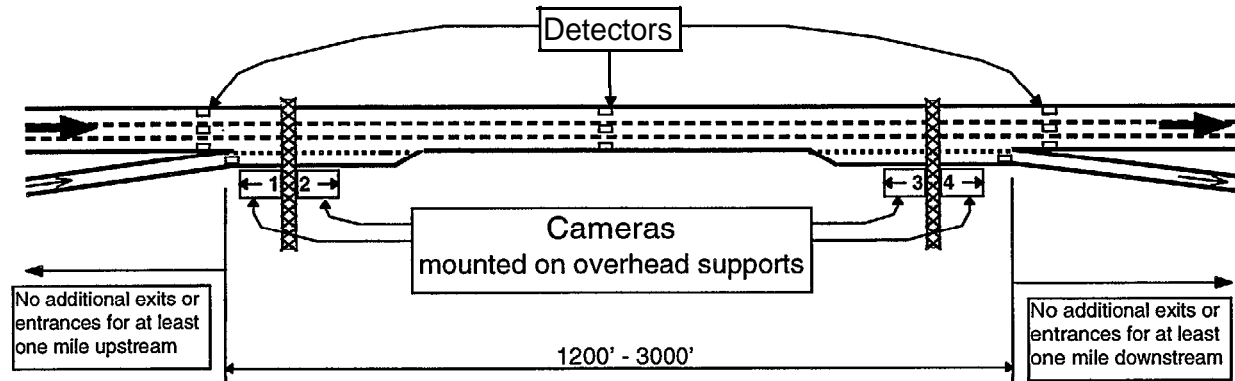
The video tape of each study point (upstream, downstream of the on-ramp, and downstream of the off-ramp), is played back in time with the detector outputs. The headways and speeds of

each vehicle at each point is recorded in addition to the lane changes. This process will be repeated for many platoons ensuring a variety of samples with different vehicle types, driver types, and relative vehicle positions.

### **Concept of Validation**

In contrast to the validation of the interrupted flow case, the freeway case involves a continuous flow of vehicles without clearly defined breaks or platoons. The simulation model will resemble the test section as closely as possible in the geometry and in the starting position and speed of vehicles. Validation can incorporate data in semi-platoons or aggregated over specified time intervals. A semi-platoon is a group of vehicles where the lead vehicle(s) is not directly impacted by the movements of vehicles downstream. The simulation will be run and the speed and headway of the vehicles will be recorded at the corresponding data collection points in the simulation model. Model parameters will be adjusted to properly calibrate and validate some of the more detailed and abstract elements within the simulation. Similarly the simulation will also be validated and calibrated with the aggregated data over fixed time intervals

(Stage 1: Freeway section with an entrance and an exit)



<u>Ideal Traffic Criteria</u>	<u>Ideal Physical Criteria</u>	<u>Ideal Conditions</u>
Volume $\geq$ 500 vh/hr/ln Volume $\leq$ 1500 vh/hr/ln Speeds $\geq$ 50 mph Trucks $\leq$ 10% Non-Peak Traffic No Incidents	Radius of Curvature = 0' Vertical Curve = flat Ramp speed $\geq$ 40mph Main speed $\geq$ 55mph Lanes = 3 One acc. and dec. lane Excellent pavement condition Excellent markings & signs	Mid-week, non-holiday Time 9am - 3pm Weather: Clear 40°F $\leq$ Temperature $\leq$ 80°F

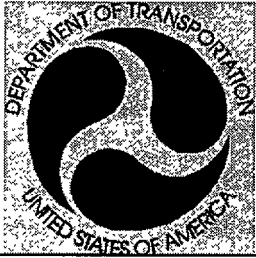
Note: Cameras may be mounted on any overhead support including overpasses, sign trusses, utility poles, buildings, or light fixtures.

**Figure 4-5 Ideal Freeway Data Collection Scenario**

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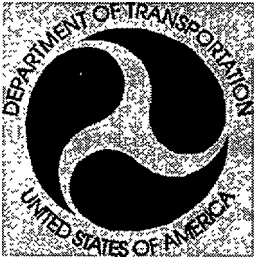


# Data Inventory

*Task C*

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# Data Inventory

## *Task C*

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### **Prepared by:**

Kaman Sciences Corporation  
PO Box 7463  
Colorado Springs, CO 80933

#### Authors:

Larry E. Owen, PI  
Scott Mastbrook  
Srinivasa Sunkari

Barton-Aschman

### **Prepared For:**

US Department of Transportation  
Federal Highway Administration  
IVHS Research Division, HSR-11  
6300 Georgetown Pike  
McLean VA 22101



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# Section 1- Objectives

The purpose of the data inventory task is to obtain professional contacts, literature surveys and information from the appropriate FHWA/USDOT program offices. Professional contacts may include researchers, state DOT's, and city personnel involved in ITS field tests. This information will determine the ITS and non-ITS field studies that have either assembled or will obtain traffic data relevant to this study. The objectives are to:

- 1 Characterize applicable future or ongoing operational tests in terms of objectives, data collection and modeling efforts, and points of contact,
2. Identify and characterize existing data from tests that have been conducted in the past,
3. Determine methods to bridge in and store desirable data in a format consistent with the database requirements,
4. Determine to what extent each data source satisfies the criteria for data requirements for validation and calibration developed in Reference 1 for Task B<sup>1</sup>.

This report summarizes these activities

## ***Important Criteria for Data Applicability***

Data requirements for validation and calibration of traffic models and stages of the validation process are two important criteria for data applicability as described below.

### **Data Requirements for Validation and Calibration Purposes**

Traffic data must contain elements of model input and output to be useful for validation and calibration purposes. Table 1-I summarizes sample of data requirements for a generic traffic model in the form of a matrix. The data requirements matrix basically categorizes the input and output data. The input data can be of two types: Descriptive data and Modifiable data. Descriptive data are, in general, non-calibratable and essential to the representation of specific site characteristics and conditions. Examples of descriptive data are number of intersections, link lengths, and traffic volumes among others. Modifiable data or calibratable data are inputs that can be changed, at the discretion of the user, to better match the local conditions. Examples of modifiable input data are number of sneakers, phase loss time, and average speeds.

Modifiable data are not optional inputs. Rather, the user must decide either to accept the default values or change the parameter to a value that better reflects local conditions. A change in input value is usually based on actual field site information or expert guidance (sources of expert guidance are individuals, "rules-of-thumb", handbooks, manuals, etc.). The user who does not have access to such information accepts the default values.

### **Stages of V&C**

A validation and calibration stage identifies a combination of facility geometrical extent and degree of complexity in traffic flow conditions. The concept of a V&C stage is important for two reasons: 1) the various stages identify the progression of the V&C process, and 2) increasing stages impose basic limitations on the data collection and reduction that can be accomplished.

**Table 1-1 Sample Data Requirements Matrix**

		<b>Aggregate level (Macroscopic)</b>	<b>Intermediate level (Mesoscopic)</b>	<b>Detailed level (Microscopic)</b>
Input	<i>Descriptive data (non-calibratable)</i>	# of intersections Cycle length range and increment	Volumes Lane configuration Link lengths Phase pattern	N/A
	<i>Modifiable data (Calibratable)</i>	Network-wide loss time	Speed Saturation flow rate Offsets Minimum phase times Link flow rates	N/A
	<i>Basic Calibration data</i>	N/A	Speed Saturation flow rate Offsets	N/A
output		stops Delay (secs/veh) Fuel consumption (gal.) Emissions	stops Delay Fuel consumption Emissions Queue length Saturation	N/A

Table I-2 shows five different levels of V&C as a function of facility extent and the degree of traffic flow complexity. Even at the lower stages of V&C, several factors influence the complexity. For example at Stage 1 of interrupted flow shown in Table I-1, the following traffic flow parameters increase the complexity of the V&C process and data collection:

- Traffic volume
- Sources and sinks
- Link length
- Distribution of turning movements
- Vehicle types
- Hills, curves

**Table 1-2 Stages of Validation Process**

<b>V&amp;C Stage</b>	<b>Interrupted Flow</b>	<b>Uninterrupted Flow</b>
<b>0</b>	Sign controlled isolated intersection	Free flow conditions
<b>1</b>	Single Link, signal controlled at each end	Representative Segment with on and off ramps
<b>2</b>	Arterial or Small Grid	Lane drop or closure (Bottleneck)
<b>3</b>	Network	Freeway Density contour map
<b>4</b>	Combinations of Interrupted	and Uninterrupted Facilities

- Number of lanes
- Driver types

The V&C process starts at a low level of facility extent with a minimum of complexity. This is discussed in more detail in the section that follows.

## **Section 2. Potential Data Sources**

### ***Applicability of ITS Operational Tests***

Table 2-1 was supplied to COTR, Mr Gene McHale of the FHWA, by Booz-Allen & Hamilton who provide support to the Operational Test group. This data was based on meetings with FHWA, Kaman Sciences and representatives of Booz-Allen & Hamilton where the requirements of the validation and calibration effort were explained.

At this time, the most promising test is the FAST-TRAC program. This program is collecting data to support modeling efforts for the evaluation of SCATS performance. At this stage, communication has been initiated with the points-of-contact of this program hopefully leading to a meeting where the requirements of the program can be discussed.

**Table 2-1 Selected Operational Tests that Measure or Model Highway/Arterial Traffic Flows**

Test Name	Description of Test	Description of Data Collection/Modeling Effort
Travel Demand Management/Emissions Detection: Ada County, ID)	Currently, only the residents of Ada County are required to have their vehicles' emissions tested in Idaho. It is suspected that untested, non-Ada County vehicles contribute disproportionate levels of emissions to the Ada County area. Phase I used License Plate Recognition (LPR) to identify vehicles in order to conduct an O/D survey through the mail. Results were to be used as inputs to models for planning purposes.	The modeling activities are not funded by FHWA and are not part of the evaluation. This test will be concluded in late April 1996.
Anaheim ATCS (a.k.a. SCOOT); Anaheim, CA	This test will evaluate two "adaptive" traffic signal control systems, 1.5 generation UTCS and Split Cycle and Offset Optimization Technique (SCOOT). Floating car studies will be used to determine changes in average link speeds, queue delays and throughputs (volumes). The field test also includes a task to compare the performance of a low cost Video Traffic Detection System (VTDS) to loop detectors.	Data collection activities include before/after implementation information. Evaluation will assess changes in travel times and queue delays on individual links in the City of Anaheim. Data will be collected using "floating car" studies. No traffic modeling activities planned. This test will conclude on or around 12/96.
Integrated Freeway Ramp Metering/Adaptive Arterial Signal Control (IRM/ASC); Orange County, CA	The IRM/ASC system will integrate an existing CALTRANS centrally controlled adaptive freeway ramp meter system (ATMS/SWARM - Advanced Traffic Management System/System Wide Adaptive Ramp Metering system) with an arterial signal system consisting of new 2070 Advanced Traffic Controllers, and the OPAC (Optimal Policies for Arterial Control) adaptive control system. The effectiveness of IRM/ASC in coping with full and partial diversion of freeway traffic onto a parallel arterial is the major focus of the test.	Data collection activities have yet to be determined, but are likely to include before/after traffic parameters such as travel times, impact of VMS, and performance of OPAC on arterial flow under normal conditions (i.e., no freeway diversion). Test will conclude 06/97.
Integrated Corridor Traffic Management (ICTM); Minneapolis/St. Paul, MN	The ICTM concept is to utilize available capacity in the parallel arterial system to accommodate short trips which are now occurring on the freeway. ICTM will integrate arterial and freeway traffic signal systems and operate them via a computerized adaptive traffic control system. Sydney Coordinated Adaptive Traffic Control System (SCATS) has been selected to provide adaptive control and facilitate the integration of the two independent control systems. ICTM will be implemented in four modules, by the end of which SCATS will be installed at 15 freeway interchange signals, 25 ramp metering sites, and 42 intersections.	The SCATS system is in place and serving the ICTM corridor. Test data collection activities employ screen-line traffic volume changes, and assessment of distribution of traffic between arterials and freeways. Activities also include statistical analysis of traffic flow data collected before and after ICTM System implementation to assess reductions in delays on several infrastructure elements. Additional test activities involve statistical before-after assessments of freeway incident data, fluctuations and consistency in freeway travel speeds, corridor-wide accident data, and user perception studies. The test is scheduled to be conducted in four consecutive phases. Phase I & II data collection activities began 02/96 and will complete 05/96. Phase IV data collection activities are scheduled to complete during the fourth quarter of 1998.
Faster and Safer Travel through Traffic Routing and Advanced Controls (FAST-TRAC); Oakland County, MI	The FAST-TRAC project involves the integration of an adaptive signal control system (SCATS), an image-based surveillance system (AutoScope cameras), and a dynamic route guidance system (Ali-Scout). The project will provide the opportunity to assess any synergistic impacts obtained through integration of these systems.	Data is being collected to support modeling efforts for both the SCATS and Ali-Scout systems. Segments of network are being modeled using NETSIM. SCATS arterial before/after implementation data is being collected for select intersections and corridors using installed AutoScope cameras directed at intersection stop bar. Additional cameras are being installed at select SCATS-equipped intersections (directed upstream) to gather additional information on formation of queue (to support determination of delay for individual vehicles). Currently, no camera installations are planned for midblock areas. Although current phase of test scheduled to complete 12/96, RCO/University is currently drafting a proposal to FHWA for additional evaluation activities.
During Incidents Vehicles Exit to Reduce Time (DIVERT); St. Paul, MN	This system attempts to alleviate incident-related congestion by guiding traffic along designated arterial detour routes via changeable message signs. The increased arterial traffic will be monitored with closed-circuit TV cameras, and managed with ramp meters and coordinated traffic signals.	Freeway travel times, delays, stops, city-street travel times, delays, stops, accident severities and rates will be studied using log data, traffic data statistical analysis, and computer modeling of operations. A twelve month data collection effort began 03/96.
Driver Information Radio Experimenting with Communication Technology (DIRECT); Detroit, MI	The DIRECT project will implement and evaluate 4 near-term, available low-cost ATIS systems which show promise of improving present delivery methods for exception traffic messages: <ul style="list-style-type: none"> <li>- Low-Power Highway Advisory Radio (LPHAR)</li> <li>- Automatic Highway Advisory Radio (AHAR) [220 MHz]</li> <li>- Cellular Call-In</li> <li>- Radio Broadcast Data System (RBDS)/FM-SCA radio system</li> </ul> Participating drivers will receive voice messages which convey traffic information (e.g., incident, congestion, and road condition reports)	Data is being collected to support modeling for overall network impact of increasing levels of ATIS market penetration. Key data item is collection of information on driver response to ATIS information (all participating Phase I vehicles are tracked). Fifteen month data collection effort begins 04/96.
TravelAid; King County, WA	Travel-Aid is a test designed to improve safety by disseminating information and speed advisories during adverse weather conditions. Test will use in-vehicle units (200 vehicles) and VMS to assess driver response to weather/traffic advisories.	Data will be gathered using 32 radar speed detectors, six weather stations, loop detectors at three locations, and accident reports. The initial Travel Aid project will have 24 field sites, which will all be centrally connected to the Hyak Control Center. A driving simulator has been used to obtain safety related data. Driver behavioral response to VMS and in-vehicle messages will be assessed in terms of changes in speed and compliance with travel advisories. Data collection scheduled to begin 10/96.

## ***RT-TRA CS Field Tests***

Kaman Sciences is supported by the FHWA to perform both before-and-after studies at RT-TRACS field sites. The first tests of RT-TRACS represent a Stage 2 validation and calibration effort for interrupted flow. Since detailed data is to be collected for evaluation purposes, it is cost/effective to use the data for both RT-TRACS evaluation as well as validation and calibration purposes. Kaman Sciences is in the process of collecting data for calibration purposes on Reston Parkway in northern Virginia area. Different aspects of the data collection are explained below.

The RT-TRACS laboratory evaluation requires that the prototypes be evaluated in a method that best approximates the actual field traffic conditions. To perform this evaluation, the CORSIM microscopic traffic simulation model has been chosen by FHWA and modified by Kaman, Viggen, and KLD to better represent an actual traffic stream as well as to allow real-time modifications to the traffic signals.

Using an accurate traffic simulation model, however, is not sufficient to produce confidence in the results of the analysis. To increase the confidence levels with the laboratory evaluation, Kaman is planning to collect traffic information that will be used to calibrate CORSIM. This calibration effort will be limited to the site chosen for field testing the prototypes, although it is possible that a number of the calibration parameters collected for this site will be carried over for use with the remaining traffic networks as defined in the RT-TRACS Task B report, "Laboratory Evaluation Plan" produced by Kaman Sciences and delivered to FHWA on 31 May, 1995.

This paper serves to define the objectives of the calibration study, as well as defining the equipment and methodology that will be utilized to prepare an accurate CORSIM input file. Actual locations for data collection at the test site will be determined immediately before the calibration data collection begins

### **Geometric Data Requirements**

It has been determined that the first phase of testing will occur on a two-way high type arterial. This roadway will include at least eight (8) signalized intersections, left turn bays, and protected left turn movements. In addition, it should be sufficiently isolated from other facilities to keep the RT-TRACS controlled signals from interfering with the coordination of surrounding intersections. Finally, access to the arterial should be relatively limited. For the first field test, it can be assumed that the prototypes are not mature enough to sufficiently handle large source and sink volumes.

It is important that there be immediate cooperation between Kaman and the local transportation officials. For the laboratory evaluation, this cooperation will include providing Kaman with detailed drawings of the arterial, including both sources and sinks, the geometry's of all of the intersections, any traffic data that has already been collected, and current signal timing information.

Most of the required geometric information should be able to be extracted from the information provided by the local transportation officials. Any additional geometric information and traffic generators or access/egress information can be obtained by field visits.

### **Traffic Data Requirements**

The traffic data that will be collected for validation and calibration can be broken down into three categories: basic traffic data, calibration data, and (extra) traffic data. Basic data includes



traffic volumes based on time of day, turning movements, link geometry, and posted speeds. Calibration data includes vehicle headways, lost time, speed profiles, travel times, and saturation flow rates. Extra traffic data includes information obtained from monitoring or driving the network that would not otherwise be noticed from the first two categories. A summary of this information is shown in the data collection matrix at the end of this paper.

## **Data Collection Plan**

The data collection for calibration of CORSIM for the laboratory evaluation is planned for four days to allow for the collection of a significantly sized data set. Collection during this period will be focused on four key aspects, with video analysis to allow for the collection of extra data at a later time. Data collection will include travel times, vehicle headways, start-up lost time, and speed profiles

### ***Travel Times***

In the laboratory evaluation plan, travel time is one of the key measures of effectiveness (MOE) that will be used to evaluate the prototypes. For proper calibration, it is important that the results CORSIM provides for travel times are accurate. The other information being collected to calibrate CORSIM, headways, lost time and speeds, will be used to adjust the model to provide accurate travel time estimates when compared to real-world travel times.

Travel times will be collected using GPS receivers connected to portable computers. Kaman has recently acquired three such receivers, of which, two will be used for this data collection effort (The third will be used as a spare for this effort).

Utilizing the Retki GPS Land Navigation system developed by Liikkuva, Kaman has developed an interface with Microsoft Excel to record all of the latitude, longitude, altitude, and speed information acquired by the GPS receiver, updated every 1 second. By using this information, precise link travel times, average speeds, delay, and number of stops can be determined.

CORSIM output includes travel times for both links and sections, as well as average vehicle speed over a link, delay and number of stops on a link. Using the information acquired with the GPS system, a determination can be made as to the accuracy of CORSIM output, CORSIM can then be calibrated to the field data by modifying the headways, lost time and speeds.

To collect the travel times with the GPS receiver, the car following method will be employed. Starting at one end of the arterial, the test car (car equipped with the GPS equipment) will select a car at random to follow through the network. Should this car be "lost" by either a red light or by turning off of the arterial, the test car will immediately acquire a new car to follow through the remainder of the network.

Because of the limited number of runs that can be made in any given peak period, two methods will be employed to acquire as large a sample size as possible. First, two test cars will be employed, doubling the sample size. Secondly, travel times will be collected for four days, Monday through Thursday.

The focus of the laboratory evaluation is during the morning peak. However, travel times will be collected during the noon rush, evening rush and an off-peak period during the day as well. Since one of the reasons for performing the laboratory evaluation on the field site test network is to provide an estimate with a fairly reasonable level of confidence as to the performance on that specific network, testing independent of the laboratory evaluation will occur on the field site network with traffic data from all three peak periods as well as an off peak period.

### ***Vehicle Headways***

The time headway between vehicles is of vital importance because it affects the safety, level of service, capacity, and driver behavior within a transportation system. Volumes and time headways, therefore, are vital in determining the effectiveness of an arterial. Vehicle headways are also important to calibrating CORSIM. By collecting headways over time, traffic volumes, headways and headway distributions can be found.

To collect headway data, a portable laptop computer will be used with a BASIC computer program called HEADWAY. After starting the HEADWAY program, the user presses one of four keys, depending on the lane or vehicle type, when the leading edge of a vehicle passes a reference point (usually a stop bar). This program creates a data set that includes the lane in which the vehicle was traveling, the time distance between successive vehicles, the vehicle type and the total elapsed time from the first vehicle to the current vehicle. This information will thus provide a queue discharge profile. When lead vehicles are either past or well behind the stop bar, appropriate modifications will be made in the data collection procedure.

Utilizing the data acquired by the HEADWAY program, the average headway and the headway distributions can be easily acquired. Because of both the intense effort required to collect headway data and the amount of raw data that will be acquired, data will only be collected on Tuesday and Wednesday of the data collection week. Headways will be collected near to mid-block on a section of the arterial that allows vehicles to reach near cruising speeds. If the geometry of the arterial permits, headways will be acquired on a different segment during each day of the data collection effort.

### ***Lost Time***

With any signal system, the lost time is one of the most necessary values to collect, because it can vary widely depending on the aggressiveness of the drivers in the area, and because the value directly effects the performance of the signal. For simulation, an inaccurate lost time value can propagate inaccurate results throughout the network. In addition to collecting the lost time, the same procedure will be used to measure the saturation flow rate during the peak period.

To collect the necessary data, the HEADWAY program will be used to record the time the signal turned green and the times that each vehicle in queue in one lane crosses the stop bar. Data will only be collected in the rightmost through only lane to avoid the different saturation flow rates associated with either a right turn lane or a shared lane.

From this data, the saturation flow and average saturation headway will be determined by vehicles four through ten in queue, and the lost time will be calculated from the first three vehicles in queue. Based on sample sizes and the duration of the peak period, lost time and saturation flow data will be collected on Tuesday and Wednesday during the morning peak period. A minimum of two intersections will be examined, and if time permits, up to two intersections during the morning peak may be examined.

### ***Speed Profiles***

Vehicle speeds are an important value in both the real world and within CORSIM, as are speed profiles. Speed profiles within CORSIM determine the aggressiveness of a driver and how near they follow the posted or desired speeds within a section. In CORSIM, both the average or posted speed is entered as well as a profile which shows the percentage of vehicles that travel within certain speed ranges.

During the calibration study, a speed study will be performed on a link that is long enough to allow vehicles to reach their desired free-flow speeds. Speeds will be acquired using a standard radar gun during off peak periods on both Tuesday and Wednesday at a minimum of one site per day. Additional sites may be utilized if it is deemed necessary during the calibration study and if additional acceptable sites along the arterial can be found.

### ***Extra Data***

In addition to purely empirical data, it is important that the arterial be observed for operating characteristics that may not otherwise be seen in the numbers that represent headways, speeds or travel times. This information may include queue formation and dissipation, lane usage, and conditional turning movements

This non-empirical data will be collected using two methods. The primary method will be through observation of the arterial while collecting the travel time data. Although the driving task requires a significant effort, the drivers of the test cars constantly observe their surroundings and the traffic conditions. To record this data, each of the drivers will pause momentarily between runs to record their observations. The drivers may also be given micro-cassette recorders to record their observations while they drive.

The second method will involve videotaping the key approach at two intersections on Tuesday and Wednesday. Videotaping will allow portions of the arterial to be viewed in the office at a later date where they can be studied in full detail. In addition, taping allows for the verification of the validity of the saturation flow, lost time, and headway data if the need should arise. Finally, videotape can be analyzed later to collect any additional data, such as queue lengths and stopped delay, in the office.

## Data Collection and Processing

Kaman Sciences is prepared to perform the CORSIM calibration data collection study during the week of 20 May in Northern Virginia. Kaman personnel will be responsible for the travel time data as well as the speed distributions. Temporary employees will be used to collect the headway data, lost time and saturation flow data, as well as keep an eye on the video cameras.

The raw data will be reduced by Kaman Sciences the following week, with the data set for the

**Table 2-2. RT-TRACS Field Test Data Collection**

<b>Data Collected</b>	<b>Method</b>	<b>CORSIM Use of Data</b>
Travel Times	GPS Receiver following a random car	Will Calibrate to link and artery travel times
Headways	HEADWAY program on a laptop	Develop headway distributions and volume estimates
Start up Lost Time	HEADWAY program on a laptop	Utilize start up lost time to provide more accurate travel times
Saturation Flow	HEADWAY program on a laptop	Use for signal timing optimization and to provide accurate travel time and capacity estimates
Average Vehicle Speeds	Radar Gun and profiles from GPS analysis	Provide accurate average or desired speed estimates
Speed Profiles	Radar Gun	Determine aggressiveness of drivers with respect to speed for travel time
Network Flow Characteristics	Driver Observations	Perform a visual validation of the system response
Intersection Flow Characteristics	Driver Observations and Video Tape Analysis	Potentially check delay estimates, verify field data collection, allow for a visual comparison of traphix with real data

field site being prepared simultaneously. Calibration of the data set will be performed in as short a time as possible in an attempt to perform a preliminary evaluation of the prototypes on the field site by the end of June, 1996.

### Equipment List

Video Cameras include:

- Camera
- Batteries (2)
- Remote
- AC Adapter
- Cables

This list does not include minor items, such as video tapes, extra batteries, audio tapes, etc.

### ***JHK Data***

For microscopic analysis of FRESIM, detailed real-time car trajectories are ideal. This is exactly the kind of data that was collected in the mid 1980's by JHK & Associates in the Washington D.C. and Los Angeles metropolitan areas. The data collection and reduction effort is described in the report *Freeway Data Collection for Studying Vehicle Interactions - Technical Report*, report no. FHWA/RD-85/108, May 1985.

A plane equipped with video equipment was flown over fourteen sites for an hour and fifteen minutes each while taking single frame video shots every second of the entire site. The sites included many different vehicular interaction scenarios including: horizontal curves, lane drops, reduced width, weaving, and upgrades. This video was reduced through 18 months of digitizing into vehicle trajectory files. The result is an hour of vehicle trajectory data along several key freeway elements

The data sets produced by this study are some of the most detailed ever collected. It presents detailed interactions between vehicles down to one-second intervals. Although this is not the only type of data that can be used for calibration and validation, it is probably the most comprehensive and can be used for many facets of the analysis. Additional data can be collected for study, but it will not be as extensive, thus not as flexible as the vehicle trajectory data collected by JHK.

### ***North Carolina Data Collection***

This research used several techniques to collect data for capacity and delay analysis in freeway work zones. The research team collected volume data for capacity analysis at twenty-four sites while they limited delay collection to select work zone conditions.

The data collection team monitored the construction season extending from the summer of 1994 through the spring of 1995 for freeway work zone sites with lane closures. The North Carolina Department of Transportation (NCDOT) provided personnel and access to available sites. The research team included employees of NCDOT and NC State University. The analysts defined the study site criteria as freeway work zones with short-term lane closures. The team identified twenty-four freeway work zones and collected data for capacity analysis. Due to light traffic volumes, queued conditions did not occur at all the delay sites selected.

The data collection team was plagued with malfunctioning data collection devices during the early stages of data collection. A computer malfunction resulted in the complete loss of the volumes and speeds in data set twelve. As a result, this data set was ultimately excluded from analysis. A listing of the sites and the data collected is summarized in the following tables

**Table 2-3 Summary of JHK Data Sets**

<b>Site</b>	<b>Type</b>	<b>Level Service</b>	<b>Length</b>	<b>Lanes</b>
I-495 WB west of Georgia Avenue, MD	Horiz. Curve	C-D	1983'	3
US 101 WB at White Oak, Van Nuys, CA	Lane Drop	D	1830'	4/1
I-95 SB at Backlick Rd, Fairfax, VA	Ramp Merge	D-E	1641'	3/1
I-405 NB at Roscoe Blvd, Van Nuys, CA	Ramp Merge	D	1788'	4/1
I-405 SB at Santa Monica Blvd, CA	Ramp Merge	E	1616'	4/1
I-10 WB near La Brea Blvd, Los Angeles	Reduced Width	C-D	1258'	5
B/W parkway NB at f-95, PG county, MD	Weaving	B-E	1606'	2/1
I-395 SB at 14th st Bridge, Washington DC	Weaving	D-E	3230'	2/2-3
I-295 SB bet. 11thst bridge & Howard Rd	Weaving	D-E	2122'	2/1
I-295 NB bet. 11thst bridge and Howard Rd	Weaving	C	1700'	2/1
Rt.11 (Harbor Fwy.) NB bet I-10 and 6th St	Weaving	E	1831'	3/2
US 101 WB bet. Topanga and Ventura, CA	Weaving	C-D	1258'	3/1
I-395 SB at Duke St., Alexandria, VA	Upgrade	D-E	1991'	3
I-405 NB at Mulholland Dr., CA	Upgrade	D-E	1341'	5

**Table 2-4. North Carolina Data Set Summary**

<b>Data Set</b>	<b>Freeway</b>	<b>NC County</b>	<b>Configurati on</b>	<b>Lane Closed</b>	<b>Urban/Rur al</b>	<b>Posted Speed</b>
1	I-95 SB	Cumberland	2-1 Weave	Right	Rural	65
2	I-95 SB	Cumberland	2-1 Standard	Right	Rural	65
3	I-95 SB	Cumberland	2-1 Standard	Left	Rural	65
4	I-95 SB	Cumberland	2-1 Weave	Left	Rural	65
5	I-95 SB	Cumberland	2-1 Standard	Left	Rural	65
6	I-95 SB	Cumberland	2-1 Weave	Left	Rural	65
7	I-440 NB	Wake	2-1 Weave	Left	Urban	55
8	I-440 NB	Wake	2-1 Weave	Left	Urban	55
9	I-440 SB	Wake	2-1 Weave	Right	Urban	55
10	I-440 SB	Wake	3-1 Weave	Right	Urban	55
11	I-40 W/EB	Guilford	2-1 Crossover	Right	Urban	55
12	I-77 SB	Mecklenberg	----	----	----	----
13	I-85 NB	Durham	2-1 Standard	Left	Urban	55
14	I-77 NB	Mecklenberg	2-1 Standard	Left	Urban	55
15	I-77 SB	Mecklenberg	2-1 Standard	Left	Urban	55
16	I-77 NB	Mecklenberg	2-1 Standard	Left	Urban	55
17	I-77 SB	Mecklenberg	3-1 Standard	Left	Urban	55
18	I-95 NB	Johnston	2-1 Standard	Left	Rural	65
19	I-95 SB	Johnston	2-1 Standard	Right	Rural	65
20	I-95 NB	Johnston	2-1 Standard	Right	Rural	65
21	I-95 NB	Johnston	2-1 Standard	Right	Rural	65
22	I-40 WB	Wake	3-2 Standard	Left	Urban	65
23	I-40 WB	Wake	3-1 Standard	Right	Urban	65
24	I-40 WB	Wake	3-2 Standard	Left	Urban	65

**Table 2-5 Data Set Characteristics**

Data Set (Site)	Rural (R) Urban (U)	Night (N) Day (D)	Weave at Taper	Merge (R/L)	# Lanes – Normal	# Lanes – Open	Lateral Distance to Work Activity (m)	Work Operation Heavy (H) Moderate (M) Light (L)	Queue Observed	On-ramp Prior	On-ramp at Taper	On-ramp at Work	On-ramp Prior	On-ramp at Work	On-ramp Prior
1	R	D/N	X	L	2	1	0.6	H		X		X	X		
2	R	D/N		L	2	1	0.6	H	X	X		X	X		
3	R	D		R	2	1	0.6	H				X	X		X
4	R	D	X	R	2	1	0.6	H				X	X		X
5	R	D		R	2	1	0.6	H				X			X
6	R	D	X	R	2	1	0.6	H				X			X
7	U	D/N		R	2	1	2.4	L & M	X	X		X			
8	U	N	X	R	2	1	2.4	M		X					
9	U	N	X	L	2	1	2.4	M	X	X					X
10	U	N	X	L	3	1	0.6	M	X	X	X				X
11	U	N	X	L	2	1	1.2	H							
13	U	N		R	2	1	1.8	M				X			X
14	U	N		R	2	1	2.4	H	X	X			X		
15	U	N		R	2	1	N.A.	L				X			
16	U	N		R	2	1	0.6	H	X				X		
17	U	N		R	3	1	2.4	H	X						X
18	R	D		R	2	1	0.6	H	X	X					
19	R	D		L	2	1	0.6	H							
20	R	D		L	2	1	0.6	H	X	X	X		X		
21	R	D		L	2	1	0.6	H	X						
22	U	N		R	3	2	2.4	H		X	X		X		
23	U	N		L	3	1	0.6	H		X			X		
24	U	N		R	3	2	2.4	H		X		X		X	X

### **The FSP Data**

The Freeway Service Patrol Project, conducted under the PATH program out of the University of California at Berkeley, was brought about to evaluate the effectiveness of service patrols. A tremendous amount of data was collected in several formats in both a “before patrol implementation” and an “after patrol implementation” study. The study before implementation took place from February 16 through March 19, 1993 with the after study taking place from September 27 through October 29, 1993. All the data was collected on a section of the I-880 freeway in Hayward, California. The study section was 9.2 miles long and varied from 3 to 5 lanes. An HOV lane covered approximately 3.5 miles of the study section. There were several sections that lacked right-hand shoulders and/or left-hand shoulders. Call boxes were installed at approximately ¼ mile intervals. Data was collected on the weekdays during peak periods (6:30 - 9:30 am and 3:30 - 6:30 pm). For each study period three different types of data were collected: loop detector data, probe vehicle data, and an incident characteristics database.



## **The Loop Data**

Loop detectors were placed approximately 1/3 mile apart on the freeway mainline and on all the on- and off-ramps. There were a total of 322 mainline detectors, 18 on-ramp detectors, and 14 off-ramp detectors. These loops were connected to standard Type 170 controllers that recorded speeds, flows, occupancies and loop on and off times. The loop data was stored each weekday from 5:00am until 10:00am and then from 2:00pm until 7:00pm on the disk drive of the laptop computers that were installed in each 170 controller cabinet. Every few days these files were transferred to floppy disks and then to a Sun Workstation where the processing took place. Due to defective disks and intermittent power failures at the 170 controllers only 434 out of a possible 456 files could be collected for the before study (19 detector stations over 24 days), and 454 out of 475 files for the after study. Each file is approximately 1.7 Mbytes making a complete day approximately 33 Mbytes and the entire study approximately 760 Mbytes.

## **The Probe Vehicle Data**

Throughout the experiment, four vehicles were driven around the study section at 7 minute average headways during the data collection period. For each probe vehicle, there were approximately six runs for each three hour shift. Although this should give 1152 runs for the before study and 1056 runs for the after study, there were many breakdowns of the probe vehicles and the computers within them. Therefore, only 881 runs were collected in the before study and 764 runs in the after study.

These vehicles had computers that recorded the car's movement and the driver's key presses and then saved these to various files on the PC floppy disk. There are a total of four data files for each car for each shift:

### ***key.dat***

This file saves the keys that the drivers type in. The drivers type a key each time they start a run, pass a gore point, or pass an incident.

### ***fsp.dat***

Certain loop detectors in the study section were set up to emit a constant radio signal. The system that produced these signals is called the inductive radio (INRAD) system. The probe vehicles were equipped to detect and record the signals. The fsp. dat files contain an odometer reading and a time stamp for each time the car drove over on of the INRAD beacons. There were a total of three INRAD beacons.

### ***nav.dat***

Probe vehicles were all equipped with digital compasses. The PCs in the cars stored the odometer reading and the digital compass reading every second in the files named nav. dat. With this data it is possible to plot trajectories of all the vehicles

### ***gps.dat***

The gps . dat file is the data from the GPS equipment in the car. It contains the latitude and longitude of the car which can also be used to plot the vehicle trajectory.

## **The Incident Data**

The incident data is one database file with approximately 80 columns of information per incident. The database was collected during the experiment by the drivers of the probe

vehicles. When they were driving on the study section and they passed an incident they would transmit via radio to a supervisor information about the incident (vehicle type, location, lanes blocked, tow truck, police, etc.). All of this would be written down by the supervisor on a standard form. This form was then coded into an Excel spreadsheet with numerical entries in each column so that a computer could process it later. It was then transferred to a workstation where it is stored as a tab delimited ASCII file.

### ***Barton Aschman's Data Collection Projects***

Barton-Aschman has participated and performed several projects that have involved data collection and modeling activity. Some of the more promising projects are listed in Table 2-6.

**Tab/e 2-6. Selected Barton-Aschman Tests**

<b>Project</b>	<b>Description of Project</b>	<b>Data Collected</b>
Chicago's O'Hare International Airport	Used microscopic traffic models like NETSIM and FRESIM to assess the impacts of construction projects on the roadways.	Calibration data like queues, travel time runs, and delay data were collected.
Drawbridge Operations in Downtown Chicago	Used TRAF-NETSIM to evaluate the impacts on traffic and pedestrians due to raising the drawbridges in a grid type downtown scenario.	Calibration data for modeling the downtown area was collected.
Traffic Impact Modeling: Chicago Central Area Circulator	An alternative analysis and environmental impact statement for transit improvement in the Chicago Central Area. NETSIM, TRANSYT-7F, and SIGNAL85 were used.	Traffic data for using TRANSYT-7F and SIGNAL85 and calibration data for using NETSIM model were collected.
Freeway Operations Study along I-94 in Hudson, Wisconsin	Feasibility of expanding a 6 mile freeway section with 5 interchanges using the microscopic simulation model, INTRAS.	Traffic data as well as calibration data for using INTRAS was collected.
I 80 Reevaluation Traffic Analysis	I 80 was to be reevaluated for the addition of HOV lanes. FREQ10PL and INTRAS models were used in this project for Caltrans.	FREQ was extensively calibrated using speed and delay runs and density counts obtained from aerial photography. INTRAS was used to supplement the FREQ results.
Route 87 Conceptual design alternatives	Freeway operations were evaluated using FREQ. TRAF-NETSIM was used to evaluate tightly spaced surface street intersections.	Calibration data for FREQ and TRAF-NETSIM was collected.
Evaluating various alternatives for modifying interchange operation (I 580/I 680 and I 80/I 580)	Numerous projects were undertaken to evaluate and improve interchange operations. Models like INTRAS and NETSIM were used.	Traffic and calibration data for INTRAS and NETSIM were collected.
Emergency Evacuation/Transportation Plan Update for the Los Alamos National Laboratory, New Mexico	CORFLO and NETSIM were used to evaluate various scenarios like early dismissal and closure procedures at the laboratory.	Travel data from GPS users, traffic counts, and vehicle occupancy surveys were collected.
Spokane Galleria, Spokane, Washington	The effects of having right turn pockets for turning into Spokane Galleria and out onto Evergreen Road were evaluated. TRANSYT-7F was used to optimize the signals and NETSIM was used to simulate both the options.	Data for the PM peak was collected and used in both the programs.
Ramirez De Arellano Corridor, Puerto Rico	A proposal for traffic calming by reducing a 4 lane highway to a 2 lane highway through a residential area was evaluated using TRAF-NETSIM and a planning model - EMME <sup>2</sup> .	An extensive inventory of the existing roadway and traffic conditions was performed.
Minnesota Signal Timing Program	NETSIM was used to evaluate the before and after conditions of retiming projects.	Saturation flow rates by approach, maximum and average queue lengths, average phase lengths, and travel time runs were conducted.

## Section 3. Conclusion

The data presented in this draft working paper are not intended to be an exhaustive list of all possible candidate data. However, they are representative of the kind of information available and list programs that offer opportunities for direct application or to supplement existing efforts. Existing data, while offering the potential for reducing costs by precluding the necessity for additional data collection and reduction efforts, does offer additional challenges. These challenges are discussed below.

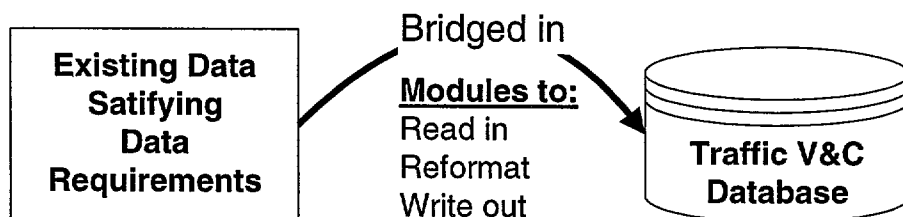
Existing freeway data (uninterrupted flow) seems to offer the best opportunity for direct utilization. Urban street data (interrupted flow) are complicated by parameters such as signal control parameters, cross street traffic and many other factors that complicate the modeling process.

### *The Problems with the Utilization of Existing Data*

The common perception is that the use of existing data might result in time and cost savings compared to new data collection and reduction efforts. However, for existing data to fulfill these expectations, in addition to being available and applicable, it must be well documented and in digitized form such that the data can be bridged into the appropriate format.

The problems associated with existing data is that it must be converted to a form sufficient for accommodating an existing database format or model inputs and outputs as described in Figure 3-1. If the data is in digitized form, then this involves writing processing modules to read, reformat and write the data in the desired format.

The approach is to exploit to the maximum extent possible all sources of existing data and all planned data collection efforts. Existing data sets that contain all of the essential parameters for validation will likely be quite sparse, and those that are incomplete will be very difficult to supplement because of the inability to recreate the original conditions for follow-on data collection. However, in some cases, less than complete data sets may be applicable to



**Figure 3-1 Bridging in Existing Data**

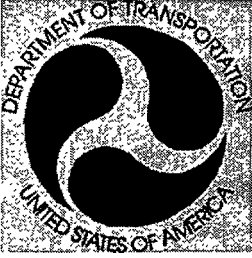
calibration.

### ***Preferred Approach***

The preferred approach is to identify ongoing or future programs that are collecting data for modeling purposes. These programs have the potential for being both applicable and cost/effective to the V&C process through supplementation of existing data collection. The objective is to develop general guidelines for data collection. These guidelines, if implemented, should simplify the bridging in process by allowing the reuse of the same modules each time with only minor modifications.

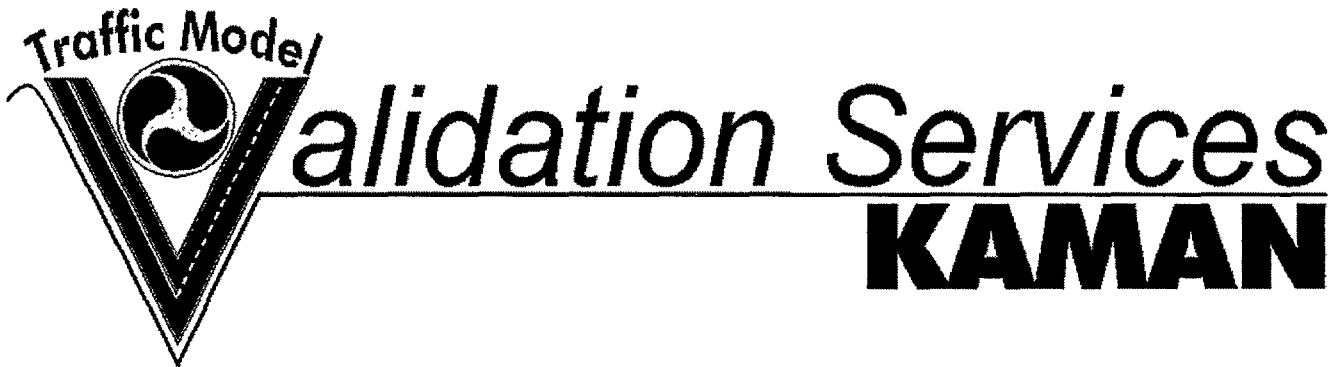
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<sup>1</sup>Owen, L. E., Kaman Sciences Corporation, "Traffic Model Validation and Data Requirements, prepared for FHWA, March 7, 1996.

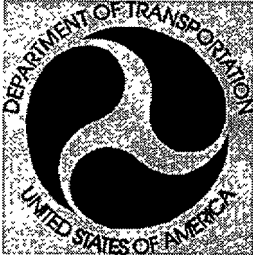


# Data Acquisition for Traffic Model Validation

*Task D&E*



December 1996

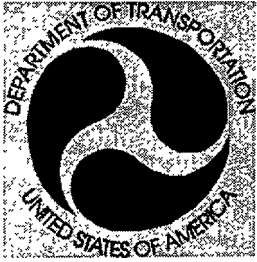


# Data Acquisition for Traffic Model Validation

## *Forward*

The overall objective of this program is to develop and demonstrate methodologies for traffic model validation. The validation process requires that comparisons be made between real-world data and simulation predictions. The objective of data collection described in this paper is to provide the real-world data. The objective is to obtain traffic flow data from several sites in geographically diverse regions of the country. The data collected from these sites will be stored in a database management system so that the validation methods can be repeated on existing, modified, and emerging traffic models. The purpose of this document is to describe the:

- Nature of the data required for model validation
- Approaches to data collection including the preferable conditions, typical schedule and data collection methods
- Characteristics of desirable locations and several means for data collection



# Data Acquisition for Traffic Model Validation

***Prepared by:***

Kaman Sciences Corporation  
PO Box 7463  
Colorado Springs, CO 80933

Authors:

Larry E. Owen, PI  
Gary Brock  
Scott Mastbrook  
Srinivasa Sunkari

***Prepared For:***

US Department of Transportation  
Federal Highway Administration  
IST Division, HSR-10  
6300 Georgetown Pike  
McLean VA 22101



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# Section 1. Real-World Data for Traffic Model Validation Purposes

A traffic system consists of facilities and users. Facilities consist of roadways and controls. Users include either occupants of vehicles or pedestrians. The operation of a traffic system is characterized by the flow of the users traversing the traffic system. The operational validation process requires that comparisons be made between model predictions and real-world system behavior. For this comparison to be meaningful, both real-world data and model prediction information must exist for a given geometric layout. Model information is obtained by executing the simulation with descriptive inputs taken from measurements and descriptions of the facilities (roadways and control) and the scenario (principally the demand volume).

In general, there is a tradeoff between the capability to collect microscopic data, the geometrical extent of the network, and the time duration of data collection activities. The intent is to identify small scale sites and collect detailed information during limited time periods of one to two hours. In addition to this detailed data collection, several 'variability' studies will be performed at each site, collecting data under higher aggregations over longer time periods to determine the day-to-day variation in the traffic parameters.

The goal of the data collection is to populate a database with traffic statistics with the purpose of validating and calibrating microscopic traffic models and simulations. The two major logic controls within traffic simulations are the car-following model and the lane-changing model. To properly validate and calibrate these models, microscopic data must be collected on both car-following and lane-changing behavior.

To collect information on car-following behavior, microscopic data on individual vehicles will be taken at various points in the study section. At each collection location, data will be gathered from the individual lanes. The locations will include the boundaries of the section and all on/off ramps. Additionally, data will be obtained at selected key intermediate points. The four variables under investigation will include the vehicle count, classification, speed, and headway. The actual data collection equipment used is immaterial as long as the relevant microscopic data can be collected on a vehicle level and the actual data able to be correlated back to an established standard. This detailed collection will be done for a one to two hour interval on one or more study days under "normal" conditions.

To collect data on lane-changing behavior, one or more lengths along the study section will be selected and bounded as "lane-changing sections". Generally, these sections will be large enough to fit in a camera lens' view, but still have accurate enough detail to distinguish the lanes. These sections will be videotaped throughout the study and lane changing statistics will later be derived from this data.

## **Section 2. Approach to Data Collection**

Data collection requires planning in terms of the desirable conditions, scheduling and deployment of specific equipment. The following elements of the data collection that are common to all data collection activities

### ***Conditions***

To provide limits on the data collection requirements of specific parameters (such as speed and headway) and to reduce the road condition variables involved, the data will always be collected under “normal conditions”. Normal conditions connotes clear weather, clear road conditions (no precipitation or ice on roadway), daylight conditions (between a half hour after dawn and a half hour before sunset), good visibility (no fog or glare), and uninterrupted traffic flow (no incidents or unplanned blockages, however, a planned lane blockage causing a lane drop is permissible for certain scenarios). The data should also be taken during non-peak traffic flow (not at rush hour, holidays, during special events, or while traffic is being diverted from another roadway) and typically between Tuesday and Thursday to avoid unusual traffic patterns. In addition, conditions such as saturated flow and small traffic volumes should be avoided. Saturated flow limits the variability of the observed parameters, while very small volumes limit dispersion observations

### ***Typical Schedule***

Before any traffic data is obtained for a selected study area, geometric data must be collected, recorded, and verified. This will include data on the number of lanes, lengths of links, position of ramps, position of cross streets, position of intersections, and any other information relevant to the description of the study area. A typical schedule for collecting traffic parameters will include a two-week period of collecting aggregated sampling data, a single day of collecting extensive detailed data, and another follow up period a week later for collecting additional “variability” data.

To determine the best time to collect detailed traffic data, sampling will be done under a specified schedule to determine the variability of the traffic. This sampling data will consist of much more aggregate data such as counts for 5 to 15 minutes over all the lanes at specified sections and ramps for three to six hours throughout the day. Sampling will be performed two weeks before a detailed study is to be done and under “normal” traffic conditions. Once enough aggregate data is collected it will be analyzed to determine the time of day that has the least variability for obtaining detailed data.

Detailed data collection shall be performed in a one to two hour period on the selected day and time with the least variability under “normal” traffic conditions. This will include collection of detailed point data at several locations that records the time stamp, classification, speed, and headway of each vehicle in each lane. In addition, data will be collected on lane changing for specified segments within the study area. Probe vehicles will be run through the entire study area to collect travel time information to establish a standard for calibrating the test data.

For at least a week after the detailed study, variability studies will continue under “normal” conditions in the same time frame that the detailed study was performed. Again, aggregate (5 to 15 minute) counts shall be collected over all the lanes at specified points. Instead of a three to six hour period, however, data needs only to be collected during the time frame the detailed data was obtained.

## ***Measurements***

The parameters to be collected include point data, spatial data, and probe data. Point data includes the time stamp, classification, headway, and speed of each vehicle (by lane) at various locations within a study area. Spatial data includes lane changing information over a specified segment within a study area. Probe data includes global positioning system (GPS) data taken from a probe vehicle driven through the study area. The variability of "sampling" data is a subset of point data, where the speeds and headways are collected and aggregated over lanes, and the time at selected data collection locations. Supplemental data may be collected with spot speed measurements, counters, or other techniques.

## ***Specific Data Collection and Reduction Methods***

Several data categories have been defined for this traffic study including detailed point data, sampling or 'variability' point data, spatial data, and probe data. For each of the data categories collected, there are different data collection and reduction techniques. This section describes these methods, along with some advantages and disadvantages

### **Detailed Point Data Collection**

Detailed point data involves collecting the time stamp, classification, speed, and headway of each vehicle in each lane for three to six target sections within the study area. This study is to be performed over the detailed collection time of one to two hours. Several types of detectors and surveillance techniques can be made applicable for detailed point data collection. These include video, loops, and magnetic imaging detectors

#### ***Video***

Video data collection involves setting up either a CCTV or a camcorder at a vantage point that encompasses part of the roadway with enough coverage and detail to discriminate between cars and the lanes over a nominal distance. To collect point data from video, preparations must be done in the field. The data collection point should be marked with a colored vertical object, such as a pole or a stake. Two other vertical markers should be placed at equal distances upstream and downstream of the data collection point. These should be visible in the video view screen even when large trucks pass the by the markers.

To reduce the video manually, a time stamp at least to 1/10<sup>th</sup> of a second must be recorded on the video tape. The tape is then played back frame by frame while data is manually recorded. For each vehicle, the four items that must be recorded include the lane, vehicle classification, the time it passes the upstream marker, and the time it passes the downstream marker. From this data, the actual time step can be calculated from average times, the speed can be calculated, and the classification can be recorded from a categorized list.

Enhanced video camera techniques to permit direct readings of vehicle speed will be tested to determine the accuracy and accessibility of the data over the traditional methods used for data reduction. Kaman developed cameras that are being utilized for an on-going Long Island highway surveillance project can provide an average platoon speed from the video data. The possibility of modifying the detection software to give the individual vehicle speed will be investigated.

The biggest advantage to video data collection is the cost. Cameras are inexpensive and usually cost less than \$500 a piece. Once they are purchased they can be reused for as many studies as needed. For most studies, there will be three to six point data collection locations, therefore at most, six cameras would be needed for data collection. Videotapes are

inexpensive and are a negligible part of the cost of data collection. Another advantage to video is that it is non-intrusive and data collection with video does not require interference with the road to place detectors

The biggest disadvantage to video is the effort required to perform the data reduction. For freeways, the general flow rate in these studies will range between 1200 and 1800 vehicles per lane per hour. For a one-hour tape of a three lane segment, this means reducing information for up to 5600 vehicles. This could take approximately 75 man hours per tape. If six segments of data collection are recorded, this could mean over 450 man hours of data reduction time for a study, and even more if there are more than three lanes per segment. Also, as the recorded data time increases, the data reduction time increases proportionately.

### ***Inductive Loops***

Temporary inductive loops can be installed over lanes and they will automatically collect data on individual vehicle headways, speeds, and classifications. They are tacked or pasted down to the roadway and connected to a controller that automatically collects and records the information for each vehicle. This information can be downloaded and an analyst assimilate and organize the data into a proper format with minimal reduction.

An advantage of loop data is the lack of extensive reduction efforts. Only a few man-hours are needed to organize the data into a usable format. One disadvantage is the cost of loop detectors. Loop detector rental per data collection point may run between \$600 and \$1000 per study. With three to six points, this could be prohibitive. Another disadvantage is that they are intrusive, requiring interference with the roadway to install. In some heavy traffic conditions, loops are often damaged or malfunction, therefore, reliability should be taken into account in detector comparisons.

### ***Magnetic Imaging Detectors***

Magnetic imaging detectors, such as those produced by Nu-Metrics®, are flat detectors that are placed in the lanes like loops. They can be fastened by straps or nailed down with covers. These detectors are designed to automatically collect the time-stamp, speed, and classification of each vehicle. Software can automatically sort and arrange the data into a user-specified format.

An advantage to the magnetic imaging detectors is that they do not require extensive data reduction. Software used in conjunction with the detectors streamlines the data reduction efforts. Magnetic imaging detectors have been tested and unlike inductive loops, have shown to be reliable under many traffic conditions. A disadvantage to these detectors is that they are intrusive like loops and require interference with the roadway to install. A major disadvantage is the up-front cost. Initial purchase price of the software is between \$1000 and \$2000. Each detector generally costs about \$1000. For a four-point data collection study, with three lanes at each point, this up-front cost can range from \$10,000 to \$15,000. However, it should be noted that they are durable and re-usable detectors which can be used multiple times with small recurring costs per study.

### **Variability or Sampling Point Data Collection**

The data collected for sampling and variability purposes can be aggregated over lanes, and over time, therefore the equipment requirements are not as great. Although the same kind of detectors used for detailed collection can be used, the most common way to collect lane aggregated data is with pneumatic tubes. These can be installed across all the lanes and used to collect counts over 5 to 15 minute intervals. Major advantages are their very low cost and the

minimal data reduction required. The disadvantage to these detectors is that they are intrusive, requiring interference with the roadway to install.

### **Spatial Data Collection**

Spatial data comprises any data that is taken over an area of specified length in the study section. An example of this is lane changing data. The only practical way to collect data of this nature is through video surveillance with manual notation of maneuvers. This requires setting up a wide angle shot of a section in the study area of sufficient length to observe lane changing activity. Reduction involves manually sorting the data into different categories such as 'left lane change', 'right lane change', 'car lane change', and 'truck lane change'.

### **Probe Data Collection**

Probe data is different from both point and spatial data in that it is collected from a vehicle moving through the study section. The most common and useful data collected from a vehicle probe is GPS data. A GPS receiver in a vehicle can automatically record the position, speed, and direction into a data file. GPS equipped probe vehicles are used for travel time studies. They can give the behavior of the probe vehicle in the traffic stream very accurately. Multiple probes can be used to achieve better data definition. The GPS unit may need to be calibrated for accuracy of the position data. Under congested or stop and go conditions the coordinates of the vehicle may not be completely accurate.

### **Other Data Collection**

Other data sources can also be used to collect information such as radar guns and manual counters. Although not a main source of continuous data, these supplemental data types are useful in traffic studies.

#### ***Radar***

Radar is used for measuring the speed of vehicles at a point on the roadway. It is a very easy way of acquiring speed data with minimal intrusion to the traffic flow. Speed can be documented either manually or automatically by connecting to a laptop computer. Collecting speeds using radar guns requires almost no setup procedures and the data collected is reasonably accurate.

However, before collecting data, the radar should be calibrated. The radar is usually correct to within 2 to 3 mph. A few other precautions should be taken to obtain accurate results. The angle between the line of sight of the radar gun and the direction of the vehicle should be as small as possible to minimize error. The data collector should also be as inconspicuous as possible to avoid attracting attention from the motorists. This would definitely have an influence on the speed of the motorists. The data collector should also have a strategy to obtain a representative example of the traffic at a particular sample. Vehicles at various speeds and also at different places within the platoons should be recorded.

#### ***Counters***

Counters are used to obtain manual traffic counts at intersections with no intrusion to the traffic flow. They are very easy to use and they can be reset at any time to obtain the counts for any desired period.

## **Existing Infrastructure**

The use of existing infrastructure is very cost effective for the data collection process and should be used whenever feasible. Inductive loops and surveillance cameras already installed will be used to the maximum extent possible upon obtaining permission from the local traffic agencies. Attempts will be made to use existing infrastructure to provide volume counts, mean speeds, occupancy, headways, and vehicle classification at minimum costs. However, this process may take considerable time and other methods may be required to be used.

### ***Installed Loops***

Loops embedded in the pavement are a very inexpensive and useful means of collecting traffic information. These loops are usually placed in the pavement for traffic control. They can either be placed at the stop-line or upstream or downstream of the intersection to detect vehicles and send the information to the signal controller. On freeways, loops are usually used to obtain occupancy and speed information. These loops will however only be useful for some specific configuration (like pulse) and on surface streets at specific locations.

Using loops to collect data has some advantages. There is no expenditure involved when using existing loops and the traffic data observed can be downloaded from the traffic controller directly to a laptop computer. Data collection can be done anytime and does not require any extensive setup procedures. Hence, loops can be used to collect traffic data inexpensively and quickly. However, data collected from the loops also has some disadvantages. If the loops are not located at the right place, there could be significant errors in the observations. In some cases, if the queue extends over the detector, each individual vehicle may not be detected and the length of the queue also may not be known. Loops also need some maintenance and they occasional tuning in order to maintain accuracy.

### ***Existing Video Cameras***

Surveillance cameras are already installed at many locations in the traffic infrastructure. With proper alignment, they can provide a significant source for video data. Due to the high-quality of these installations, they can usually be a reliable source of video information when available and the techniques already discussed for video data reduction can be used.

## **Section 3. Site Selection Criteria and Application of Data Collection Methods**

The sites of interest for traffic model validation purposes fall into two general categories: uninterrupted and interrupted flow. Within each category, specific traffic flow patterns and geometrical layouts are desired. Correspondingly, the data collection methods described in the previous section are deployed to obtain the data. The preferred site configurations and deployment of data collection methods are described below.

### ***Freeway Sections***

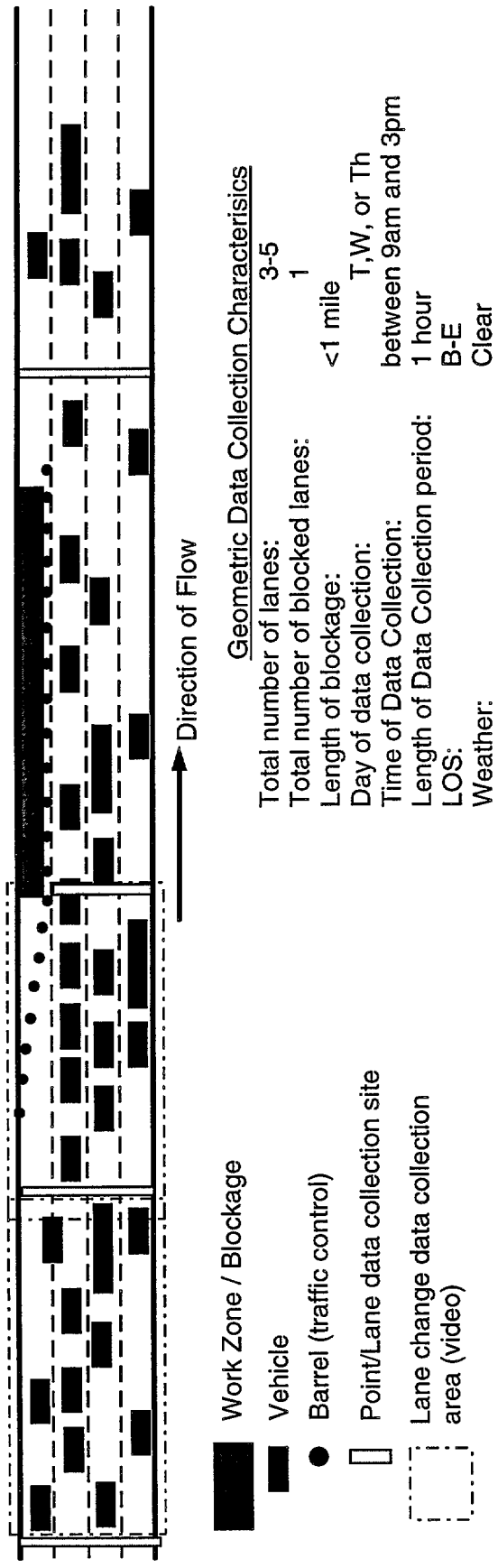
As part of the validation and calibration effort for microscopic simulation models, some data collection needs to be conducted for various freeway scenarios. These studies will be on a very small scale but will be detailed in nature. One of the most important criteria for site selection is to select a location which has some existing traffic monitoring infrastructure. This infrastructure could also be supplemented with additional equipment from other sources including video, loops, tubes, magnetic imaging, GPS probes, radar, and other kinds of equipment. Data would be collected under “normal” traffic conditions as discussed earlier.

The schedule for collection of the data will follow the typical test sequence illustrated earlier. First, sampling of aggregated counts and speeds will be performed. Once a one to two hour time frame is selected, detailed data collection will follow with the gathering of data on a vehicle by vehicle basis at point stations, spatial lane-change data, and probe vehicle GPS data. Finally, additional point variability studies will be done for two weeks after the detail study.

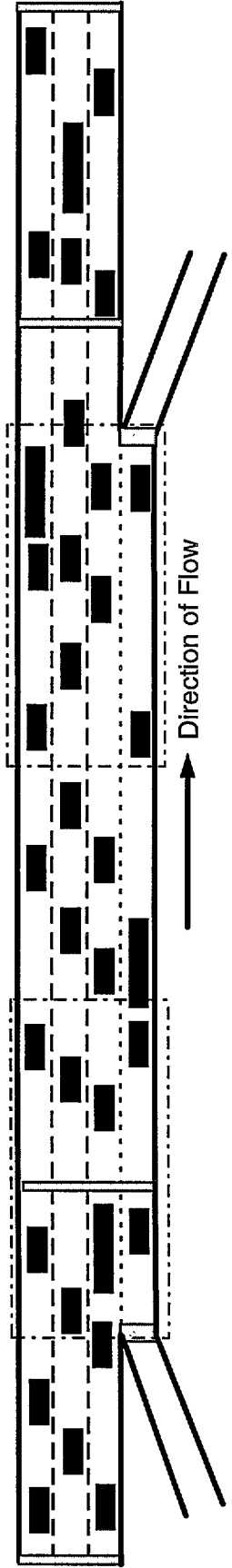
To capture the various ranges of driver behavior, two basic scenarios have been selected that include a lane-drop situation, and a weaving situation. The lane-drop situation can be of a fixed (permanent) or temporary (construction) type of site with enough traffic to exhibit well defined merging behavior. The weaving section can have between one and three on/off ramps within a short enough distance and enough traffic to exhibit well defined weaving behavior. General specifications for these scenarios are illustrated in figures 1 and 2.

Point data will be collected at the beginning and end of the study section, at all off and on ramps, and at specified illustrative intermediate locations. Data collected at these points will include the time stamp, headway, speed, and vehicle classification. Spatial data collected through video will be reduced into lane change data as described earlier. Finally probe vehicles outfitted with GPS receivers will record travel times throughout the detailed study.





**Figure 3-1. Freeway Data Collection Scenario (Lane Drop/Blockage)**



Geometric Data Collection Characteristics

Total number of lanes: 3-5  
 Total number of ramps: 2-3  
 Day of data collection: T, W, or Th  
 Time of Data Collection: between 9am and 3pm  
 Length of Data Collection period: 1 hour  
 LOS: B-E  
 Weather: Clear

- Vehicle
- Point/Lane data collection site
- Lane change data collection area (video)

**Figure 3-2. Freeway Data Collection Scenario (General Weaving)**

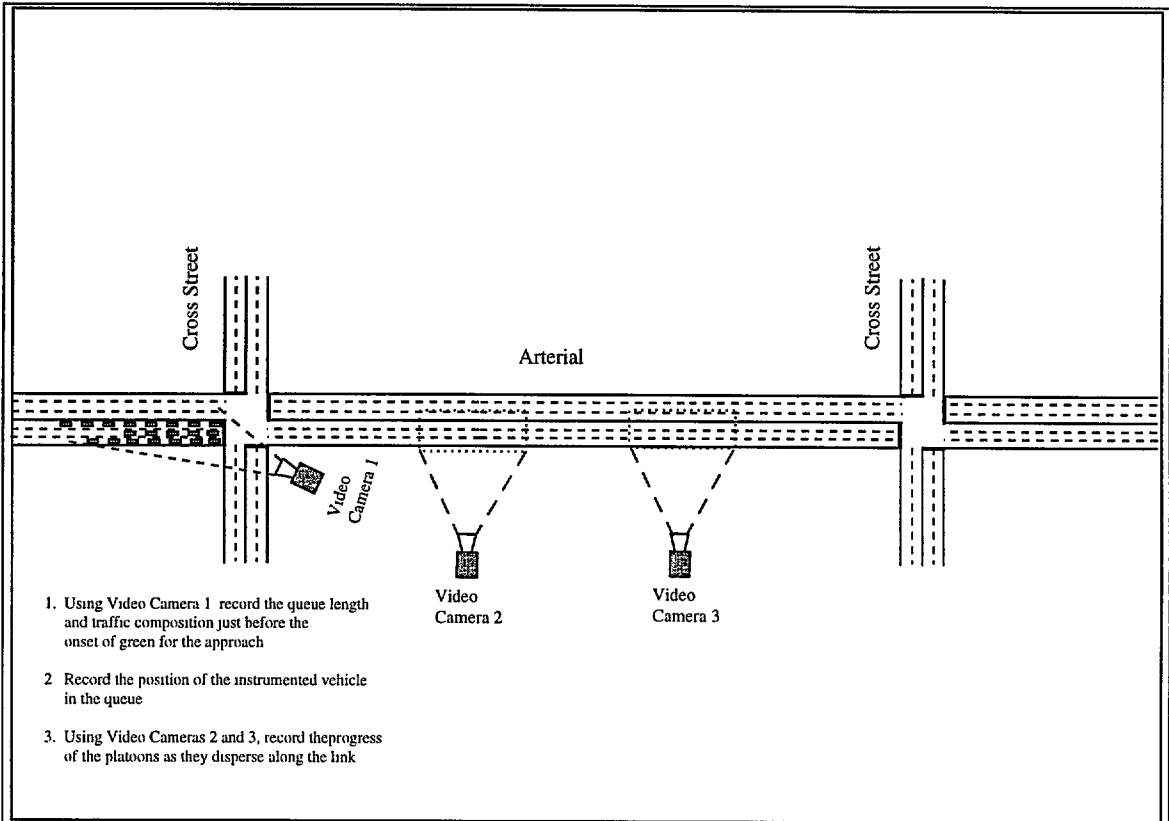
## ***Urban Street Links***

As part of the validation and calibration effort of the microscopic simulation models, some pilot studies must also be conducted for urban street links. These studies will be on a very small scale but detailed in nature. As mentioned in the earlier sections, this detailed data will be collected under “normal” traffic conditions.

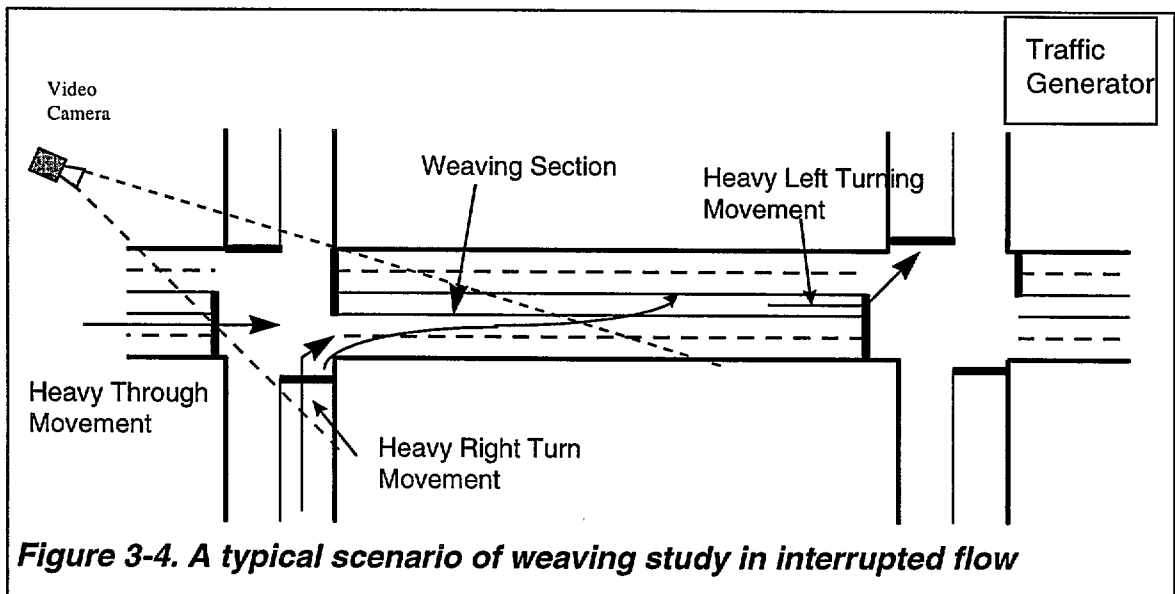
Some interesting traffic features will be observed on a small section of the arterial. One of the features is platoon dispersion which could be observed in great detail along a single link as shown in figures 3 and 4. Some platoon dispersion studies have already been conducted in Colorado Springs and others are being considered at other locations. Links for studying platoons would have to be about one mile in length and exhibiting varying sizes of platoons and traffic composition like heavy vehicles. The links may also have varying degrees of interaction from sources and sinks in the link. Links with different kinds of signal control (fixed, semi-actuated, and fully actuated) at the upstream node could also be considered.

Another interesting feature would be a section of the arterial exhibiting extensive weaving patterns. This would be typically observed at a major traffic generator which is very close to an intersection. Weaving could occur due to the combination of some high merging movements and the presence of the traffic generator. A typical example is shown in figure 4. The presence of some tall buildings in the vicinity would facilitate the positioning of video cameras. Although video is emphasized in these figures, it should be noted that the type of detectors used is immaterial as long as the proper relevant microscopic data is collected. The schedule for collecting data from urban street links will be similar to the freeway case for the collection of aggregated and detailed data.

Queue length and traffic composition will be recorded at an upstream node just before the signal turns green and the platoon is released. Point data will be collected at two or more points downstream including the time stamp, headway, speed, and vehicle classification. Spatial data collected through video will be reduced into lane change data as described earlier. Finally, probe vehicles outfitted with GPS receivers will record travel times throughout the detailed study.



**Figure 3-3 A typical scenario of platoon dispersion study in interrupted flow**

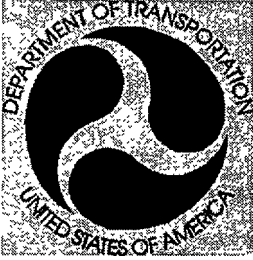


**Figure 3-4. A typical scenario of weaving study in interrupted flow**

## **Section 4. Summary**

The methodology and data collection methods described in the previous paragraphs will be used to obtain microscopic data for freeway and urban street links. Object oriented databases will be populated by the reduced and raw microscopic data collected from each site. This information will assist in the validation and refinement of the car following and lane changing models in FRESIM and NETSIM. In addition, as the data from other test programs becomes available, the analysis methodology developed for this project can be used to assist in the validation and refinement of other simulation model parameters.

The object oriented nature of the databases used in this project will provide easier access and manipulation of the stored information over ordinary relational databases. An object oriented database also allows more efficient sharing of information between other object oriented programs or relational databases. This will permit other researchers to utilize the database for various traffic studies. In addition, the databases will eventually be made available via internet connection to the FHWA web site for use by the traffic community.



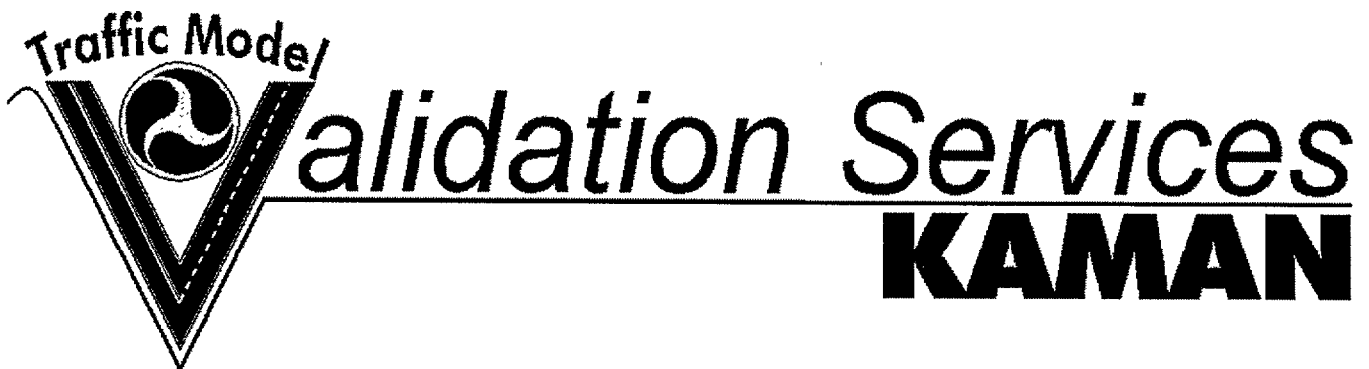
# Database Management System

Vendor Recommendation and Preliminary Design

*Task F*

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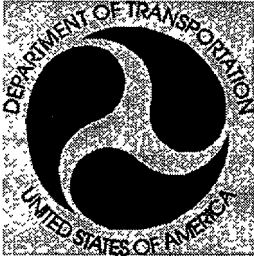
*Draft Working Paper*



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# Database Management System

## Vendor Recommendation and Preliminary Design

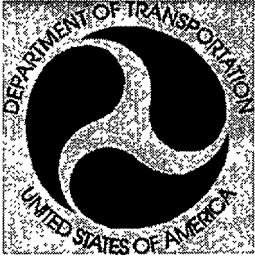
### *Task F*

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#### *Forward*

Traffic models are widely and very successfully used by traffic professionals for optimization, planning and analysis. As these models expand in scope and complexity to meet the diversity of applications, validity continues to be an issue with users and decision makers. Often, the documentation, methodology or extent of the validation efforts are insufficient to establish a high confidence level in model results. Part of the difficulty with validation is suitable and accessible data to complete the process. To address these issues, the Federal Highway Administration has sponsored this research effort to identify the most effective procedures for validating certain components of the TRAF family.

This paper proposes a preliminary design and architecture of an automated validation and calibration services system. The proposed Validation Services System for Traffic (VaSST) will be deployed as a web site on the world wide web and will provide data, techniques, and automated methods for performing validation and calibration of traffic models. Sections two and three of this document provide operating system, hardware, and DBMS recommendations for VaSST. Section four defines the preliminary software architecture of the system. Section five contains diagrams of the preliminary data model. In addition, a white paper explaining some of the basic difference between relation database and object database can be found in Appendix-A. Section one, "Functional Requirements" is incomplete at the time of this draft release.



# Database Management System

## Vendor Recommendation and Preliminary Design

### *Task F*

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***Prepared by:***

Kaman Sciences Corporation  
PO Box 7463  
Colorado Springs, CO 80933

***Authors:***

Larry E. Owen, PI  
Rick Pavlik, Lead  
Scott Mastbrook  
Gary Brock

***Prepared For:***

US Department of Transportation  
Federal Highway Administration  
IST Division, HSR-10  
6300 Georgetown Pike  
McLean VA 22101



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# Section 1. Functional Requirements

This section is under development.

## Section 2. Server Recommendation

### SERVER O.S. RECOMENDATION:

The Windows NT Advanced Server operating system is the recommended OS for VaSST. Both UNIX and NT Server are robust and scaleable. However, NT Server was chosen over UNIX based on cost, consistency, and ease of use.

From a cost stand point, NT server is a big winner. Although UNIX operates on many platforms, it is not commercially available on Intel Pentium Pro based servers. These servers are much cheaper than comparable UNIX servers offering a considerable price performance advantage. On hardware platforms that support both operating systems, NT server is consistently sold for less than half the cost of the UNIX OS. Not only are the direct hardware and OS costs less than UNIX, but the cost of software development kits (SDKs) and DBMS software tends to be significantly cheaper on the NT Server environment.

One of the problems with UNIX is that each hardware vendor offers their own flavor of the OS. While much of the core OS is consistent, they all tend to have their own idiosyncrasies. NT Server is much more consistent across various hardware platforms. The different flavors of UNIX tend to differ drastically in the types of server administration tools they offer. Often times vendors will charge extra for GUI based UNIX administration tools. NT Server consistently offers the same easy to use Windows interface. The NT Server GUI is the same easy to use interface found on Windows/95 and NT workstation. In addition to cost, consistency, and ease of use, NT Server also offers some important features not found on standard Unix such as software based RAID (Redundant Array of Inexpensive Disks) control.

### SERVER HARDWARE RECOMENDATION:

The subsections below describe the minimum recommended server configuration, potential upgrade options, a competitive comparison of commercially available servers, and a recommendation for VaSST.

### Minimum Recommended Server Configuration:

<b>OS:</b>	Windows NT Server
<b>RAM:</b>	128 MB
<b>SMP:</b>	Two processor SMP expandable to four or more processors
<b>Disk Drive Type:</b>	Fast Wide SCSI
<b>Disk Drive Qty:</b>	Six 2GB drives
<b>Drive Control:</b>	Two Fast/Wide SCSI2 controllers
<b>RAID:</b>	Minimum config will utilize W/NT soft RAID level 5 for DB files. Four drives will be used in RAID set. This drive set will be placed on a dedicated F/W SCSI channel.
<b>NIC:</b>	10 Mb/s
<b>UPS:</b>	2hr protection with detection software
<b>Monitor:</b>	20 inch monitor (allows system to be used as a Workstation)
<b>Tape Drive:</b>	4mm DAT 8GB capacity
<b>CD ROM:</b>	4x SCSI

### **Performance Upgrade Options:**

If and when the configuration defined above is no longer sufficient, the following upgrade options can be used to improve system performance and capacity:

<b>RAM:</b>	Additional RAM can be added to increase the size of DB block buffers. This will allow more DB information to reside in RAM, limiting the amount of disk I/O.
<b>RAID Hardware:</b>	Optional SCSI RAID controllers can easily be added to improve disk I/O performance.
<b>RAID Cache:</b>	On certain RAID controllers, cache can be expanded to improve disk I/O performance.
<b>Disk Capacity:</b>	PCI expansion slots can be used to add disk controllers and disk drives for additional storage capacity.
<b>Processors:</b>	Additional processors can be added to improve CPU performance. Systems which support processor upgrades can be upgraded to faster processors.

**Table 2-1 Competitive Comparison Chart**

All systems specified below meet or exceed the minimum server configuration defined above (i.e. 128MB RAM, two SMP processors, six 2GB Disk Drives, etc.). The only exception is the IBM RS6000 E30, which has 160MB RAM and does not support SMP. Costs are based on vendor quotes and incorporate GSA discounts.

Feature	HP NetServer LX Pro	Dell PwrEdge XL	DEC Alpha 2100A	IBM RS600 E30 160MB RAM	Compaq Proliant 5000	IBM PC Server 704
<b>Processor Qty</b>	PentiumPro 200mhz 2	Pentium 166mhz 2	Alpha 4/275 2	PowerPC 133mhz 1	PentiumPro 200mhz 2	PentiumPro 166mhz 2
<b>Max Processors</b>	4	4	4	1	4	4
<b>Upgradable Proc.</b>	Yes	No	Yes	Yes	Yes	Yes
<b>RAM</b>	128mb	128mb	128mb	160mb	128mb	128mb
<b>Secondary Cache</b>	512KB/CPU	1MB/CPU	4MB/CPU	512KB L2	256KB/CPU	512/CPU
<b>Bus Architecture</b>	Dual-Peer PCI	PCI/EISA	PCI/EISA	PCI/ISA	Dual-peer PCI	Dual-peer PCI
<b>Open PCI Slots</b>	6	4	5	4	4	4
<b>Internal Hot Swap Drive bays</b>	12	6	8	6	4	12
<b>ECC Memory</b>	Yes	Yes	Yes	Yes	Yes	Yes
<b>Max Memory</b>	2GB	768MB	2GB	1GB	2GB	1GB
<b>ECC Bus</b>	No	No	No	No	Yes	No
<b>Hardware RAID</b>	Optional	Optional	Optional	Optional	Optional	Included
<b>10/100 Mb/s NIC</b>	Included	Optional	Optional	Optional	Included	Included
<b>Disk Drives</b>	4GB x 6	4GB x 6	2GB x 6	2GB x 6	2GB x 6	2GB x 6
<b>Ext. Storage Rqrd</b>	No	No	No	No	Yes	No
<b>Tape Drive</b>	8GB DAT	AutoLoader DAT	8GB DAT	8GB DAT	4/16GB Turbo DAT	4/10GB DAT
<b>Redundant Pwr</b>	Yes	No	No	No	No	Optional
<b>Redundant Cooling</b>	Yes	No	No	No	No	No
<b>Approx. (GSA) Cost</b>	<b>\$27,900</b>	<b>\$22,100</b>	<b>\$43,200</b>	<b>\$32,250</b>	<b>\$28,200</b>	<b>\$34,800</b>

### **Server Recommendation:**

All the servers specified above are capable of performing as the initial VaSST Server. Thus, the preferred solution must offer the best combination of performance, cost, and expandability. The HP NetServer LX Pro is the recommended choice based on the following features:

- The HP NetServer line has an outstanding reputation for quality and performance.
- HP NetServers are the fastest growing server line in the market and are currently ranked second in market share behind the Compaq Proliant series
- The HP NetServer significantly outperformed Compaq Proliant and DEC Alpha servers in competitive (audited) TPC-B benchmark testing running W/NT Operating System and MS SQL Server RDBMS.
- The HP NetServer offers the only standard fault tolerant features (i.e. redundant fans and power supplies).
- The HP solution is significantly cheaper than the comparable IBM PC Server 704 solution even though the price includes 4GB drives.
- The HP NetServer was the number one top performer in Network World's Server Test Series. The NetServer was also rated as a value leader.
- The HP NetServer offers significant expandability.
- HP has formed partnerships with several key software vendors to ensure that NetServer products maintain the highest levels of performance obtainable. Key partnerships include:
  - + Oracle
  - + Sybase
  - + Microsoft
  - + SAP

## Section 3. DBMS Recommendation

### *DBMS Considerations*

There are several available options to consider when selecting a database management system. These include relational databases, object wrappers, and pure object oriented databases. Relational databases such as Oracle, Sybase, Ingres, and MS SQL server are based on two dimensional tables. These tables can be accessed and combined on the fly to build new tables. These tables are formally referred to as relations and the concepts behind relational databases are mathematically founded on relational calculus. Relational databases are simple, elegant, and flexible and have become the predominant technology in the market. One of the primary concepts of RDBs is data independence. Data independence implies that the data is stored in a fashion which is independent of any particular programming language or application which requires access to the data. Data independence allows RDBs to be especially good at supporting adhoc queries. Another reason RDBs have become so widely accepted is due to the fact that they all support (in varying degrees) a standard interface for communicating with the database. SQL (Structured Query Language) is the standard mechanism for interfacing with RDBs. SQL is a bit of a misnomer since it not only supports queries but also supports data definition and data manipulation. The declarative nature of SQL allows it be performed interactively from a command line interpreter and imbedded in application programs such as C, C++, or COBOL.

Today's object oriented programming (OOP) environment poses two primary problems for relational databases. The first problem is a semantic mismatch between the object models used by today's object oriented programming languages and the relational model used by RDBs. This not only causes the problem of dealing with two different models during the design and analysis of an application, but also creates an impedance mismatch for programmers who must write routines to convert objects to rows prior to storage and then back again when retrieving objects from the database. On many projects, 20-40% of the programming effort is spent writing these translation routines which can become quite complex when many complex relationships exist between data elements.

The second problem with RDBs is their ability to efficiently handle complex data (such as geometric data, spatial data, time series data, images, video, HTML, Java Applets, etc.) and complex relationships between such data. RDBs were designed to manage conventional character and numeric data and thus only support two dimensional tables and a fixed set of built in data types. And although RDBs can crudely model and store complex data, they tend to experience performance degradation when queries and traversals are performed against the complex relationships of such data. This is due to the mechanisms RDBs use to relate data (foreign keys, table joins, and intersection tables) which, albeit simple and elegant in concept, do not scale well for certain types of complex data. (Note: A relational database which requires many intersection tables to resolve "many-to-many" relationships between primary tables is a likely candidate to experience performance problems. Please see Appendix - A "Comparing Relational and Object Databases" for a detailed discussion of object versus relational databases).

The impedance mismatch problem described above basically boils down to programmer productivity. This is precisely the problem that object wrappers address. Object wrappers are software layers placed on top of RDBMSs that provide programmers with an object oriented interface to an underlying relational database manager. Object wrappers are effective at mapping records stored in a relational database to objects required by an object oriented client.

program and thus simplify development. However, the object wrappers reliance on a relational DBMS as the underlying storage manager does not address the semantic mismatch between object and relational models, nor the performance problems RDBs can have with complex data. Companies such as Ontos, Persistence, O2 Technology, and others offer these types of products

With the acceptance of OOP into mainstream computing, many relational database companies are also beginning to address these issues. Computer Associates International (developer of the popular Ingres and OpenIngres RDBs) has recently purchased an ODBMS product (Illustra) to be used as the baseline for their new Jasmine database. Jasmine is a pure ODBMS which is being marketed as a multimedia database for the web. The next release (version 8.0) of Oracle corporation's RDB is scheduled to have object oriented extensions. The ANSI SQL committee is currently working on defining the next version of the SQL standard (SQL3). SQL3 will incorporate object oriented extensions which allow SQL to better integrate with the object model and programming languages used by programmers. It is important to note that, as with object wrappers, extended RDB's and SQL3 only address the impedance mismatch problem between RDB's and OOP. They do not address the performance constraints RDB's have in managing complex data.

A "pure" ODBMS addresses both the productivity and performance issues described above. An ODBMS provides traditional database functionality (e.g. persistence, transactions, distribution, concurrency, and recovery), but uses an object model to define, associate, and store objects. This allows a consistent (object) model to be used by both the system designers and the object programmers. Another benefit of an ODBMS is that the programmatic interface to the database is performed using the standard syntax of the object oriented language. The programmer does not need to learn and imbed a special database language such as SQL when accessing the database. Standard language syntax which has special database semantics is referred to as a database language binding. These language bindings have been designed to keep the impact of interfacing with a database very transparent to the programmer which has a significant impact on programmer productivity.

Another primary advantage of an ODBMS is it's ability to directly store any data types and structures that can be declared in the object programming environments it supports. By allowing complex structures to be stored in an object native form with direct references to related objects, an ODBMS can accede the performance of an RDB when accessing complex data. In a sense, an ODBMS provides a superset of the functionality found in a typical RDBMS. Not only does an ODBMS directly store relationships among complex data allowing very fast traversals of data, ODBMSs also provide query language support (including SQL and ODBC) as well as user defined indexes for performing queries on such data in a flexible and efficient manner.

Based on the complex content of the VaSST database, Kaman recommends the use of an ODBMS for storing and managing VaSST prototype data. The scope of this recommendation is for proof of concept only. A final recommendation will be made based on the results of our prototyping activity. The sections below provide a comparison of commercial objects databases, an evaluation of these databases based on the requirements of the VaSST, and an ODBMS vendor recommendation.

## ***Comparison of Object Databases***

Versant, POET, Object Design Inc., and O2 Technology offer four of the top "pure" Object databases currently available. These companies have all offered commercially available ODBMS products for the last five to eight years. These four companies were selected based



on their support of C++ and Java language bindings, supported hardware/OS platforms, involvement in the ODMG (Object Data Management Group) standards organization, and their commitment to providing Internet based solutions. There are several key technical differences between these four vendors and their corresponding products. These differences fall into the three basic categories: Client/Server Architecture, Database Language Bindings, and Object Identifiers. An overview of each of these categories is provided below.

## **Client/Server Architecture**

All of object databases under consideration support a client/server architecture. In a client/server environment, one or more client processes (residing on either the same machine or distributed) are connected to a database server process. The client processes request objects from the database server either explicitly using a query or implicitly via normal object traversals. From an architectural standpoint, the primary difference is whether or not the database server is object aware. A server is considered object aware if it has the capability to retrieve, lock, and return objects to the requesting client process. This is in contrast to a page server which locates, locks, and returns (possibly over a network) entire pages of database disk memory (generally 4kb each) to the requesting clients. In a page based architecture, the client is generally much larger, requiring additional logic for searching, sorting, locking, etc., which would be handled by the server in an object aware architecture. The performance benefits of these conflicting architectures is a hotly debated issue. Versant and POET offer object aware solutions, whereas ODI and 02 Technology offer page based solutions

Object aware server vendors argue that they perform better at handling concurrent requests since the server maintains locks at the object level. They argue that since locks are held at a lower level of granularity, there is less likelihood of locking conflicts between two or more client processes which require access to the same data. Since locks are on objects (instead of an entire page), there is less of a chance that a client will need to wait for a lock to be released before it can start its transaction and thus overall system performance is maintained. Object aware vendors also stress that their architecture better supports distributed environments since only the objects required by clients are sent over the network, thus placing much less of a burden on a possibly over taxed network. This can be very important in a highly distributed environment or real-time control environments where response time is critical.

Page server implementations argue that since fewer numbers of locks are required, their approach can actually be faster since reducing locking overhead allows transactions to be performed faster and thus reduces the chance of locking conflicts even though locks are held at a higher level of granularity. Some page server vendors allow page locks to be upgraded to object locks when contention occurs for a given page. They also argue that their servers scale better since much of the database processing is distributed among each client.

In actuality, both of these arguments hold true depending on the type of application and transactions being performed, the network bandwidth over which clients will be communicating with the server, and the physical clustering of data (objects) on disk. Page servers tend to perform well on CAD and CASE applications which often have very long transactions in which clients check out and modify a large portion of data over an extended period. In addition, these types of applications tend to have minimal concurrency requirements and operate over high speed LANs. Object aware databases tend to perform better in environments where there are a high number of concurrent users accessing smaller amounts of data (such as telecommunication or distributed real time control applications). Object aware databases also perform much better in situations where clients need to perform queries against the database. Since page servers require clients to perform all search predicate logic, this requires many and

potentially all disk pages in the database to be transferred to the client when a query is executed.

The primary benefit of an object aware database is that it will perform well in all types of transaction environments, whereas a page server has severe limitations in highly concurrent environments or environments in which clients are distributed over a taxed network or a network with bandwidth constraints such as a wide area network or the internet. The internet based operating environment of VaSST currently has even greater bandwidth restrictions than a wide area network. Today, the internet bandwidth issue is mitigated by the architectures used to integrate web servers and databases. Current web based solutions which require access to databases are based on a three tier architecture. The architecture incorporates an additional application process which resides on the same machine or within the same LAN as the Web server. This application process is actually a server to the Web server and responds to requests from the Web server by retrieving data out the database and dynamically formatting an HTML page which is returned to the Web server and then back to the browser. It is our belief that as the WWW matures (primarily in the area of security), very thin clients distributed as java applets will require direct access to database objects stored on web servers. We feel that object aware database servers such as Versant or POET are in a much better position to deliver this content to an internet based client than the heavy client architectures of page servers. The thin client architecture of Versant and POET could even become more of an advantage as the industry is now introducing new low cost "network" computers which require very thin clients. Another advantage of object aware servers is that the default clustering of objects on disk provides sufficient performance, whereas page servers often require special attention to clustering which can complicate and prolong design and development.

## **Client Language Bindings**

As stated previously, one of the primary benefits of object databases is the ability of client software to transparently access data (objects) from the database. While this is a key feature of all ODB systems, the degree to which this is implemented has a major impact on actual source code development. The two basic philosophies are database aware and database transparency. The database aware philosophy is that programmers should know when they are dealing with persistent (database) objects and should expect to treat them differently than transient objects. In a database aware binding, there are several predefined base classes and/or template classes which are used to derive/implement persistent capable classes, transactions, collections, references and relations. Although each of these mechanisms is implemented using standard language syntax, incorporating all these can have an impact on a class definition (especially when modifying existing code to incorporate a database). An advantage of database aware bindings is that they provide additional transaction semantics. These include such things as automatic enforcement of referential integrity constraints, more control over object locking, and additional transaction control (such as checkpoint commits, savepoints, nested transactions, etc.).

The database transparency philosophy attempts to minimize the impact of interfacing with a database. Implementations of this philosophy consider all classes persistence-capable and thus do not require persistent capable classes be derived from a base class. In addition, standard pointers can be used to define associations between classes (instead of special predefined reference templates which implement database "smart" pointers). An advantage of this approach is easier accommodation of existing code and class libraries.

The ODMG (Object Data Management Group) is the standards committee responsible for defining standard language bindings and a standard object query language for object databases. These standards are defined to allow portability of source code from one ODBMS

to another. Current language binding standards exist for both C++ and Smalltalk. A Java language binding is currently being defined by the ODMG and should be completed in Q1 of 1997. The ODMG C++ standard language bindings is considered database aware. O2 technology and POET currently comply with the ODMG C++ language binding. Versant is committed to supporting ODMG standards and the next release of their database will be fully compliant with the C++ language binding. While ODI is a voting member of the ODMG, their language bindings do not currently comply with the standard. ODI is very committed to the database transparency language binding philosophy (they do support some proprietary mechanisms which provide additional transaction semantics). Although all vendors support bindings using standard OOP language syntax, software written in compliance with the standard binding can easily be ported to operate with another compliant ODBMS. We feel that, although the standard is not perfect and will continue to evolve (like all standards), it should be supported. We recommend that source code developed in conjunction with VaSST be ODMG compliant.

## **Object Identifiers**

In object models, every instance of an object requires a unique identifier called an object ID. Object IDs are used to reference object instances and do not change throughout the lifetime of the object. Object IDs (OIDs) are generated by the object system and are independent of any data contained in an object. Users and programmers have no control over the identity or form of OIDs. When a persistent object is created, the ODBMS is responsible for assigning the OID. The size and content of the object IDs generated by an ODBMS have a significant impact to the overall architecture, scalability, and performance of an ODBMS as well as the portability of actual data.

Like the other issues, there are two contrasting methods for implementing OIDs. Physical object IDs contain the actual physical disk storage address of an object. This allows for very fast access times of objects. There is, however, some overhead incurred since an object's in memory location must be converted to a disk location and vice-versa as objects are transferred between storage and memory. This conversion between an object identifier and its in-memory location is referred to as "swizzling". In contrast to physical object IDs are logical object IDs often referred to as LOIDs. LOIDs use a location independent identifier for identification of objects.

Although there is still much debate over the pros and cons of these two implementations, it is fair to say that logical OIDs allow for greater scalability and flexibility since objects can be easily redistributed between both computing and/or storage devices. This is in contrast to physical OIDs which normally require the system be taken off line when objects are redistributed. Replication is also simplified with the use of LOIDs. Versant uses logical object IDs. ODI, O2 Technology, and POET use physical object IDs.

## ***Selection Criteria Comparison***

Please note that the DBMS selection criteria and weighting defined below are based solely on the requirements and architecture of VaSST. The vendor ratings are based on currently available product feature sets, deployment history, performance bench marks, and system architecture. It should be noted that the criteria and ratings for the WWW based VaSST vary from those of TSIS, the TReL, and operational 7x24 control systems (such as an operational ATMS) each which has its own unique set of criteria.

Criteria	Weight	Versant	POET	ODI	O2 Tech.
Open Architecture	10	4	3	4	4
Performance	10	5	3	4	4
Scalability	10	5	3	4	4
Transaction semantics	5	5	4	4	4
Concurrency	7	5	3	3	3
Data Integrity/Reliability	15	5	3	4	4
Security	3	4	4	4	4
ODMG Compliance	10	2	5	1	5
Overall Ease of Use	10	3	4	5	3
Support	10	4	2	4	4
DB Administration	8	4	4	3	4
Deployment Costs	5	3	4	3	4
Development Costs	5	3	4	3	4
<b>Vendor Scores</b>		<b>439</b>	<b>370</b>	<b>387</b>	<b>425</b>

## Criteria Descriptions

Open Architecture: This pertains to the ODBMS capability to support and/or integrate with the following:

1. Relational database integration
2. Web server integration.
3. Pre-existing and standard class libraries such as GUI class libraries (XVT, MFC, etc.), Rogue Wave libraries, the C++ STL (Standard Template Library), and Java's standard libraries
4. ODBC driver (and thus ANSI SQL/92 and COTS adhoc reporting tools)
5. ODMG standard language bindings and OQL
6. Object request brokers (ORBs),
7. Compiler & Language Independence (i.e. multiple clients compiled with different compilers and/or different languages can share database objects)
8. Multiple hardware/OS platforms

Performance: Ratings are based on deployment history, independent ODB benchmarks, and system architecture.

Scalability: Based on ODBMS capability to sufficiently scale in size of physical database and number of concurrent users Ratings are based on size and, type of object identifiers, benchmarks, and architecture.

Support: Vendor's capability to provide sufficient training and ongoing technical support in a timely manner.

Overall Ease of Use: This basically boils down to the number of hours spent on training, developing, and supporting the system. Ratings are based on documentation, development tool sets (i.e. web development tools, schema management, compiler integration, object query/update tools, etc.), transparency of language bindings, and DBA tools.

DB Administration: Ease and flexibility in administering a production database. Includes such things as online backups, online schema evolution, disk space management, support for clustering and indexes, performance monitoring and tuning, programmatic interfaces to DBA functions, etc.

Transaction Semantics: The ability of the ODB to effectively support various types of transaction and locking mechanisms (such as nested transactions, long transactions. Ratings are based on transaction semantics provided by each ODB as well as deployment history. Given the type and number of transactions performed on VaSST, the relevance of this criterion is considered low.

Concurrency: The ability of the ODBMS to support a significant number of concurrent accesses without impacting the response time of the system. Ratings are based on system architecture, lock management (e.g. the ability to support both pessimistic and optimistic locking), locking granularity, etc.

Data Integrity/Reliability: The ability of the ODBMS to maintain data integrity and effectively recover from adverse conditions such as power failures, hardware crashes, and program errors. Reliability pertains to the overall robustness of the ODBMS software. Ratings are based on deployment history and customer references.

ODMG Compliance: The degree to which the ODB complies with the object model, language bindings and object query language portability standards defined by the Object Database Management Group. The ODMG (Object Data Management Group) is the standards committee responsible for defining standard language bindings and a standard object query language for object databases

Deployment Costs: All costs associated with deploying a production system. These include client and server runtime costs, runtime costs of any special web server integration software, costs of DBA tools, technical support costs, etc.

Development Costs: All costs associated with developing the system. These include training costs and the costs of development tools and required class libraries.

NOTE: Although some of the participating ODBMSs (ODI and O2 Technology) offer productivity solutions for integrating their ODBMS with web servers, these solutions require custom programming using proprietary APIs and C++ class libraries. Although these solutions may offer productivity gains, the resulting source code would no longer be portable to another database system. We do not recommend the use of proprietary Web server integration tools. Thus, these tools were not included in the selection criteria.

## ***Preliminary DBMS Recommendation***

Based on our analysis, we recommend the Versant ODBMS be used as the proof of concept database for VaSST. The scope of this recommendation is for proof of concept only. A final recommendation will be made based on the results of our prototyping activity. The Versant database is a pure object oriented database and offers all the advantages of object databases discussed previously. Versant has been deployed successfully in a variety of different application areas and was the overall winner of the 007 benchmark performed by the University of Wisconsin (The 007 benchmark is the most current and comprehensive of the independent ODBMS benchmarks). We feel Versant's object aware architecture is superior to the page based architectures of ODI and O2 Technology offering strong performance against a wide

variety of applications. Versant's object aware capability and telecommunications experience should prove to be a real advantage in developing internet applications.

Industry analysts from the META Group (a leading information technology market assessment firm) have stated that "while the whole OODBMS market looks set to continue its rapid growth, Versant may have earned the best long term prospects of any OODBMS supplier". Customers including AT&T, Bell Northern Research, GTE, TRW, EDS, Sprint, UNISYS, Kodak, Seimens, Panasonic, Hitachi Telecom, Primus, ScotiaBank, and others have successfully deployed systems based on Versant's ODBMS. These systems include Web based multimedia management systems, health care management systems, health care imaging systems, telecommunications management systems, airline reservation systems, animation systems, and advanced financial trading systems. Versant was developed from the ground up by a team of database engineers. The result is a database which is considered to be very robust and has been successful at keeping regional electric power grids, nationwide banking operations, and satellite networks up and running, 24 hours a day, 365 days a year.

Although POET has a similar architecture to Versant, POET entered the market as a PC based solution and is just now providing scaleable solutions targeted at enterprise wide applications. Being a relative new comer, POET was not invited to the 007 benchmark, nor were they able to provide us with a single success story or reference. Based on our discussions with POET, we do not feel they yet offer a truly robust and scaleable database. The physical design of their database has serious limitations since it is limited to a single file. This can pose serious problems in some operating system environments such as certain flavors of Unix where the file system only allows a maximum file size of two gigabytes. Also, their limited use of a server side cache will certainly limit performance.

Looking beyond VaSST, we feel Versant is the only ODBMS on the market today that can support all of the varying requirements and hardware/software platforms involved in ITS. These range from single user PC based analysis tools such as TSIS to the mission critical 7x24 operational control requirements of an ATMS.

Although Versant tends to cost more than some of the other offerings, this should be insignificant on this particular project since the number of developers and concurrent users accessing VaSST should remain low. The only real concern we have with Versant is the status of their ODMG C++ binding. They currently offer a beta version of the ODMG C++ binding which only operates under the Solaris OS. The next release of their product (version 5.0) will provide full compliance on all supported platforms. However, version 5.0 is not due to be released until some time next year. Since a good portion of the prototype will be developed prior to the availability of the standard binding, we will need to work with Versant to develop a plan for translating non-standard code into compliant code when the ODMG binding becomes available.

## ***ODBMS Feature Comparison***

The data below has been compiled from interviews with sales and technical representatives from each of the participating-vendors as well as from product literature and trade journals. Although not complete, the data should prove helpful in comparing the four ODBMSs.

**Table 3-1 Company:**

Feature	Versant	POET	ODI	O2 Tech.
<b>Founded</b>	1988 (US)	1991 (Germany)	1987 (US)	Project 1986 (France) Company 1990
<b>Employees</b>	100	90	220	80
<b>Public/Private</b>	Public	Private (VC Funded)	Public	Private
<b>'96 Revenues</b>	20 mil (Approx)	10mil (Approx)	32mil (Approx)	10mil (Approx)
<b>Relative Market Position</b>	2	4	1	3
<b>Closest Sales/Support Office</b>	Denver, CO	San Mateo, CA	S.E. in Boulder Sales in San Mateo, CA	Palo Alto, CA

**Table 3-2 Language/Architecture**

Feature	Versant	POET	ODI	O2 Tech.
<b>Page/Object Server</b>	Object	Object	Page	Page
<b>Object Identifiers</b>	Logical 64 bit	Physical 48 bit	Physical	Physical
<b>Client DLL Size (incl comm DLL)</b>	1.3mb (shared)	1.2mb (shared)	6.0mb (shared)	2mb (shared)
<b>Client Cache Overhead</b>	25kb per client + 16 bytes per obj	32 bytes per object	unused objects + 5% of cache	unused objects + 5% of cache
<b>Client Minimum Cache</b>	1mb	500k	8mb recommended	4mb recommended can go smaller
<b>Server Minimum Cache</b>	2mb	?	?	4mb
<b>Minimum Recommended Server Size</b>	3mb + 200kb per client (1.25mb of cache is overhead)	547kb+cache?	339kb+cache?	Server executable 200k + 4mb cache
<b>Asynchronous Comm.</b>	No	No	No	No
<b>Client Safe Threads</b>	Yes	Yes	Yes	Not Yet (ver 5.0)
<b>ODMG C++ Compliant</b>	Yes	Yes	No	Yes
<b>ODMG OQL Compliant</b>	No	Yes	No	Yes
<b>Interactive Queries</b>	No	Yes using Windows Development tools	Yes using Object Inspector Tool	Yes using interactive OQL to generate HTML queries

Feature	Versant	POET	ODI	O2 Tech.
<b>Locking Granularity</b>	Object	Object	Page	Page – Upgradable to object
<b>Persistence thru Reachability</b>	C++ -- No Java -- Yes	C++ -- No Java -- Yes	C++ -- No Java -- Yes	Yes using proprietary C++ Binding
<b>Compiler Independent Persistence</b>	Yes	Yes	Yes	Not Yet (Q1/97)
<b>Language Independent Persistence</b>	Yes	Yes	No	Yes
<b>Page Clustering</b>	Default on single class - configurable by class	None - objects are placed on pages serially as they are added to DB with no consideration to data model (not configurable)	Controlled at time of object instantiation thru new operator. ODI offers maximum control over clustering.	Yes on class or collection using cmd line interpreter
<b>Indexes</b>	Yes	Yes	Yes	Yes
<b>Object IDs</b>	Logical 64 bit	Logical 48 bit	Physical	Physical
<b>Raw Files</b>	Yes	No	Yes	No
<b>Server SMP Support</b>	Not Yet (Q1/97)	Yes	Not yet	Not Yet (Q1/97)
<b>007 Benchmark Performance</b>	Overall winner - Stand Behind results	Not Invited	Protesting Results	Did well -- Stand Behind results

**Table 3-3 Internet Support**

Feature	Versant	POET	ODI	O2 Tech.
<b>Dynamic HTML Generation</b>	Versant Web (Framework) integrate Apps with Web Server. Versant Internet adapter. (Beta in Q1 of 96)	Impulse (Nov) 1  SQL ObjFactory (Dec)  Wildflower (Feb)	Yes -- development of C++ host side client required.	Yes - O2Web will support any OQL query
<b>Java Binding</b>	Gateway Binding now, Full Binding Q1, ODMG?	Gateway Binding  Full Binding?	In progress	In progress
<b>Java Applet Binding</b>	Not Yet	No	In progress	No - useRMI
<b>HTML as Objects</b>	Yes	Yes	Yes	Yes
<b>Applets as Objects</b>	Yes	Yes	Yes	Yes



**Table 3-4 Tools/Utilities**

Feature	Versant	POET	ODI	O2 Tech.
<b>Adhoc Queries</b>	ODBC Based	Developer Browser or ODBC	ODBC or Browser	OQL/HTML
<b>Performance Monitoring</b>	Yes	No	Yes	Yes
<b>Schema Management</b>	Yes	Yes	Yes	Yes
<b>Schema Evolution</b>	Yes (online)	Yes (online)	Yes (online)	Yes
<b>ORB integration</b>	Orbix	Next Year (Orbix)	Orbix	Orbix (no specific version or glue required)
<b>ODBC Support</b>	Yes	Yes	Yes	Beta Q1 Next Year
<b>RDB Interfaces</b>	Yes (Versant/M)	Obj Factory (Dec)	Yes (SQL Gateway)	Yes (O2Dbaccess)
<b>Disk Space Recovery</b>	Yes – Automatic	Yes – Manual	Yes – Manual	Yes – Garbage collector launched when needed (programmatic)
<b>DB Backups</b>	Online	Online – manual	Online	Online/offline/incremental
<b>DB Recovery</b>	Log/Roll Forward	Log/Roll Forward	Log/Roll Forward	Log/Roll Forward
<b>Clustering Performance monitoring</b>	NO	NO	Based on pages moved	Based on pages moved
<b>DBA utilities</b>	VUTIL	Yes	Yes	O2 monitor
<b>DBA Programmatic Interfaces</b>	Yes	Yes	Yes	Yes
<b>Win95/NT Based Tools</b>	No	Yes	Yes	No

**Table 3-5 Pricing**

Feature	Versant	POET	ODI	O2 Tech.
<b>NT Web system (4 User)</b>	8,000	5,000	1 Runtime Server 2250 4 runtime clients 3000 Object Forms 3500 TOTAL=8750	6,000
<b>Unix Client Runtime</b>	700 per	139 per		2,000 per
<b>NT Client Runtime</b>	350 per	139 per		2,000 per

Feature	Versant	POET	ODI	O2 Tech.
<b>Unix Runtime Server (8)</b>	18,800	No Charge		No Charge
<b>NT Runtime Server (8)</b>	12,200	No Charge		No Charge
<b>NT C/S Development (Schema Developer)</b>	5,500	1,998	8,250 Server + 2,750 per developer (Approx 2k for extended class libraries)	4,000
<b>Non Schema Developer</b>	1,540	n/a	750	
<b>Unix C/S Developer</b>	9,000	4,998	4,500	4,000
<b>VAR/OEM per user licensing</b>	Under \$100 (Competitive)	\$50 Negotiable	Zero for PSE Pro \$50 Negotiable	\$50 per (Negotiable)
<b>Training</b>	2,250 week	2,000 week	350 day	800 day
<b>Consulting</b>	Principle 2k/day Senior 1.8k/day	1,500 day	1,500 day	1,200 day
<b>Tech Support</b>	15% of all licenses	2,000 per year (named caller)	15% of all licenses	15% of SW costs

## Section 4. PROPOSED ARCHITECTURE

This section describes the proposed VaSST architecture. The system will operate as a web site on the internet. The system will utilize commercial of the shelf Web Server and DBMS software packages to provide optimal access to all services. The services can be accessed via the internet (or intranet) by any networked computer with a Java compatible web browser.

The services provided by VaSST include access to real world traffic flow data and model calibration information. Simulation input files generated from real world traffic flow studies will be FTP'd to client workstations where actual traffic flow simulations will be run. Upon request, the real world traffic flow behavior data will be transferred to client workstations where post processing and comparisons of model and real world behavior can be performed. The diagram below is a preliminary view of the VaSST software architecture.

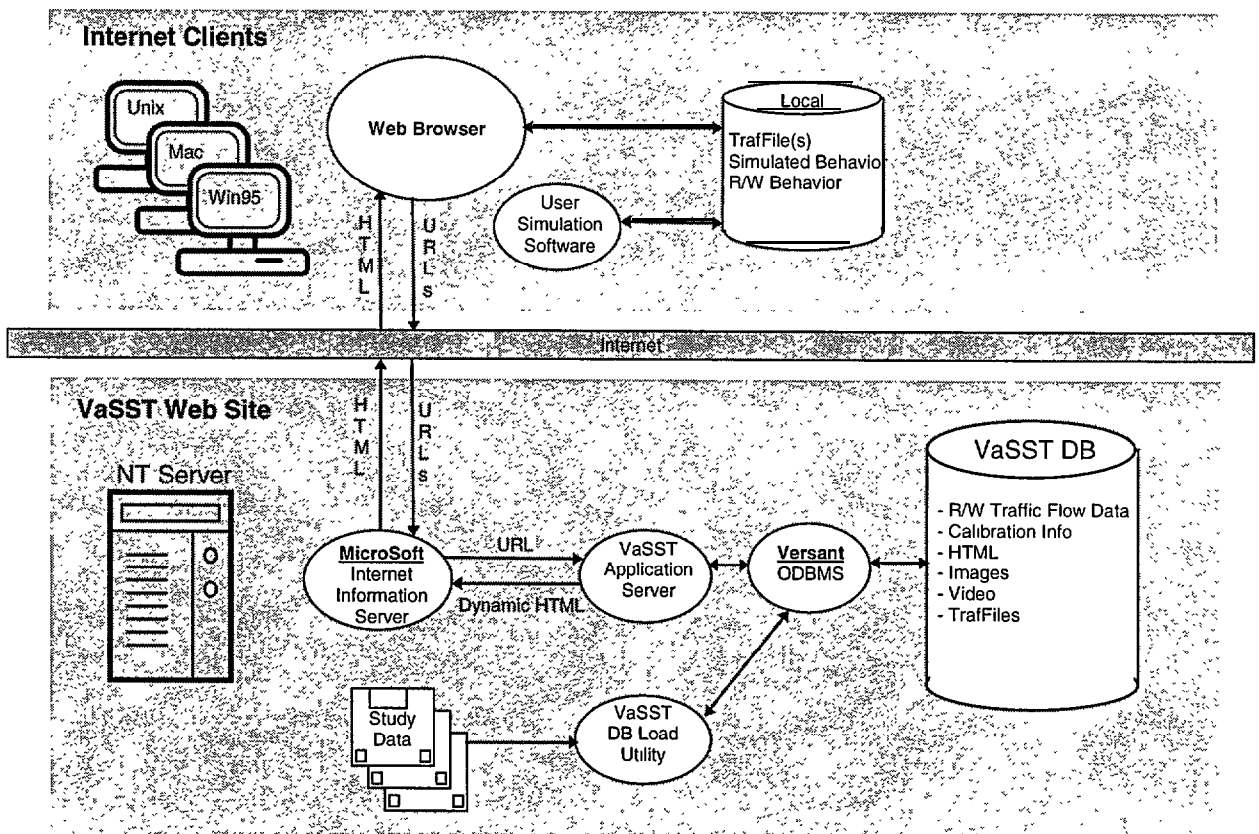
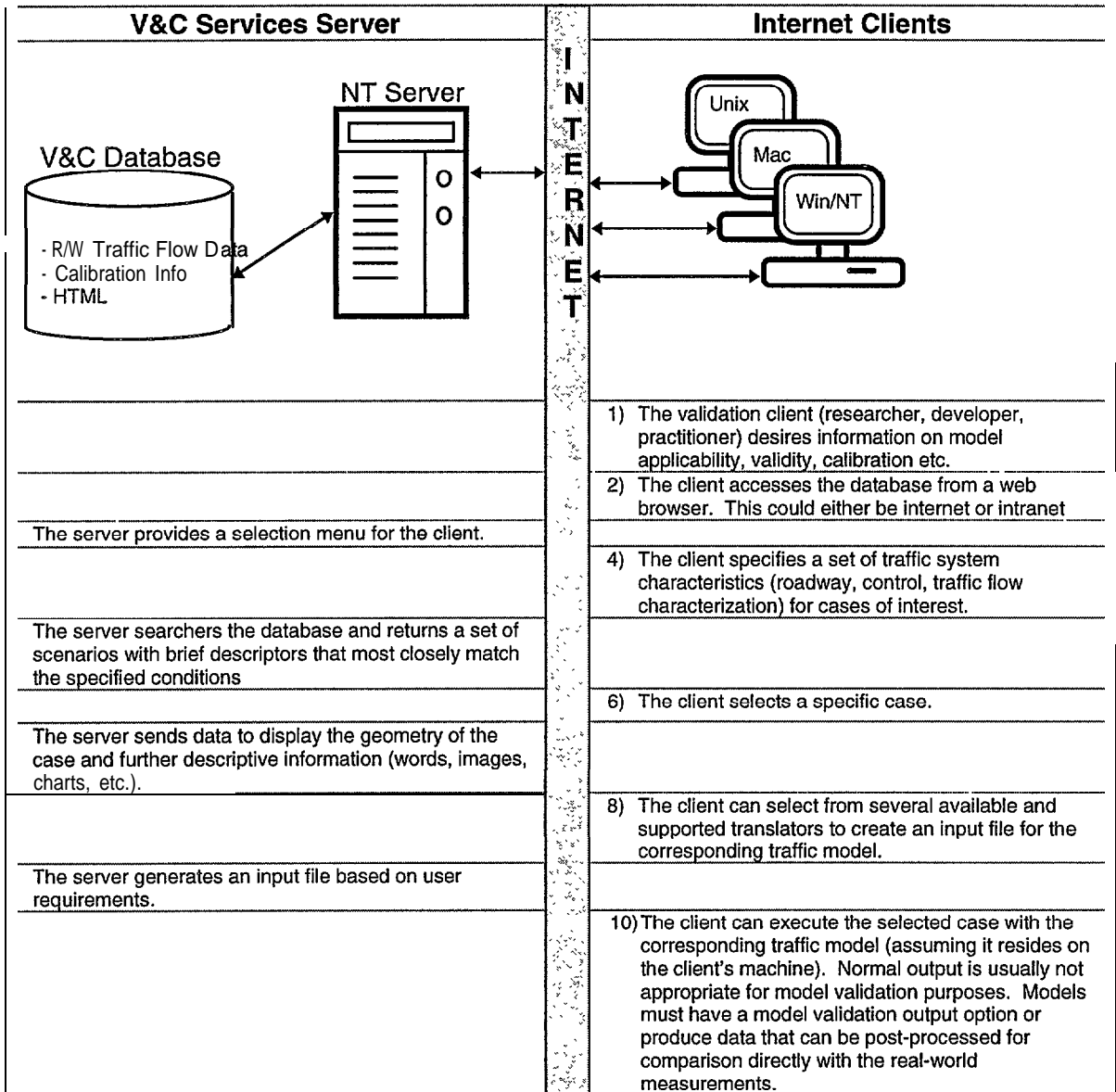


Figure 4-1 Preliminary VaSST Architecture

The figure below provides a high level conceptual diagram of how a user will interact with the system.



**Figure 4-2 User Scenario**

## Section 5. PRELIMINARY DATA MODEL

The VaSST data model is currently based on Raumbaugh's OMT object modeling technique. We are currently using the Rational Rose CASE tool to document the model. The OMT Class diagram notation is described in the figure below.

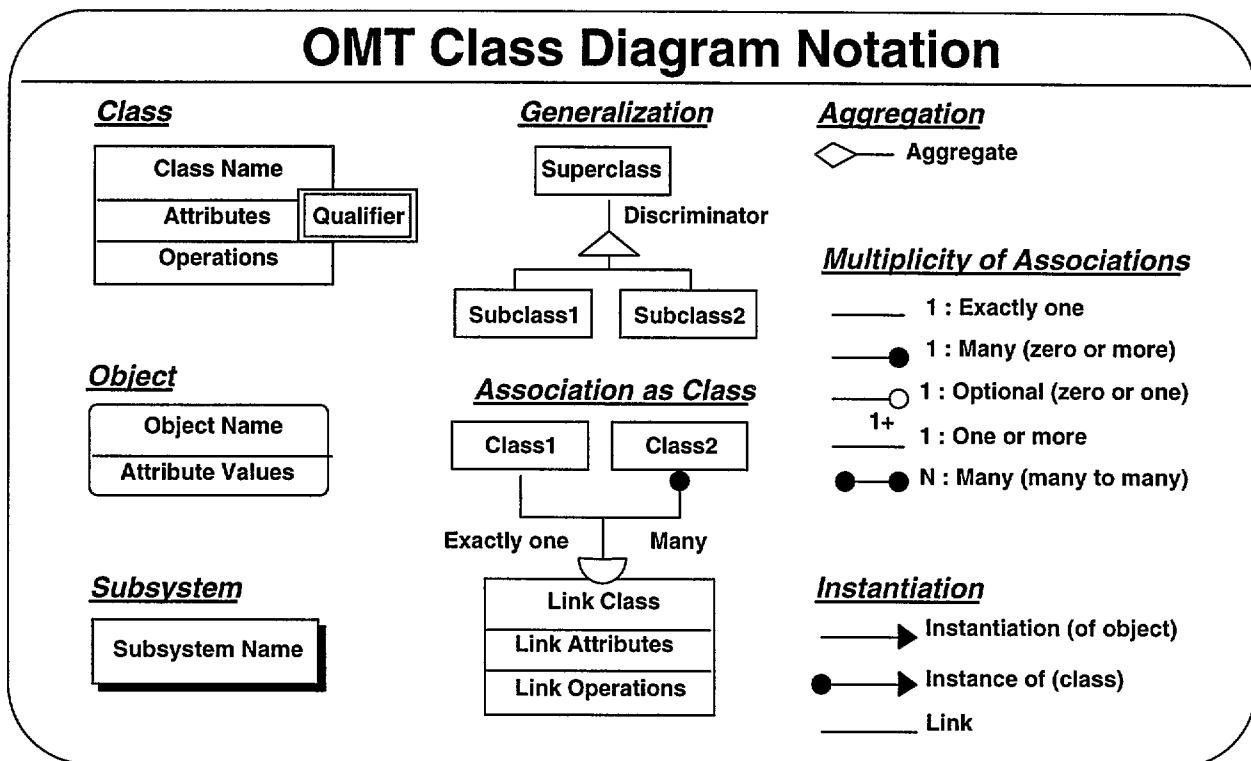


Figure 5-1 OMD Class Diagram Notation

The preliminary model below focuses primarily on data. Additional class methods will be defined during the detail design phase of the project. There will eventually be three categories of data in the VaSST database. These categories consist of real world traffic flow data (the "Data Collection" category), Traffic Facility data (the "Network Geometry" category), and validation and calibration data (the "Validation" category). To this point we have only modeled the Data Collection category. It is our recommendation that the Network Geometry data be modeled in conjunction with other ITS projects which have a greater dependency on facility data. In the interim, we will compile and directly store the necessary input files required to run traffic simulations. The development of the data model for validation requires additional research into validation requirements for specific models to be validated.



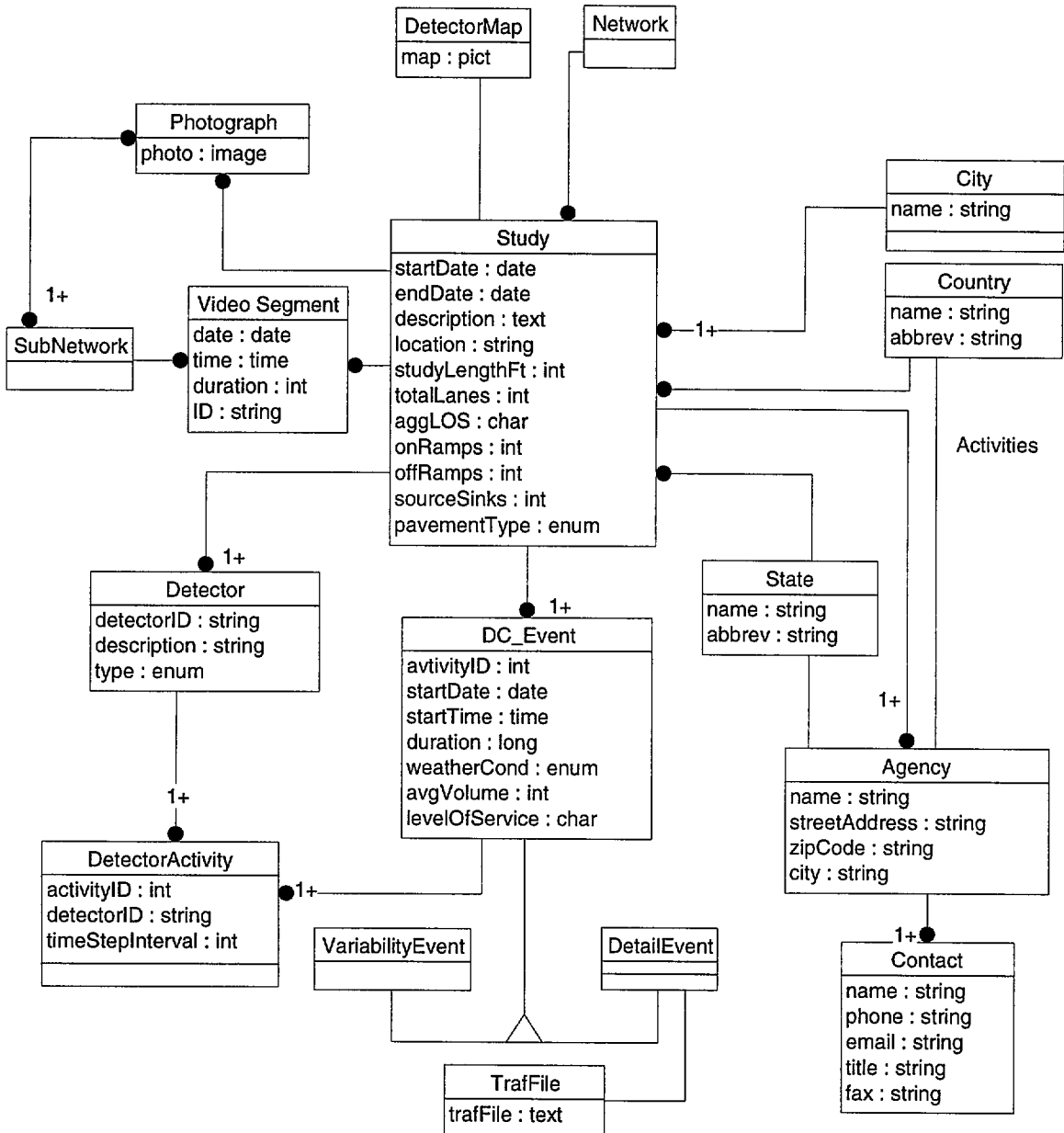
***Figure 5-2 V & C Services Categories***

The diagrams on the following pages specify the attributes and relationships between various data collection entities. The following diagrams are provided:

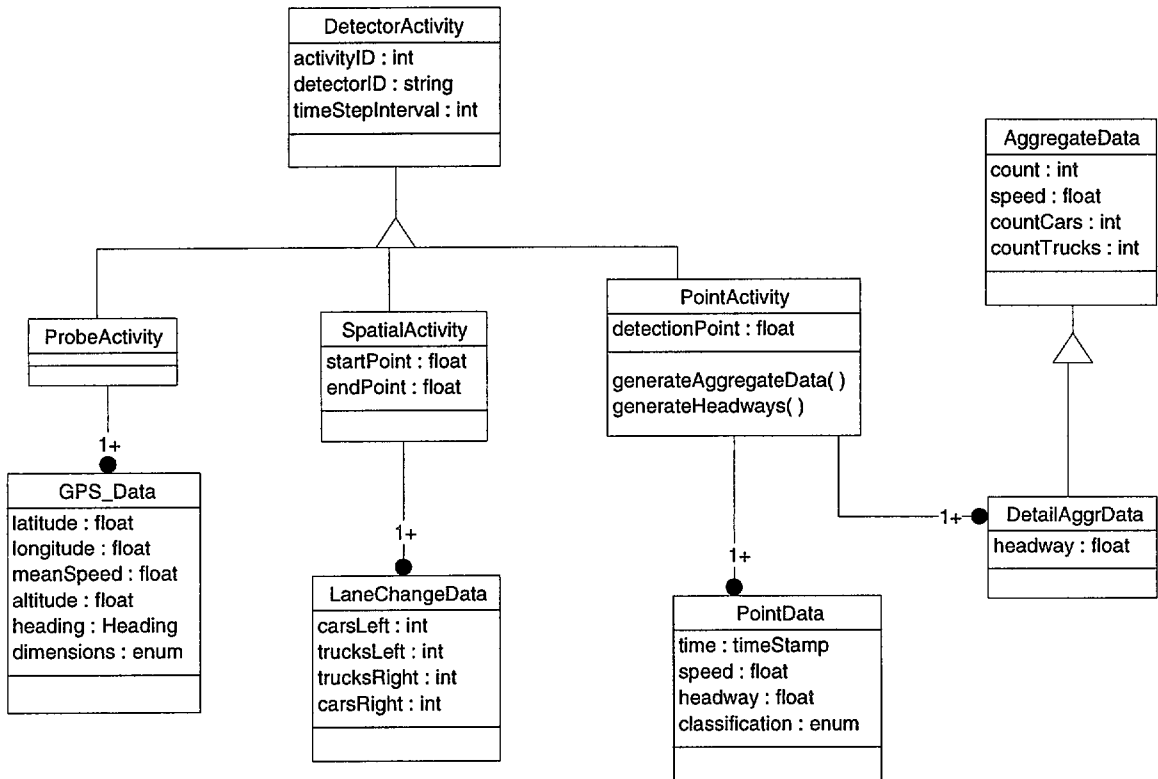
- 1) **Data Collection Study:** displays relationships between the root object “Study” and it’s associated classes
- 2) **Detail Data:** displays the relationships between various types of detector activity and their associated data.
- 3) **Variability Data:** shows type of data collected during variability data collection events.
- 4) **Detector Activity:** highlights inheritance relationships between the data collection events and detector activity.

Descriptions of the primary entities (Classes) are provided following the diagrams

## Data Collection Study -- Class Diagram

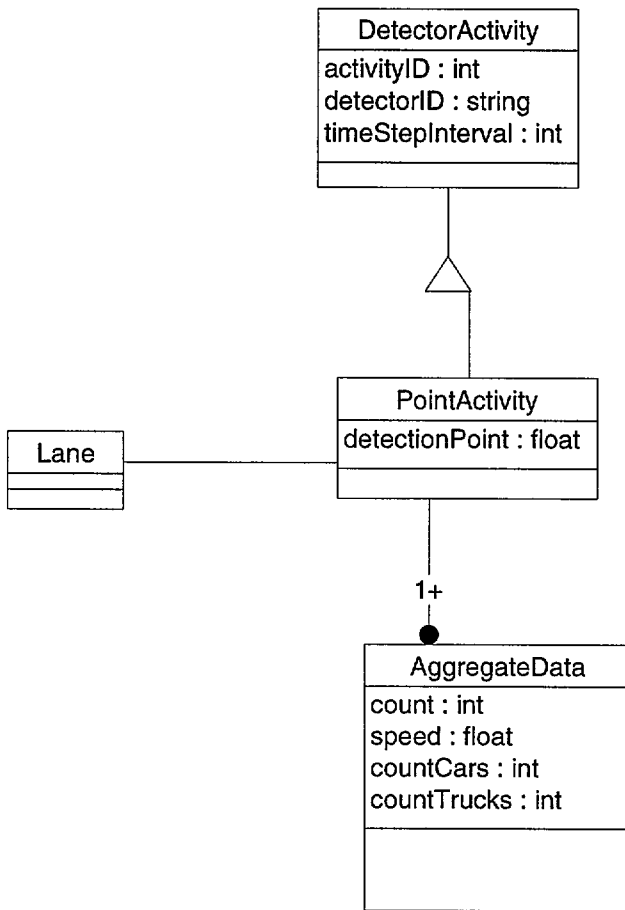


## Detail Data -- Class Diagram

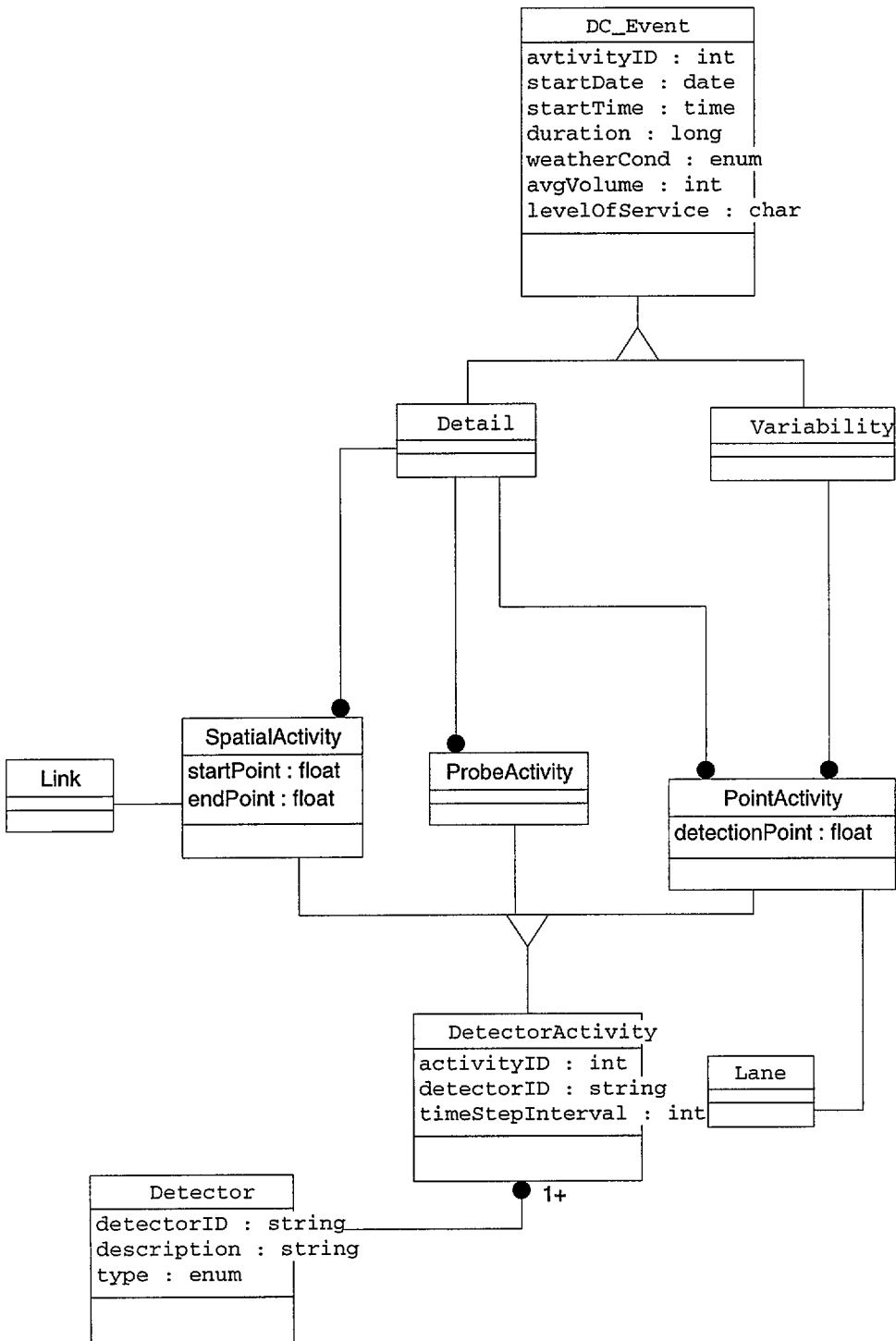




## Variability Data -- Class



## Detector Activity -- Class Diagram



## Class descriptions

<b>Study</b>	The study encompasses the entire data collection work completed at a specific location over a specific time period. Significant data attributes include the average level of service, number of sources/sinks, number of lanes and length of the study section.
<b>DC-Event</b>	The data collection event is directed at a specific event that occurs during a data collection study. It includes the starting time, duration, and weather conditions during the specific data collection event.
<b>Detector</b>	A detector is a specific piece of data collection equipment used during a data study. Attributes include an ID and a description.
<b>Detector Activity</b>	The detector activity object was created to avoid a many to many relationship between detector and data collection event. The only field common to all detector activities is the time step interval.
<b>Detail Event</b>	A detail event is a specific type of DC-Event where very detailed, vehicle specific data is collected on a microscopic data.
<b>Variability Event</b>	A variability event is a specific type of DC-Event where aggregate, macroscopic data is collected.
<b>TrafFile</b>	The TrafFile is a geometric description of the study area coded into a special formatted text file.
<b>Detector Map</b>	The detector map object is a picture in vector or raster form that indicates the actual locations of the detectors during the study.
<b>Photograph</b>	The photograph object is used to store image files created from photographs taken of the study section.
<b>Video Segment</b>	The Video Segment object is used to store video files created from videos taken during the study.
<b>Point Activity</b>	Point activity is used for data collected at specific points within a study area. Examples of this are the speed and headway of vehicles as they pass specified points
<b>Spatial Activity</b>	Spatial activity is used for data collected over a space in the study area, such as lane changing data.
<b>Probe Activity</b>	Probe activity is used for data collected from probe cars moving through the study section. An example of probe data is GPS data.
<b>PointData</b>	This object is used to store microscopic data collected under detailed study events, This data includes a timestamp of each vehicle along with its speed, headway, and classification.

<b>Aggregate Data</b>	This object is used to store point data collected on an aggregate basis. Over a given timestep interval the speeds and counts of all the vehicles passing a given point in a given lane are aggregated.
<b>Detailed Aggregate Data</b>	This object stores headway in addition to the speeds and vehicle counts

## Section 6. References

- 1) "Server Test Series", *Network World*, An IDG Publication, Series of weekly articles in 1996
- 2) "DBMS Response Time Tempers Web Strategies", *Software Magazine*, Sentry Technology Group, September 1996
- 3) *The Object Database Standard: ODMG-93 (Release 1.2)*, Edited by R.G.G Cattell, Morgan Kaufman Publishers, 1996
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- 6) *OBJECT ORIENTED TOOLS BULLETIN - Part3.5: Databases and OODBMS*, META Group, Inc., April 1996
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# Appendix A. RDB versus ODB White Paper

## *Introduction*

Large quantities of data are collected during the measurement of traffic parameters. The data ranges from basic counts of vehicles to actual video of the scene. Most researchers desire to archive the raw data in addition to the reduced data for use in other studies. The selection of an optimum database management system (DBMS) to effectively manipulate this data can be a challenging task. However, object databases have been developed to address some of the object peculiar data management issues and as such, they have many strengths over relational databases for handling large amounts of real world data.

Object database managers (ODMs) have become more prevalent as computer aided design tools, graphic information systems, multimedia and other software engineering tools have helped pushed their development. Object oriented databases permit more versatility in data operations than traditional relational databases, since the data is stored by relating to real world objects. As a matter of fact, relational databases are a subset of object oriented databases and information can be passed between the two types using proper formatting. However, the object orientation of databases permit operations to be performed directly on the objects, allowing many new avenues of data handling than before.

The following sections will describe several database characteristics to include a discussion of relational and object database unique characteristics. Comparisons between object and relational databases will also be discussed.

## ***DBMS Characteristics***

The properties of a DBMS that allow sharing of data to be safe are known as ACID Properties - atomicity, consistency, isolation, and durability. These are described below:

Atomicity - Refers to the "all or nothing" flavor of an entire sequence of operations as it applies to the database. As the user performs updates to the database, either all or none of the updates are visible to the outside world. This is called a transaction. A transaction either commits or aborts. In this way either the whole change or no change is performed, and not just part of the change should something go wrong in either the software or the hardware of the computer system.

Consistency - Consistency refers to the preservation of the integrity of the information in the database despite the actions of multiple users working at the same time.

Isolation - As shared objects are accessed by multiple users, the DBMS must manage possible conflicts between concurrent transactions. Concurrent transactions are those that occur at the same time. The series of safeguards that a DBMS uses to prevent conflicts between concurrent transactions is referred to as isolation. Serializability is a concept basic to understanding isolation through transactions. Transactions are serializable if the interleaved execution of their operations produces the same effects on the database as their execution in some serial order.

Durability - Once a transaction is committed, the updates of that transaction must never be lost. Durability refers to the ability of the system to recover committed transaction updates if either the system or the storage media fails.

ACID properties allow a DBMS to provide a safe, secure, multi-user access to shared data. The ACID properties make the objects persistent. An object is persistent when it can be

manipulated in a programming language and saved in the database before exiting the program: when you return at a later time that object is available to you.

## ***Relational Concepts***

In relational databases all data is stored in two-dimensional tables, which were originally called relations. An application will generally have a series of tables to hold its data. Thus a database is just a collection of two-dimensional tables. The rows of the tables are composed of fields containing types known to the database. In most systems new data types cannot be added.

Each row in a table corresponds to one item or record. The position of a given row may change whenever rows are added or deleted. Items in the tables can be identified only by their values. In order to uniquely identify an item, it must be given a field or set of fields which is guaranteed to be unique within the table. This is called the primary key for the table and is often a number. If one object contains the primary key of another object, then this allows a relationship between the two items and is called a foreign key. Rows of different tables can be combined using joins.

Relational databases are good for managing large amounts of data. They provide flexible query mechanisms for retrieving sets of rows. Relational database systems are based on two-dimensional tables in which each item appears as a row. Relationships among the data are expressed by comparing the values stored in these tables. Languages like Structured Query Language (SQL) allow tables to be combined on the fly to express relationships among the data.

Many important features database systems have that object oriented programming languages do not are:

1. fast queries
2. sharing of objects among programs
3. sophisticated error handling for database operations
4. permanent storage

Relational database systems (RDBS) and record oriented systems based on B-Tree or Indexed Sequential Access Method (ISAM) are the standard systems currently used in most software developments. Each requires that all data be portrayed as a series of two-dimensional tables.

In summary, a relation or table in the relational database contains the definitions of the data. The columns or fields in the table identify the attributes. A row (or tuple) contains all the data of a single instance of the table. Every row must have a unique identification or key based on the data. Foreign keys are a primary keys in one relation that are kept in another relation to allow for joining of data.

## ***Object Oriented Concepts***

There are several concepts that are specific to object oriented programming. The following paragraphs provide a brief description of some of these.

Polymorphism - Every object in an object oriented system has its own identity, which does not depend on the values it contains. This allows pointer references to establish the relationship among objects. When an object is read from the database, it is given all the code and data members that it had when it was originally read. This is true even if you read it without knowing its complete type information. Since relationships among objects are generally established using pointers, container classes can be created to express many to one relationships.

Encapsulation - Encapsulation refers to the concept of including processing or behavior with the object instances defined by the class. It allows code and data to be packaged together. Encapsulation means that code and data are packaged together to form objects, and that the implementation of these objects can be hidden from the rest of the program. Packaging the code and data together helps clarify the relationships among them. An object which is read from the database has the same code and data that it had when it was stored. Objects may also have private and protected parts with each being managed accordingly.

The definition of methods for the class is an integral part of encapsulation. A method is programming code that performs behavior an object instance can exhibit. When code and data are not packaged together, for calculations or any routine replicated in many applications it is very difficult to ensure that changes in the routine is made everywhere it is used. Using a library improves the situation, if the use of the library is enforced. Nevertheless, with a library, one can never be sure which routine is supposed to be used with which data. It is entirely possible to execute the right code on the wrong data the wrong code on the right data. Object systems recognize which methods belong to which data. The correct execution of methods is called dispatching and is handled by the object system. Encapsulation makes it possible to maintain routines, such as calculations, conceptually as part of the data.

Inheritance - Inheritance is a means of defining one class in terms of another. Classes which are derived from other classes can be stored with one operation. The database system must know the class hierarchy and manage object storage accordingly. Inheritance allows a new class to be built using code and data declared in other classes. This permits common features of a set of classes to be expressed in a base class, and the code of related classes.

Object Instances - Many entities are created when abstracting a real-world item or process into an object schema. Each of these single entities is called an object instance.

Object Identity - Object oriented database systems integrate the object identity in the database with the identity of objects in memory. When an object is stored, it knows when if it corresponds to an object in the database and when an object is retrieved it knows if the object has already been loaded into program memory. There is no need for the programmer to maintain the relationship between database objects and objects in memory.

References among Objects - True object oriented database systems can automatically resolve pointer references in the program's objects and represent them in the database.

Object Identification (OID) - Every object instance has a unique, unchanging identity called an object identification. OIDs are used to reference object instances. OIDs are generated by the object system. Users or programs have no control over identification or the form of the OID. Second, OIDs are independent of the data contained in the object. The internal data values are not used to generate identification, so there is nothing in the data itself that is reflected in the OID. Finally, the OID lasts the lifetime of the object. The identification of the object never changes even when the data contents may change. Some OID characteristics are listed below:

- 1 OIDs are independent of the data contained in the object. The internal data values are not used to generate identification.
2. OIDs are generated by the object system. Users or programs have no control over identification.
3. OIDs last the lifetime of the object. Identification of the object never changes even when the data contents may change.



Relationships - An ODBMS differs from an RDSBMS in that an ODBMS directly supports relationships. When real life is abstracted and represented in an object schema, the OIDs are critical for keeping track of who's who and what's what.

Classes - Object instances can be grouped together into a class, which is a grouping of objects that have similarity. The class identifies the structure and the data items for each of the objects. A class, when it is a part of a larger object schema, is sometimes referred to as a class object because it serves as an instance of a class. The notation of a class includes the name of the class at the top with its attributes or characteristics of note shown below the name. Attributes can also contain a reference to object instances of the same class or object instances of other classes.

Reuse - This is actually one of the biggest design challenges of object technology - to be effective in designing class definitions for reuse and then to be effective at reusing the definitions

There are several similarities and differences in the terminology between relational and object models (see Figure 1). The term relation from the relational model is similar to a class. Both relations and classes define the structure from a similar group of instances. Row from the relational model is similar to the term object instance, since both contain instance data. The term column from the relational model is similar to the term attribute, since both contain a single item. See figure-1 for a comparison of RDBs and ODBs.

However, a significant difference between relational and object terminology exists because of the way executable code is associated with data. The relational model uses stored procedures and the object model uses methods. The stored procedures of the relational model are not similar to methods of the object model. Methods are computationally complete because they are written in full object programming languages such as C++ or Smalltalk, while stored procedures from the relational model are usually extensions of SQL and are not complete programming languages

## ***Comparison with Relational Databases***

The semantic mismatch between object oriented programming languages and relational databases has led to the development of object oriented database systems which directly support the object model. Object oriented database systems are usually much simpler to use in object oriented programs.

Many- to-many relationships can create a problem in an RDBMS because the relational model does not allow for repeating groups. Storing data redundantly is dangerous because it can result in update anomalies - inconsistencies that occur when something that exists in two places is changed in one place but not in another.

Joins can be a performance issue for RDBMs and many joins can kill performance. This performance problem occurs because multiple tables with some matching key information are being accessed to combine data from all the tables by matching that key information. The more tables needed, the more joins are needed, and the slower the process becomes

The object model handles many-to-many relationships easily. There are no joins - only transversals of the relationships. A transversal follows the link or pointer using OIDs to other objects.

Complex data also frequently uses type codes. Type codes are a common way of classifying data in a relational schema. They are often numbers or alphanumeric codes. Type codes often indicate that different processing must be done for each type and that a hierarchy of types

exists. The special processing needs for each type require program code that checks for each of the type codes. The reason this checking appears in program code is that commercial RDBMSs do not handle types well. In fact, they have no “understanding” of type codes for the kind of processing that must be done in program code. In contrast, types are an inherent part of the class hierarchy in an ODBMS and the code for each type can be attached to the appropriate classes in the class hierarchy. The type codes would be translated into a class hierarchy in an ODBMS with the method code attached.

Relational databases do not support the ability to combine code and data to form objects, so functions must be written to extract data and store it in the database. Functions must also be written to build objects and retrieve their data from the database. Since relational databases cannot store functions, the function hierarchy must be restored when objects are read from the database. This usually requires type information to be stored in the database to enable the application to build objects appropriately before loading their data. The data hierarchy can be represented by creating a separate table for each point in the hierarchy. Relational databases offer no support for polymorphism. Enough information must be stored about the data types to enable the reconstruction of objects properly before loading their data. The primary key can be used as a form of database identity by ensuring that no two rows in a table have the same primary key by defining the field to be unique. However, this does not prevent loading multiple copies of an object, which can cause inconsistent updates. In other words, the object identity in the database is lost as soon as the object is loaded into memory. References among objects are expressed by foreign keys. Any pointer in the objects will be expressed as a foreign key in the database table. The code used to store objects must follow the pointer references and ensure that the proper foreign key is stored for each referenced object. If it is intended to follow pointer references in objects that have been retrieved, then all foreign key references must be carefully followed, the appropriate objects loaded, and the pointer variables correctly initialized.

The documentation for each class should generally contain detailed information on how it is stored in the database. Objects stored in relational databases should generally contain all primary keys as data members to make it easier to test whether keys have been assigned. Each object will need a primary key for each row in each table used to store it. Since the database structure is not closely related to the class structure, this tends to complicate the classes significantly, but generally some way is needed to determine if and how an object has been stored in the database.

A primary goal of relational databases is data independence. Data can be physically reorganized without affecting how it is used. Data is normalized and completely separated from the processing that is performed on it. Thus the data can be used for different applications, many of which may be unanticipated when the database is first designed. The data can be physically reorganized without affecting how it is used. The database generally stores only data and not procedures. Data can be accessed by any process and the data is designed for any type of use.

A primary goal of the object oriented database is encapsulation and class independence. The data is associated with a specific class that uses specific methods. Classes can be reorganized without affecting how they are used. The database stores that data plus the methods. The data and the methods are inseparable, since data is designed for use by specific methods only. The data is not designed for any type of use but for use by the class. The class will be used in many different applications, many of which are not yet anticipated. We have class independence, not merely data independence.

With a relational database, the data can be physically reorganized without changing application programs that use the data. With an object-oriented database, the data and the methods associated with the class can be reorganized without disrupting systems that use the class

Object-oriented databases support objects, whereas traditional databases store passive data. Objects are active and requests cause objects to execute their methods. The object-oriented database supports complex data structures and does not break them down into tables. Complex data structures are encapsulated in the classes.

Objects are designed for high reusability and rarely change. Whereas, in relational databases the processes using data constantly change.

The data structures in object-oriented databases may be complex. However, users are unaware of the complexity because of encapsulation. The structure is much simpler in relational databases since the user perceives the data as columns, rows, and tables

In relational databases each table is separate and join operations can be used to relate data in separate tables. In object-oriented databases, the data may be interlinked so that class methods achieve good performance. Tables are one of many data structures that may be used. Binary large objects (blobs) are used for sound, images, video, and large unstructured bit streams.

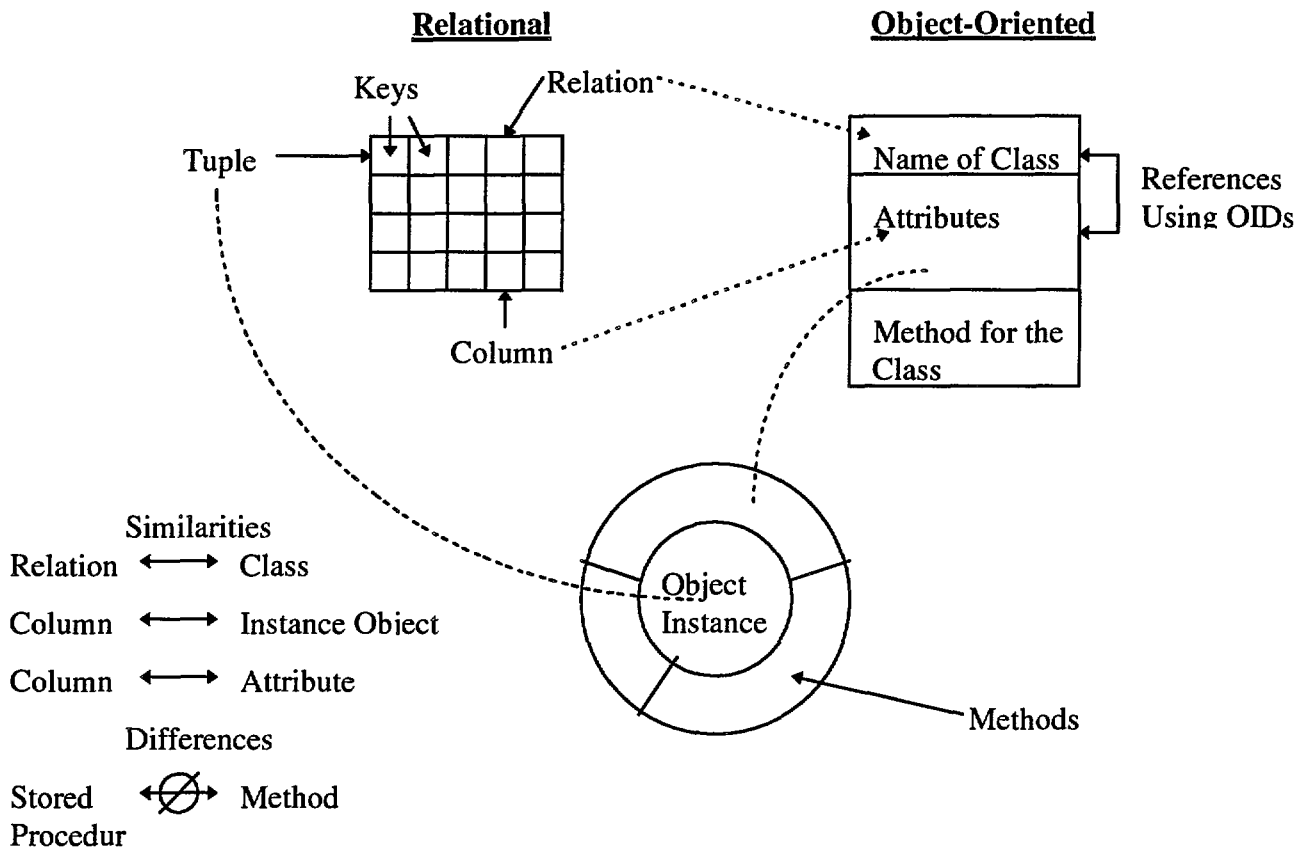
Normalization of data is done to help eliminate redundancy in data for relational databases. However, it does nothing to help redundancy in application development. For object-oriented databases, nonredundant data and methods are achieved with encapsulation and inheritance. Inheritance helps to lower overall redundancy in development.

The SQL language is typically used for the manipulation of tables in relational databases. Object-oriented requests cause the execution of methods in a object-oriented database. In addition, diverse methods can be used.

In relational databases, performance is a concern with highly complex data structures. For object-oriented databases, there is class optimization. The data for one object can be interlinked and stored together so that it can be accessed from one position of the access mechanism. Object-oriented databases give much higher performance than relational databases for certain applications with complex data.

For relational databases, the model of data structure and access represented by tables and Join operations is different from that in analysis, design, and programming. Design must be translated into relational tables and SQL-style access. For object-oriented databases, the models used for analysis, design, programming, and database access and structure are similar. Application concepts are directly represented by classes in the object-oriented database. The more complex the application and its data structures, the more this saves time and money in application development.

In summary, relational databases were never designed to store objects and objects were never designed to be stored in two dimensional tables. They are poorly adapted to express the basic attributes of objects like encapsulation, inheritance, polymorphism, object identity, references among objects, and other user defined data types. Whereas, object oriented languages are good at expressing complex relationships among objects. They are excellent at data manipulation but provide little or no support for data persistence and retrieval. The object model is based on the tight integration of code and data, flexible data types, hierarchical relationships among data types, and references



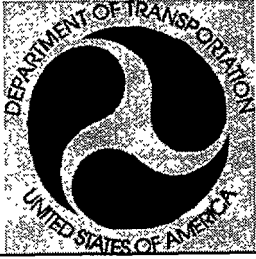
**Figure A-1 Pictorial Showing Basic Similarities and Differences Between Relational and Object-Oriented Databases**

### Summary

As discussed above, relational and object DBM systems each have their own strengths for certain types of data handling requirements. However, the description of traffic parameters in real world terms more closely fits the definition of object models. Since objects are handled more effectively with object DBMSs than with relational DBMSs, the object DBMS structure becomes the preferable method for manipulating large amounts of real world traffic data.

## **References**

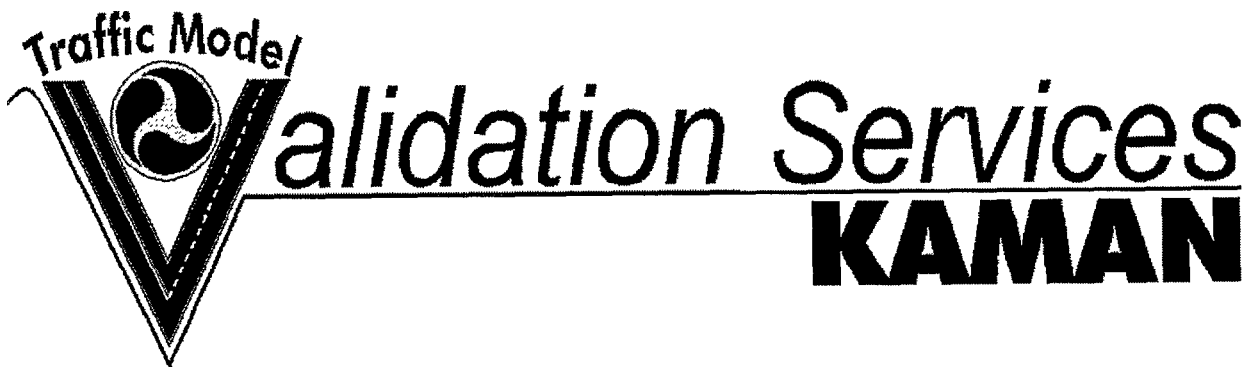
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# Traffic Model Validation Methodology

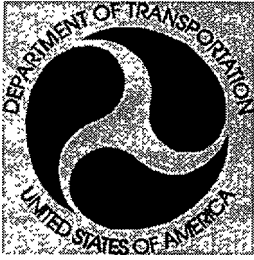
*Task G*

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December 1996



# Traffic Model Validation Methodology

## *Task G*

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### **Forward**

Models of traffic system operation are widely and very successfully used by traffic professionals for optimization, planning and analysis. As these models expand in scope and complexity to meet the diversity of requirements, model accuracy and applicability continues to be an issue with practitioners and decision makers. However, the documentation, methodology or extent of the validation efforts are often insufficient to establish a high confidence level in model results. Part of the difficulty with validation is the paucity of suitable and accessible data to complete the process. To address these issues, the Federal Highway Administration (FHWA) has sponsored a research effort (DTFH61-95-C-00125) to identify, implement and make accessible the most effective procedures for validating traffic models

The purpose of traffic model validation is to transfer confidence in model capability to the traffic engineering community. Because no single litmus test exists to establish validity, confidence in model predictions is only obtained through extensive testing at many levels. In addition, validation is an ongoing process as models are developed, modified and new applications considered. This paper identifies a framework where this process can continuously be extended and updated. This paper describes:

- The methods that will be used to produce initial validation and calibration results for selected critical functions of the TRAF family of models, and thus, demonstrating the utility and efficacy of the above framework.
- The design of a system so that the researcher, developer and practitioner can have direct and interactive access to the procedures and data used in this study.

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# Section 1. An Overview of Traffic Model Validation Procedures

## *Introduction*

Traffic system operation is characterized by the flow of the mobile elements (users and vehicles) through the facilities (roadways and control devices). Traffic engineers design and modify the facilities to optimize safety and efficiency of traffic flow. The flow of the mobile elements is a complex interactive process that is a function of facility design, user objectives, perception and reaction, and vehicle dynamics. In models of traffic system operation, the algorithms that predict the responsive nature of vehicles and users are referred to as the traffic flow components, e.g. car-following logic

Three types of traffic software tools are typically used to analyze and design traffic systems:

- Signal Optimization
- Assignment
- Simulation

These categories do not uniquely classify traffic models, and the unifying nature of Intelligent Transportation Systems (ITS) and other technologies continue to both force and enable a merging of the three techniques into a common model structure. A signal optimization or traffic assignment model may or may not be classified as a simulation depending on the degree of analysis that the model can perform. Signal optimization or traffic assignment models that are not simulations are generally referred to simply as analytical models.

This paper's focus is on traffic simulation and traffic flow. However, the applicability of the information should be appropriate for any model that either explicitly contains traffic flow components or implicitly assumes characteristic behavior of traffic flow.

## **Traffic System Simulation**

A **Traffic System Simulation** is a symbolic software model for conducting experiments on a traffic system. This is accomplished by using inputs that explicitly reflect the facilities and scenario description of a real or hypothetical traffic system. These inputs enable the simulation to predict the referent system's dynamic behavior due to existing or modified conditions. A simulation must have substantive component models to describe both the facilities and traffic flow. The traffic flow components are based on constructs related to scale and random variation.

Macroscopic and microscopic are the most fundamental constructs of traffic flow modeling. Macroscopic and microscopic perspectives' are often employed with respect each of the three fundamental traffic parameters: speed, flow and density. Recent trends in model categorization have also identified mesoscopic modeling that combines aspects of both macroscopic and microscopic modeling (such as DYNASMART).

Whether a model is stochastic or deterministic is also an important characteristic. Stochastic methods are usually associated with microscopic modeling and deterministic methods with macroscopic models. The remainder of the document addresses simulations that are both microscopic and stochastic.

## The Basis for Determining Traffic Model Accuracy

The fact that a traffic model compiles, executes, and produces data does not guarantee that the results reflect the real-world system being modeled. However, even the best traffic system simulation is never an absolutely accurate translation of the real-world system. Additionally, due to limited computing power, microcomputer-based traffic simulations cannot be expected to have highly sophisticated driver/vehicle models that perhaps could be implemented on a supercomputer. Therefore, realistic expectations for model performance must always be less than an exact one-to-one correspondence to the real-world system. These premises imply that the desirable degree of accuracy and hence, the applicability is dependent on the extent of aggregation. No single test can ever demonstrate the sufficiency of a simulation to reflect real-world behavior. Therefore, the approach to transferring model confidence involves many layers and tiers with several tests being performed at different levels and stages

### **Traffic Model Validation**

Given the requirement to establish model accuracy, verification and validation are the traditional methods employed<sup>3</sup>. Each of these methods consists of comparative tests that measure model consistency with a benchmark as shown in Figure I-I. Verification consists of exhaustively evaluating calculated values from the software model compared to the corresponding values from the theoretical model.

The verification process does not measure the relative merits of the theoretical model and hence, receives little attention in this paper. The validation process is divided into two aspects: conceptual and operational. Conceptual validation assesses the theoretical and software models against sound and accepted theoretical foundations. The operational validation process consists of comparisons between model predictions and measured real-world system behavior. These processes are discussed in more detail below.

### **The Conceptual Validation Process**

The primary focus of conceptual validation is on the underlying traffic flow theory. Conceptual validation is not necessarily a precursor to operational validation. Rather, conceptual validation is a concurrent and reoccurring process that takes place in conjunction with operational

#### **Simulation Constructs Related to Scale**

**Microscopic Modeling** - A model that continuously or discretely predicts the state (position, speed, acceleration) of individual vehicles;

**Macroscopic Modeling** - Models that aggregate the description of traffic flow; macroscopic measures include average speed, flow and density;

**Mesoscopic Modeling** - Models that have aspects of both of the above.

#### **Constructs Related to Random Variation**

**Stochastic Modeling\*** - A model in which the results are determined by using one or more random variables to represent uncertainty about a process or in which a given input will produce an output according to some statistical distribution;

**Deterministic Modeling\*** - A model in which the results are determined through known relationships among the states and events, and in which a given input will always produce the same output;

validation as described below. Conceptual validation may be reexamined to explain anomalous or inconsistent behavior detected during operational validation.

Conceptual validation requires the identification of the model's underlying theory, usually described in the model's documentation, supporting academic literature, comparisons with alternative approaches, and the source code of the model itself. Conceptual validation results in a qualitative assessment of a model's theoretical underpinnings, and its implementation, evaluated in the light of sound and accepted theoretical methods. The two primary methods employed during conceptual validation are the model walkthrough and computer animation.

### **Model Walkthrough**

The primary method for conceptual validation is by model walkthrough. A walkthrough involves a small group of qualified individuals who carefully review and revisit the model's logic and documentation. This group may also contrast existing logic with alternative methods as well as review the basic structure of the model.

### **Computer Animation**

The best way to confirm some of the conclusions from the conceptual validation is to observe the animation of the simulated real-world case with models such as *TRAFVU*<sup>4</sup>. If there is enough detailed information, animation of the real-world and simulated conditions can be displayed side-by-side. In most cases, animation is only possible with the simulated data. Animation enables the user to identify anomalous behavior by visually displaying the movement of vehicles as they respond to the facilities and other vehicles.

## ***The Operational Validation Process***

The procedures associated with operational validation are designed to present visualizations and quantitative measurements of the consistency between model prediction and operational measurements from real-world systems. Because no single test can establish validity, operational validation occurs at different stages and levels. The process subsequently described can effectively identify the level at which a model is invalid. However, the process does not conclusively indicate the model adequacy for all possible applications and users.

### **Stages of Validation**

A validation stage identifies a combination of the facility geometrical extent and degree of complexity in traffic flow conditions. The concept of a stage is important for two reasons: 1) the various stages identify the progression of the validation process, and 2) increasing stages impose basic limitations on the extent of the data collection and reduction that can be accomplished.

Table 1-1 shows five different stages of validation as a function of facility extent and the degree of traffic flow complexity. Even at the lower stages of validation, circumstances can lead to quite complex traffic flow conditions and data collection requirements. For example at Stage 1 of interrupted flow shown in Table I-I, the following traffic flow parameters increase the complexity of the validation process and data collection:

- Variability in traffic volume
- Sources and sinks
- Link length

- Distribution of turning movements
- Distribution in vehicle types
- Hills and curves
- Number of lanes
- Driver types

The validation process is designed to start at a low level of facility extent with a minimum degree of traffic flow complexity. This is discussed in more detail in the data collection section below.

## **The Levels and Methods of Operational Validation**

Given a particular stage of validation, the process then progresses through various statistical levels as described in Table 1-2. These levels correspond to the degree of aggregation and imply that some quantitative measure of association between real-world and simulation will be computed. In an effort to improve the comparison at any level, calibration can be attempted.

### ***Highest Level of Aggregation - Cumulative Averages and Variances***

The highest validation level involves comparison between cumulative averages and variances of standard unambiguous traffic flow characteristics integrated over time. Standard unambiguous traffic flow characteristics include throughput, speed, density, volume or their equivalent such as occupancy and headway. Traffic flow measures of effectiveness (e.g. fuel consumption) that impose another level of abstraction will, in general, be avoided unless direct field measurements of these parameters are involved.

The first level of comparison are cumulative averages of standard measures such as speed, occupancy and travel time that most traffic models produce. The comparative measures between real-world and synthetic averages represent necessary conditions for determination of validation and calibration, but are generally insufficient for microscopic model validation in particular.

The variability of simulation results can be assessed by computing the variance in the aforementioned parameters based on different initial random seeds. The real-world variability can be measured based on sampling techniques as prescribed for volume, speed, headway and travel-time<sup>5</sup>.

### ***Second Level of Aggregation - One-dimensional Distributions***

One-dimensional distributions are made by considering one traffic flow parameter such as speed or headway as illustrated in Figure 1-2. The real-world and simulated distributions are created by collecting the data into bins forming a density plot. The distribution can be tested for normalcy and the real-world and simulated data can be compared using the chi-square test. The unbinned data can be tested by the one-dimensional K-S test to test whether the values are from the same distribution.

### ***Third Level of Aggregation - Two-dimensional Scatter Diagrams***

In the third level of aggregation, comparisons are made between two-dimensional diagrams of standard unambiguous traffic flow characteristics as a function of either time, distance or another traffic flow characteristic. This is usually accomplished considering each vehicle with a common origin-destination pair. Within two-dimensional scatter diagrams, the breakdown with

respect to lane and modal can be aggregated or treated separately. This is illustrated in Figure 1-3 for a scatter plot of speed as a function of time where the lane behavior and lane changers are identified separately. Note that the simulation does not necessarily predict the variation in speed by lane. However, aggregating the data over lane and lane changing behavior results a fairly good comparison. By using two-dimensional diagrams, the character of the speed as a function of the time-varying demand volume becomes evident. Cumulative averages, as described above, do not validate this behavior.

Statistical goodness-of-fit techniques such as chi-square and one-dimensional K-S tests are not applicable to the determination of the degree of association between two-dimensional distributions. The two-dimensional cumulative probability distribution is not well-defined in more than one dimension. However, researchers have developed a two-dimensional K-S test<sup>6</sup> surrogate so that a statistic can be defined for the comparison between two two-dimensional distributions.

The two-dimensional K-S test provides an indication of the consistency between real-world and synthetic data. The K-S statistic is a value between zero and one, with zero indicating different distributions and unity indicating consistency. Increasing the value of the K-S statistic indicates better agreement between real-world and synthetic data, and therefore, can be used in conjunction with calibration as described below.

#### ***Fourth Level of Aggregation - Three-dimensional Contours***

Traffic flow varies, in general, both temporally and spatially. An example of this is shown in Figure 1-4. As stated above, statistically based measures are only possible in two dimensions through surrogate solutions. No such surrogates are defined for three-dimensional applications and hence, this level is not truly statistical. However, pattern matching is theoretically possible in many dimensions (e.g. the array consisting of time, distance, speed, headway is a possible four-dimensional pattern).

The nearest neighbor classifier' (NNC) is perhaps the simplest pattern matching algorithm to implement. The NNC makes use of the correspondence between similarity and distance. That is, if the real-world contour is used as the baseline, the closest match from a set of simulated cases is that realization that minimizes some defined metric. There are several standard options for defining this metric: Euclidean distance, city-block distance and octagonal distance. (Esthetically, city-block distance seems like the appropriate measure for traffic applications.) For an exact match, each of these measures produces a zero value. Hence, the smaller the metric the closer the match. The downside of utilizing contour plots is that they are often not visually intuitive.

The value of the NNC metric indicates a degree of the consistency between real-world and synthetic data. The NNC metric is a value between 0 and infinity, with zero being indicative of an identical pattern to the test pattern. Decreasing the value of the NNC metric indicates a better agreement between real-world and synthetic data, and therefore, can be used in conjunction with calibration described below.

#### ***Calibration***

For many values, such as driver reaction time or gap acceptance, traffic simulations usually define a standard set of default input values. Scenario or regional conditions may not correspond to the average conditions on which the default values are based. In an attempt to improve the comparisons described above, iterative steps can be taken to modify the default values of these parameters that control traffic flow when the precise values are unknown. These steps are referred to as calibration.

Calibration is the implicit recognition that not all parameters can or will be known or measured with precision, but whose values are bounded or distributed within some reasonably established limits. Additionally, only specific parameters are available for calibration purposes (see the next section for the identification of such parameters). For example, adjusting any descriptive traffic input parameter, such as volumes, to achieve a better comparison to real-world traffic flow data is usually inappropriate. Adjusting input parameters beyond either physical or common-sense limits just to obtain a better comparison is also unacceptable for validation purposes. Calibration also carries the connotation of small scale changes or refinements to a limited set of default input values. Calibration requires engineering judgment, therefore, the set of parameters that can be calibrated effectively is also dependent upon the degree of user sophistication and experience with the model.

## **Data Requirements**

The data requirements for operational validation are organized into matrix form as shown generically in Table 1-3. Data requirements for operational validation are derived from descriptive simulation inputs, calibration inputs and data for validation purposes. In turn, data for validation purposes consist of model prediction and real-world system behavioral data formatted for direct comparison (see Figure I-1). The data requirements also will be used for data dictionaries and data modeling in the validation system's database as discussed below.

The most common examples of descriptive input parameters describe the facilities such as geometrical layouts and control system operation. Other input parameters, such as gap acceptance or driver reaction time, may not be readily inferred from field measurements. These parameters are candidates for calibration.

Simulation outputs are computed to describe the operational performance and behavior of the real-world traffic system. These outputs are usually in the form of averages over the network or links. These output parameters are useful for top-level validation. However, more detailed data beyond those normally output are usually necessary for validation particularly at early stages

## **Data Collection and Reduction**

Data collection and reduction must result in the existence of information to satisfy the requirements specified in Table 1-3 for descriptive, calibration and validation data. The discussion of data collection is for the most part restricted to small scale geometries of urban streets and freeway sections generally associated with Stage 1 as identified in Table 1-1. For Stage 1, microscopic data (e.g. speed and headway) associated with individual vehicles can be collected at several points within the section of interest.

### ***General Approach to Data Collection***

The general approach to satisfying the data requirements is to take detailed measurements of traffic flow during a given time period. Resource limitations prohibit continuous day-to-day detailed data collection and reduction. However, day-to-day measurements, with approximately the same demand volume and conditions, are required to specify the variability in real-world behavior. Therefore, sampling techniques are employed for follow-up measurements, which are taken on a day-to-day basis during the same time period, but with less detail. For example, information on demand volume, incidents and GPS (Global Positioning System) instrumented probe cars are collected during subsequent time periods. The information on demand volume and incidents are necessary to normalize results. The probe car information provides both link and network speed and travel time and requires little data reduction. Repeated detailed data

collection is only needed when the sampling techniques indicate that the original data collection activities occurred under anomalous conditions.

### ***Specific Approach to Data Collection for Stage 1***

Data collection plans are prepared based on the desired level of detail. As indicated above, resource limitations preclude detailed data collection for extended periods of time on large networks. However, small scale data collection can be performed on a fairly microscopic level. The data collection methods required for the detailed level are slightly different than what is required on an aggregate level. The methods generally associated with Stage 1 data collection rely on the following:

- Video data from elevated positions.
- Probe cars using GPS for travel time runs.
- Manual techniques (e.g. radar guns, counters).
- Any existing infrastructure (e.g. loops, cameras etc.).

Based on appropriate data reduction, these methods provide microscopic data and are not intrusive to normal traffic operations. Video data is one of the most popular data collection methods. Video data collection has several advantages: inexpensive, non-intrusive, a permanent record and the data is always available for retrieval for verification, traffic flow parameters including speed, headway, vehicle types and lane changing can be identified. However, data reduction of video into microscopic data cannot be easily automated, and hence, is a very time consuming process. GPS probe car information, on the other hand, is very easily reduced and can produce detailed travel time data. Probe vehicles provide only representative samples, but are very useful for detecting any microscopic trends within the arterials.

The two illustrations, one for interrupted and uninterrupted flow respectively, describe the approach to Stage 1 data collection. Stage 1 geometry consists of a relatively low degree of traffic flow complexity. The concept is to minimize the number of calibration parameters and model input uncertainties through either direct measurement or scenario simplification. The perspective for these cases is fundamentally microscopic and is intended for NETSIM and FRESIM applications respectively.

**Data Collection in Interrupted Flow** The simple geometry of the interrupted flow (Stage 1) is illustrated in Figure 1-5. This scenario is selected to validate a traffic model's prediction of vehicles discharged from an upstream node, the pattern of those vehicles as they traverse the link (platoon dispersion), and their progression through or stoppage at a downstream node.

**Data Collection in Uninterrupted Flow** In the uninterrupted flow situation shown on Figure 1-5, the Stage 1 case is different because the traffic is not broken up into distinct platoons, but is continuous along the freeway. As platoon dispersion is the major factor in the interrupted flow case, freeway turbulence is the major factor in the uninterrupted flow case. Freeway turbulence can be defined as the changing of speeds, densities, and flows over a section of freeway due to a mixture of factors. Some of the factors affecting freeway turbulence include on-ramp flows, off-ramp flows, road geometry, driver's gap acceptance, driver's attitudes, vehicle types, weaving vehicles, number of lanes, lane widths, changing conditions, time of day, incidents, and others. In light of the validation complexity levels chosen, a simple case of freeway turbulence can be observed in a simple section with a single entrance and exit. This segment under ideal data collection conditions is shown in Figure 1-5.



### ***Data Collection at Advanced Stages of Validation***

As the validation process progresses through more advanced stages, supplementary data collection alternatives must be considered. Table I-4 contains a summary of alternative data collection methods and the data requirements that they can fulfill. These sources include information obtained through manual counts, point detectors, video surveillance, aerial measurements, and chase cars.

### ***Use of Existing Data***

Most of the traffic data already in existence has been acquired through conventional automatic means such as loop detectors, traffic counters, and in some cases, by manual methods such as chase vehicles, roadside observation, manual counts, etc. It is natural to assume that the use of existing data might result in time and cost savings compared to new data collection and reduction efforts. Kaman Sciences has documented several possible data collection activities in Reference 8.

### ***Traffic engineering community involvement***

The purpose of the methods described in this paper is to transfer confidence in model results to the traffic engineering community. An important step in this study is to engage the traffic engineering community in a continuing dialog regarding the methodology, data requirements and results of traffic model validation. The eventual objective of this effort is to make the data and methodology used in this study accessible to the community at large (see the description of the system below).

The traffic engineering community brings three important perspectives to traffic model validation:

- Researchers supply the innovation that manifests into the development of new and improved theoretical models
- Developers provide the implementation of the concepts into useable software and continue to maintain and modify the traffic models
- Practitioners apply the models to real-world problems

Without the experience, opinions and perspectives of the members of this community, the vision of this program can never be realized.

To start this process, an inquiry was sent to members of the development and research community. To further this process, a similar feed-back form will shortly exist on the internet site at:

- <http://www.fhwa-tsis.com/database/database.html>

### ***A Synthesis of Comments from the Traffic Engineering Community***

The initial documentation on validation methods and data requirements was sent to members of the developer and research community. Some of the key comments are summarized below.

- In order to inspire practitioner confidence in the models, it should be demonstrated that various components and sub-systems of the model work reasonably well. Various statistical methods like chi-square, t-tests and others should be used to perform a goodness of fit between field measurements and models output. An understanding of the difference between measured and predicted measures of effectiveness (MOE's) is

necessary. Standard deviation of the measured data is also a good measure of precision. The inputs having the greatest influence on output and their uncertainty should be identified.

- In the calibration process, all parameters, including well established parameters and their range for various scenarios should be considered. Sample sizes should not be ignored. Again, special attention should be paid to the parameters having a significant influence on the MOE's. A hierarchy of the critical parameters may be useful. The importance of experimental design and quality control was emphasized. In other words, if the verification, conceptual validation, and calibration (of components) were done properly, the operational validation should be relatively smooth if the experimental design and the quality control for the data collection were done properly.
- Some data collection efforts for model validation and calibration like in NCHRP 3-47, 3-49, FTMSs in Toronto and CALTRANS, and some studies conducted by North Carolina State University and the Texas Transportation Institute were identified.
- While a few respondents indicated the need for a common format for the data, the majority were of the opinion that it should not be the case. The data collected should be event based and as raw as possible (not aggregated). The issue is not the format of the data. It is the retrieval of the data. The user should then be able to modify and store it in a format the user can use. The level of detail and the variables to be collected are also equally important.
- The need for more accuracy may place additional and different stipulations on the data requirements for the models. But the trends may be on the data collection side. Increased use of probe cars, video imaging technology, and differential GPS and other technologies will have a higher impact on the data requirements for the simulation models. The importance of microscopic simulation models is in using and assessing the benefits of ATMS. They are also useful to develop an improved ATIS.

## ***Summary and Conclusions***

The conceptual and operational validation processes introduced in this paper consist of various stages and levels where tests and visualizations are performed in a systematic manner. The data to describe, calibrate and perform the tests for model accuracy compared to real-world traffic systems were defined for early stages of operational validation. The methods to collect and reduce real-world data to satisfy the data requirements of operational validation were described. The overall methodology described in this paper has been applied to the validation of CORSIM elements described in Sections 2 and 3 below.

The purpose of model validation is to transfer confidence in model performance to a target audience. The target audience, in this case, is the traffic engineering community consisting of researchers, developers and practitioners. Confidence in model performance will only be conveyed when the target community is involved in the process. A preliminary inquiry was submitted to this community and the opinions expressed continue to be integrated into the approach to validation. Efforts are described to further encourage additional participation by the traffic engineering community and to make accessible the methods and data that result from this study.

**Table 1-1 Stages of the Operational Validation Process**

Stage	Interrupted Flow	Uninterrupted Flow
0	Sign controlled isolated intersection	Free flow conditions
1	Single Link, signal controlled at each end	Representative Segment with on and off ramps
2	Arterial or Small Grid	Lane drop or closure (Bottleneck)
3	Network	Freeway Density contour map
4	Combinations of Interrupted and Uninterrupted Facilities	

**Table 1-2 The Comparative Levels of the Validation Process**

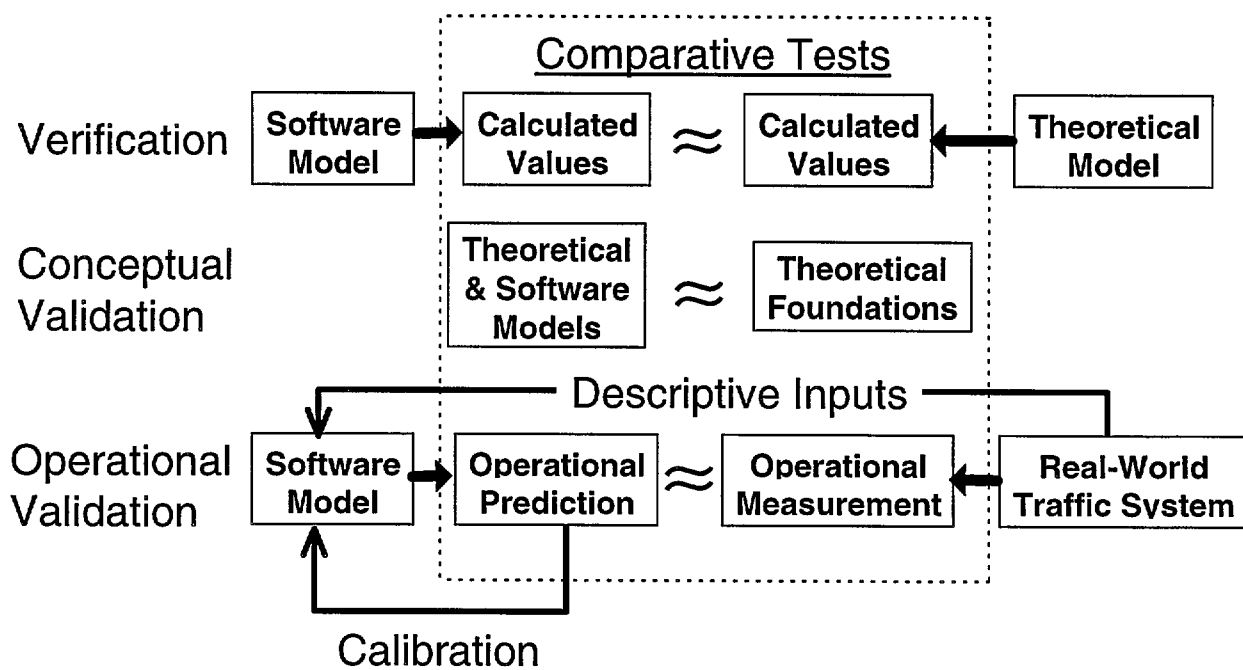
Level	Description	Procedure
Statistical-1	Cumulative averages over all time and space, e.g. average speed, travel time, delay, number of stops	Mean and standard deviation
Statistical-2	Cumulative one-dimensional distributions	Tests for normality, goodness-of-fit tests Chi-square, One-dimensional Kolmogorov-Smirnov tests
Statistical-3	Two-dimensional diagrams or scatter plots averaged over limited spatial and temporal values, e.g. average vehicle speed versus entry time, average headway versus entry time.	Two-dimensional Kolmogorov-Smirnov Tests
Statistical-4	Three-dimensional contour comparisons with minimum temporal and spatial averaging, e.g. average density as a function of time and space position	Pattern matching
Calibration	Attempts to improve the comparisons	Variation of uncertain parameters

**Table 1-3 Data Requirements Matrix for a Generic Microscopic Traffic Simulation**

		<b>Network</b>	<b>Link/Node</b>	<b>Vehicle/Driver</b>
<b>Input</b>	<i>Descriptive data required (non-calibration)</i>	<ul style="list-style-type: none"> <li>• # of intersections</li> <li>• Cycle length range and increment</li> </ul>	<ul style="list-style-type: none"> <li>• Volumes</li> <li>• Lane configuration</li> <li>• Link lengths</li> <li>• Turning percentages</li> </ul>	
	<i>Basic Calibration</i>	<ul style="list-style-type: none"> <li>• Driver reaction time</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• Saturation flow rate</li> <li>• Offsets</li> </ul>	<ul style="list-style-type: none"> <li>• Fleet composition</li> </ul>
	<i>Detailed Calibration</i>		<ul style="list-style-type: none"> <li>• Roadway characteristics</li> </ul>	<ul style="list-style-type: none"> <li>• Performance characteristics</li> <li>• Lane changing gap</li> </ul>
<b>Output</b>	Standard	<ul style="list-style-type: none"> <li>• stops</li> <li>• Delay (secs/veh)</li> <li>• Fuel consumption (gal.)</li> <li>• Emissions</li> </ul>	<ul style="list-style-type: none"> <li>• stops</li> <li>• Delay</li> <li>• Fuel consumption</li> <li>• Emissions</li> <li>• Queue length</li> <li>• Saturation</li> </ul>	
	Validation Specific	<ul style="list-style-type: none"> <li>• Average travel time</li> <li>• Average speed</li> <li>• Throughput</li> </ul>	<ul style="list-style-type: none"> <li>• Speed Distribution</li> <li>• Headway Distribution</li> <li>• Density or occupancy</li> </ul>	<ul style="list-style-type: none"> <li>• Speed</li> <li>• Headway</li> <li>• # Lane changes</li> <li>• Gap acceptance</li> </ul>

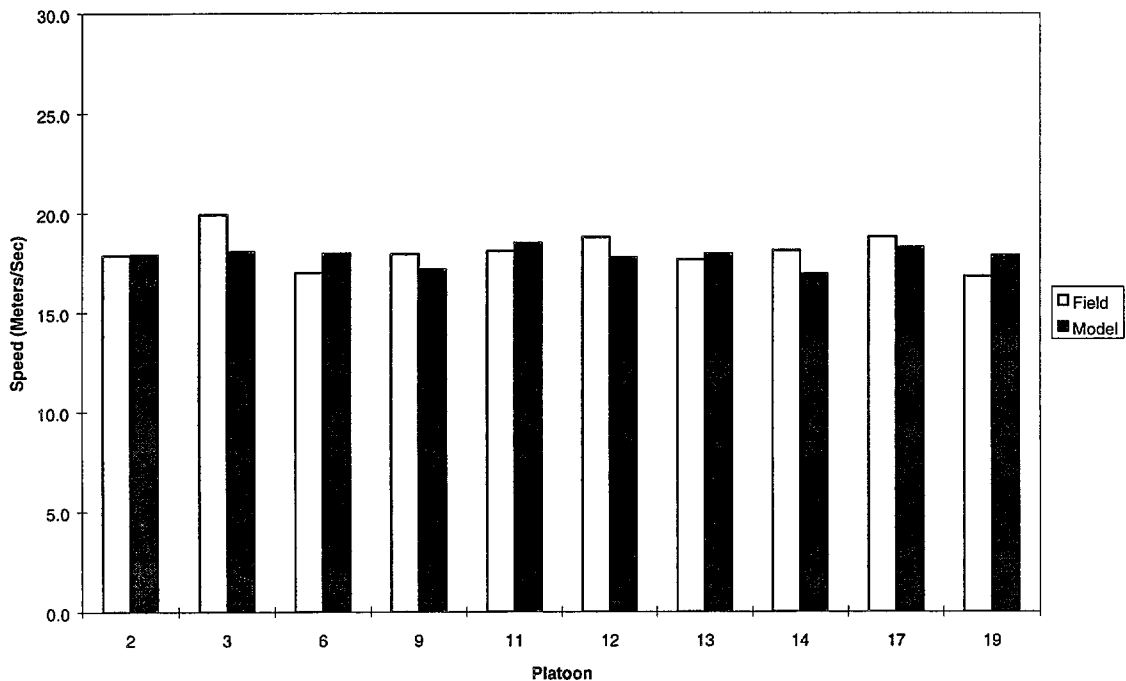
**Table 1-4 Alternative Data Collection Approaches**

<b>Data Collection Technique &amp; Equipment</b>	<b>Parameters Measured</b>	<b>Comments</b>
<u>Manual Counts</u> Manual Count Boards Electronic Count Boards Tablets/Clipboards & Pencils LapTop Computers Radar Guns	<ul style="list-style-type: none"> <li>• Traffic Volumes</li> <li>• Turning Movements</li> <li>• Queue Counts</li> <li>• Vehicle Headways</li> <li>• Start-up Lost Times</li> <li>• Gap Acceptance</li> <li>• Time Mean Speed</li> <li>• Stopped Delay</li> </ul>	Labor Intensive Requires Human Interpretation
<u>Point Detectors</u> Pneumatic Tubes Inductance Detectors Radar/Microwave Detectors Magnetic Imaging Traffic Counters	<ul style="list-style-type: none"> <li>• Gross Volume Counts</li> <li>• Lane Volume Counts</li> <li>• Time Mean Speed</li> <li>• Occupancy</li> <li>• Headways</li> <li>• Vehicle Classification</li> </ul>	Inexpensive Works only at one point Can't measure any MOEs other than time mean speed Apparent reliability higher than actual reliability Often part of existing infrastructure
<u>Video Surveillance</u> CCTV Camcorders	<ul style="list-style-type: none"> <li>• Gross Volume Counts</li> <li>• Lane Volume Counts</li> <li>• Speeds</li> <li>• Occupancy</li> <li>• Headways</li> <li>• Vehicle Classification</li> <li>• Flow Rates</li> <li>• Queue Lengths</li> <li>• Delay</li> <li>• Turning Movement Counts</li> <li>• Gap Acceptance</li> </ul>	May require special software depending on requirements Equipment can be costly but does not require permanent installation Allows for visual verification of the models by comparison with TRAFVU
<u>Aerial Measurements</u> Helicopters Blimps Tall Buildings	<ul style="list-style-type: none"> <li>• Gross Volume Counts</li> <li>• Lane Volume Counts</li> <li>• Speeds</li> <li>• Occupancy</li> <li>• Headways</li> <li>• Vehicle Classification</li> <li>• Flow Rates</li> <li>• Queue Lengths</li> <li>• Delay</li> </ul>	Prohibitive costs for helicopters and blimps Stability Issues Infrastructure must be there for buildings
<u>Other Methods</u> Probe Cars License Plate Recording	<ul style="list-style-type: none"> <li>• Travel Time</li> <li>• Delay</li> <li>• Two-Fluid Model Parameters</li> </ul>	Surprisingly inexpensive Large samples not needed



**Figure 1-1 Traditional Methods to Assure Model Accuracy**

Field vs. Model Speed (Section A)



Field vs. Model Headway (Section A)

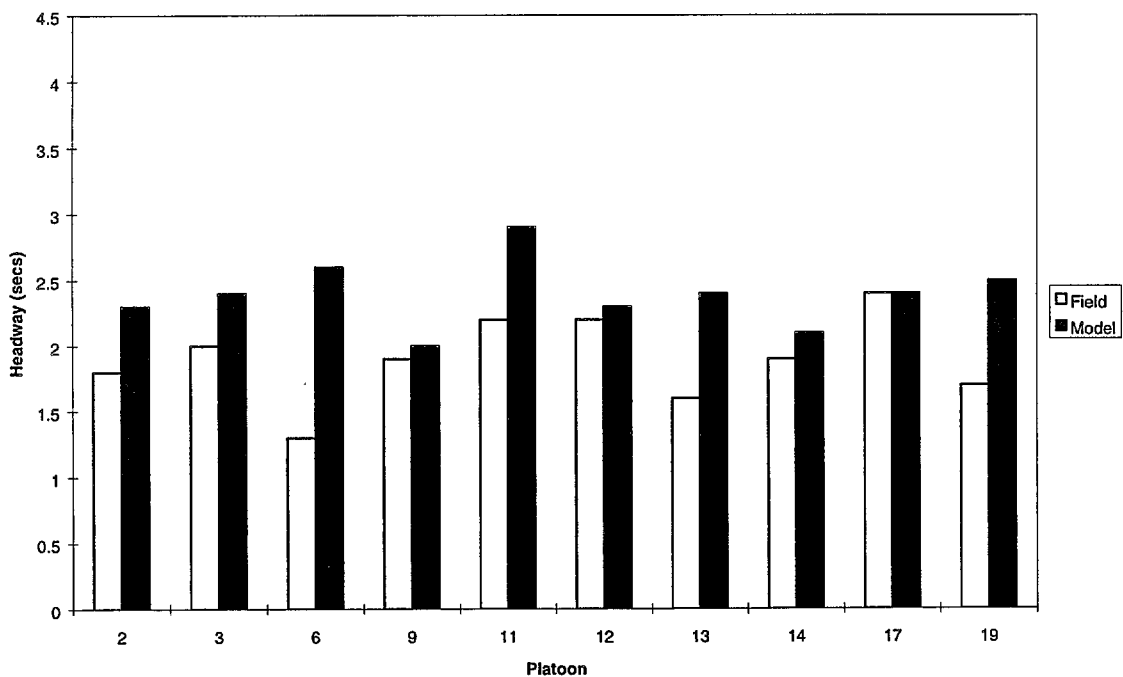
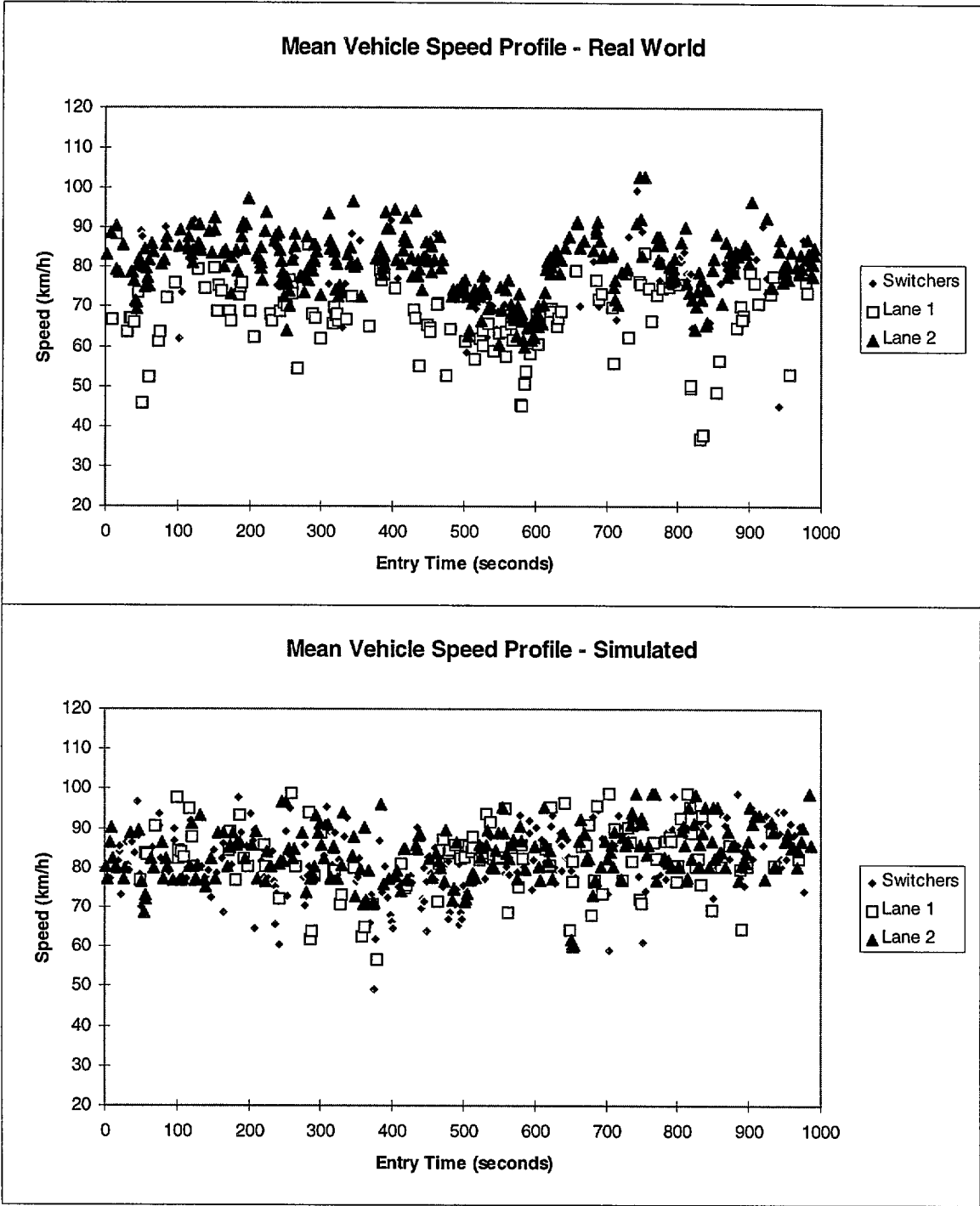
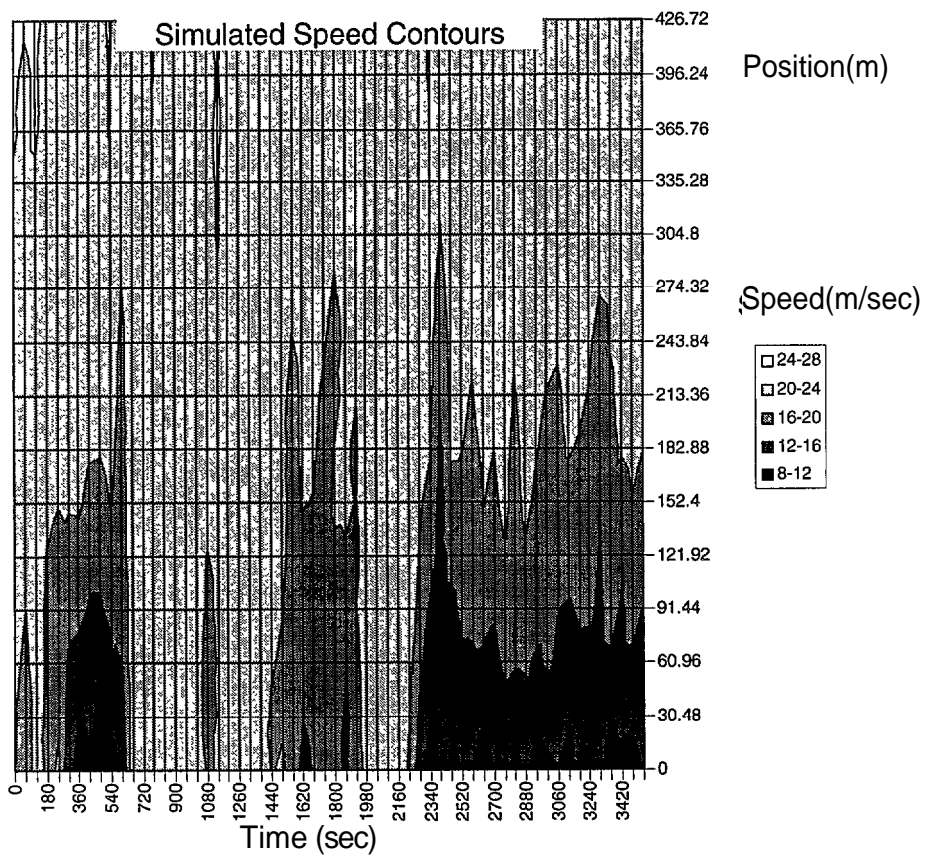
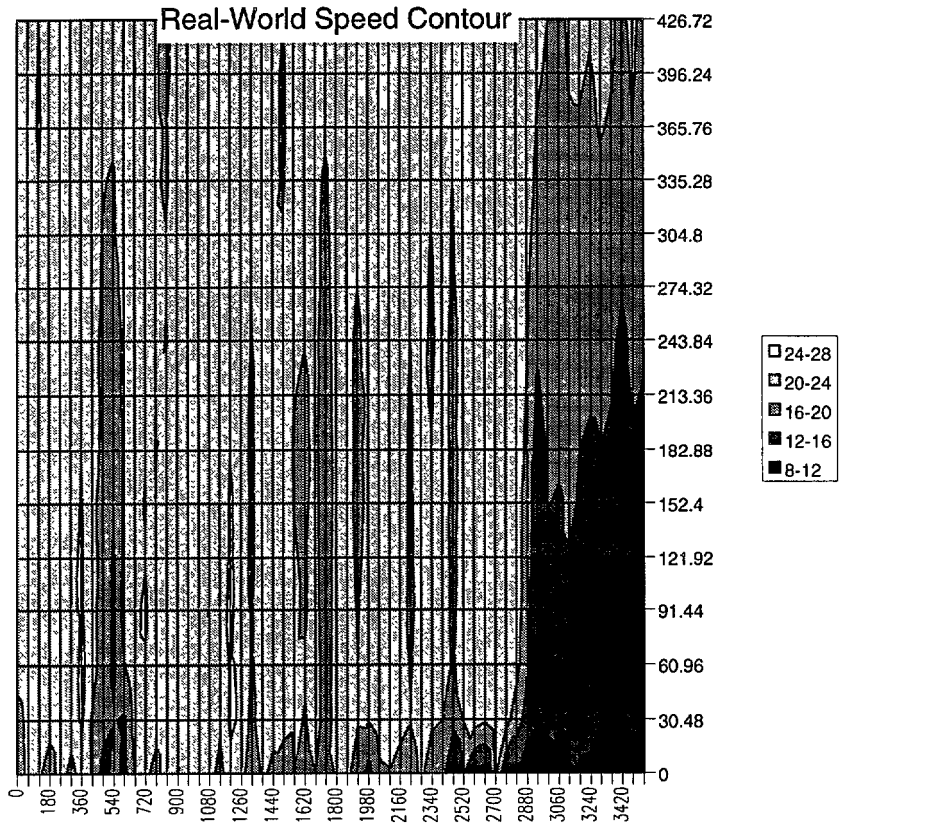


Figure 1-2 Example of One-Dimensional Distributions Comparison



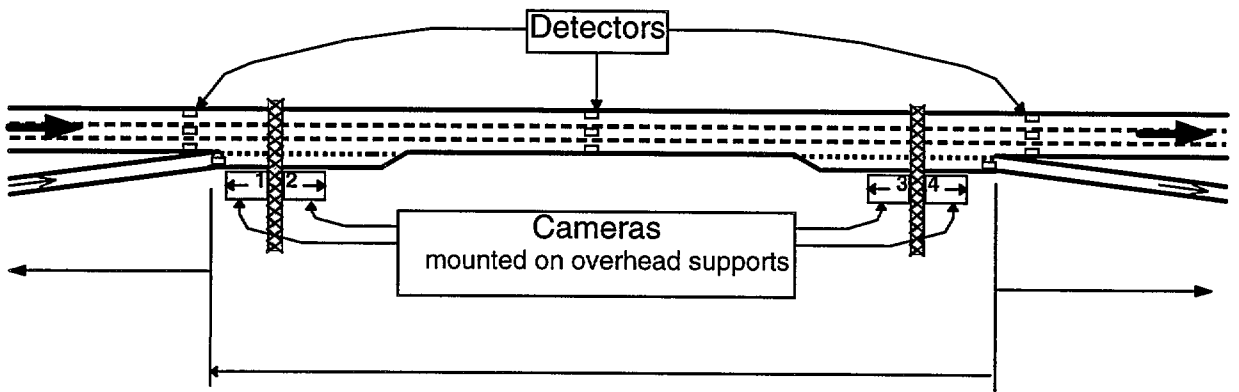
**Figure 1-3 Example of Two-Dimensional Scatter Diagram**



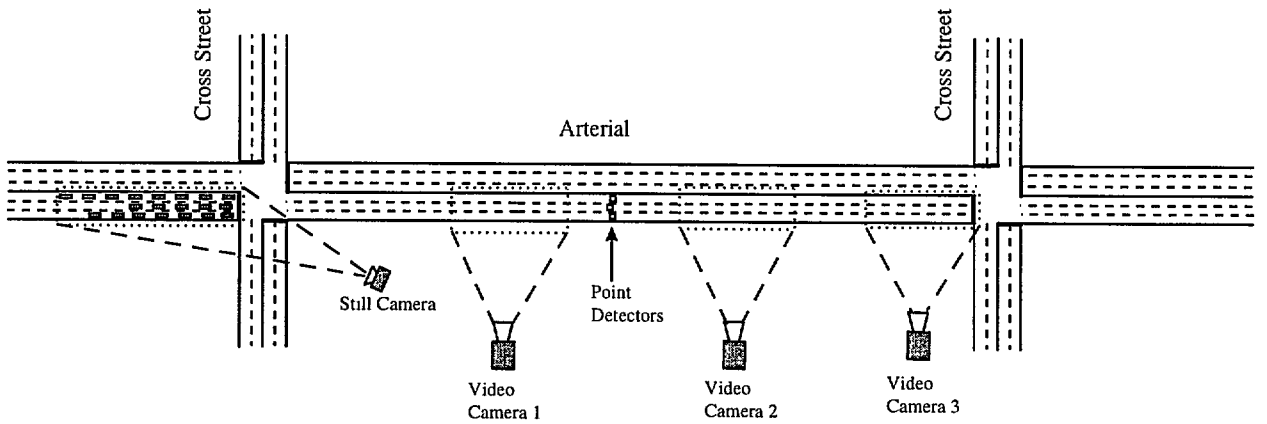


**Figure 1-4 Example of Three-Dimensional Contours Comparison**

(Stage 1: Freeway section with an entrance and an exit)



(Stage 1: Urban street section with a single link)



**Figure 1-5 Data Collected for Interrupted and Uninterrupted Traffic Flow Validation**

## Section 2. Illustration of NETSIM Validation

NETSIM and FRESIM are the microscopic simulation members of the TRAF family of microcomputer-based models. NETSIM was developed in the 1980's for simulation of arterial street networks. This program has been modified over the years and is used by traffic professionals worldwide. The origins of FRESIM are derived from INTRAS, a model that was originally released in the late 1970's to model freeway operations. FRESIM includes additional features such as ramp metering and was re-released as FRESIM in the early 1990's.

In 1995, NETSIM and FRESIM were integrated to facilitate the combined simulation of arterial and freeway networks in the simulation package CORSIM (CORridor SIMulation). This connects the two simulation packages with 'interface nodes'. This package is of great value to traffic and transportation engineers, allowing simulation of a number of scenarios ranging from implementing advanced traffic control systems to simulating incident scenarios, construction sites, and proposed geometric changes. In addition, modeling can be done for critical Intelligent Transportation Systems (ITS) applications particularly in various Advanced Traffic Management strategies.

NETSIM and FRESIM have been widely distributed and utilized. In the future, CORSIM is expected to be distributed to the same community. However, issues of model accuracy have persisted over the years. This paper presents an illustration of the techniques to validate model performance and the approach to data requirements and data collection to support this activity. The validation and calibration plan for the model is divided into different stages. Advancing stages correspond to increasing geometrical and traffic flow complexity with the first stage looking at a study of the dispersion of a platoon along a link. Later stages will include more complex scenarios involving multiple intersections, combined scenarios, and in the final stage, complex integrated networks. This paper presents the investigation and results of the first stage and builds a framework for future stages.

### ***The Validation Process***

The basic goal of the research presented in this paper is to illustrate the validation process. This foundation includes an in-depth look into existing data requirements, data collection needs, calibration parameters, and other problems inherent to the study of microscopic traffic simulation models. This research will help lay the groundwork so that future efforts can construct specific validation methodologies. Hence, while this paper discusses attempts to validate and calibrate a sub-model in NETSIM, the overall objective is to illustrate the methodology involved in validation and calibration of the overall NETSIM model.

### **Data Requirements**

Investigation of NETSIM parameters is critical to the analysis and discussion of validation and calibration. The section titled *Traffic Model Validation and Data Requirements* submitted to the Federal Highway Administration, discussed several optimization and simulation programs including the TRAF family of models. For each of the models, a data requirements matrix was developed that illustrated and categorized both the input and output variables.

The data requirements matrix for NETSIM identifies both input data for descriptive and calibration purposes, and output data applicable for validation. The data is further broken down into network-based, link-based and vehicle-based data. Descriptive data, such as link geometry, demand volumes, and signal timing, cannot be calibrated. Calibration parameters are further divided into basic and advanced. Basic calibration data can be adjusted based on

either measurements or experience, such as free flow speed. Advanced calibration data are usually associated with microscopic parameters and distributions within the simulation, such as car following sensitivity factors. In the illustration included in this paper, examples of the various parameters include:

- Descriptive parameters such as the number of lanes, the link length, and the queue content.
- Basic calibration such as the free flow speed.
- Advanced calibration such as vehicle acceleration or gap acceptance.
- Validation parameters includes speed and headway at two observation points.

## ***Conceptual Validation***

Conceptual validation is intended to assess the underlying theoretical principals of the important traffic flow components and to compare those components with sound theoretical foundations. This procedure is important for identifying calibration parameters and explaining the results of operational validation. Conceptual validation is revisited during the operation validation process to help clarify any observed anomalies. In NETSIM's case, the primary traffic flow components reside within the car-following and the lane-changing logic. These components influence the dispersion of a platoon along a link.

While the original car-following logic is believed to be based on the Pitt algorithm<sup>9</sup>, the program logic, as it exists today, resembles a merged car-following/lane changing rule-based expert system. Rule-based systems rely on if-then-else constructs as opposed to direct numerical solutions. These rules have evolved over two decades of iterations from user (experts) testing and modification. The use of rule-based constructs certainly does not invalidate the model, and in fact, such systems typically work well within their domain of applicability. However, conceptual validation or calibration of the behavior of logic based on this type of construct is difficult because the theory becomes obfuscated by the inherent interdependence of the rules. As a result of this assessment, it is uncertain how well NETSIM's logic reflects sound car-following principals embodied by models such as the GM algorithm. However, the reasonableness of NETSIM's input-output relationships and viewing the animation of traffic flow behavior imply that the underlying assumptions do reflect some degree of physical realism.

## ***Operational Validation***

Platoon dispersion is a very complex traffic issue. It is influenced by a number of factors like distance to the downstream node, area, platoon size, free-flow speed, driver characteristics, presence of heavy vehicles, and link geometrics among others. A scenario was selected to minimize complex external influences on the traffic flow patterns. The scenario consisted of a single link of reasonable length with minimum sources and sinks within the link.

### **Real-World Data**

The objective of operational validation is to observe the progress of a platoon from the stop-line along the link and compare it with the progress or the dispersion of a platoon as simulated in NETSIM. The two most important characteristics of platoon dispersion are the change in speeds and headways of the vehicles in the platoon as they progress along the link. The speeds of the vehicles tend to increase until they reach their desired speeds (free flow speed)

and the headways tend to increase as the speeds increase. These two parameters were used to compare how well the model is simulating the real world.

This section briefly describes an overview of the research. The objective was to investigate the change in headways and speeds of individual vehicles in the field along the link. Headways and speeds of the vehicles which were in the queue at the onset of green were measured at two sections along the link. These exact queues were then created in NETSIM by circumventing normal vehicle generation. The queues were discharged and their progress observed along the link. The change in the individual speeds and headways of the vehicles in the platoon were observed at the same sections as was measured in the field. The results of the simulation were then compared with observations in the field. By performing comparative tests at various levels of aggregation, the accuracy of the model can be assessed. An attempt was made to identify any parameters which could influence the simulation and produce better correlation to the real world.

### ***Site Selection***

Several sites in Colorado Springs were surveyed. The site selected was the link on Union Boulevard between Austin Bluffs and Academy Boulevard. Union Boulevard is a north-south arterial having three lanes and has a link length of about two kilometers (km) between the two intersections. There was only one driveway on the west side of the link which had minimal volumes. Thus, there were almost no sources or sinks in the link and the vehicles in the platoons should not have any other interaction except among each other. There are hills on both sides of Union Boulevard, which provide excellent vantage points for setting up video cameras. The link is fairly straight with a slight curve in the southern section. However, it has a couple of sharp curves very close to the northern end. The speed limit is 72 kmph (45 mph). This site makes it ideal for studying platoon dispersion since it has almost no external influences.

### ***Data Collection***

Since the geometrics at the northern end were complicated, it was decided to observe only the north-bound platoons till they reached the desirable speed (free flow speed). A number of runs were made on the link, some spot speed studies were conducted and it was observed that a majority of the vehicles were reaching a desirable speed at a distance of 0.8 km from the upstream intersection

Three video cameras were set up as shown in Figure 2-1 to observe and record the progress of the platoon. The built-in clocks in all three video cameras were synchronized. These clocks had a resolution of one second. Camera 1 was used to record the queue at the intersection. Cameras 2 and 3 recorded the progress of the platoons at a distance of 366 m and 800 m from the stop-line respectively. These cameras were set up on a hill such that two tall utility poles on the east side of the street were in their field of view. This was done so that during the data reduction process the distance between the poles could be used to calculate the speeds of the vehicles. Data was recorded for about one hour in which about 25 platoons were observed. A probe car was also conducting travel time runs along the link while the traffic data was being recorded.

### ***Data Reduction***

The first step in the data reduction process was to observe and record the number of vehicles in the north-bound queue in each of the through lanes and the composition i.e., number of heavy vehicles and their position in the queue from Camera 1. The queue lengths were

observed at the onset of green for the north-bound through movement. Only queues having a significant number of vehicles were selected and the time the first vehicle crossed the stop-line was noted. A total of 18 platoons were selected from the one hour data sample.

A time stamp was printed on the video tape from Camera 2 and Camera 3. This time stamp has a resolution of one tenth of a second and was synchronized in both video tapes. This was done to obtain the headways and speeds of individual vehicles accurately since the resolution of one second obtained from the internal clock in the video camera is too long for microscopic studies.

Then two televisions with two VCR's were set up side by side. The video from Camera 1 was played in one VCR and the platoon composition at the stop-line was observed. The second VCR was used to play the video from Camera 2. As mentioned earlier, Camera 2 was observing the street at a distance of 366 m from the stop-line and had the two tall utility poles in its field of view.

The platoon observed in Camera 1 was then observed in Camera 2 in slow motion. The exact time each vehicle from the same platoon crossed each utility pole was recorded. The time a vehicle crossed the first utility pole was termed as the time of entry and the time the same vehicle crossed the second utility pole was termed as the time of exit.

Two observers reduced this data from the video tape. While one observer recorded the entry and exit of vehicles in the left lane, the second observer recorded the entry and exit of vehicles in the middle and right lane. Hence, the exact time each vehicle crossed each utility pole was observed and the time required for each vehicle to travel between the two poles noted. Thus, the headway of each vehicle at a point was accurately obtained. By measuring the distance between the two poles, the speed of each vehicle in the platoon was calculated. Care was taken to make sure that all the vehicles, and only the vehicles which composed the platoon observed in Camera 1 were observed in Camera 2. In many cases, some vehicles joined the queue after the onset of green when the platoon was already in motion. Many of these vehicles even overtook some of the vehicles in the queue and had to be removed while reducing the data from Section A and Section B. This procedure was repeated for all the 18 platoons selected during the data collection

The same procedure was repeated for the video collected from Camera 3. Hence, the individual speeds and headways of the vehicles in 18 platoons were accurately obtained at two sections along the link.

### **NETSIM Simulated Data**

Once the field data was reduced and individual headways and speeds obtained for all the vehicles in the respective platoons at the two sections, the platoons were simulated in NETSIM. Among the 18 platoons that were reduced from the field data, ten platoons were selected based on total number of vehicles in the queue and queue balance. Some of the platoons had only 1 O-12 vehicles across all lanes resulting in an average of about 3-4 vehicles in each lane. Such platoons would not display a proper dispersion along the link because the platoon was very small, and so they were not considered.

The queue balance (i.e., the number of vehicles in each lane) was also observed and queues having approximately equal number of vehicles in each of the lanes were selected. If the queue in one of the lanes was very large compared to the other two lanes, the vehicles in that lane would be much slower compared to the other lanes. This could also result in a higher than usual number of lane changes. A large queue imbalance was observed for some platoons, as a result these platoons were not selected for simulation.

The vehicle generator in NETSIM was circumvented in order to create the exact queue composition observed in the field. The number of vehicles in each lane and the position of the heavy vehicles were replicated. The simulation was then run. For each platoon the random seed number was changed and ten simulation runs were made. Each random seed represents the way the platoon with the same composition progressed down the link. In the real world, having the same platoon composition does not mean that the platoon progresses in exactly the same way. A total of 100 simulation runs were made for the ten platoons. A post-processor to easily read a detailed output file (also used by the animation program, *TRAFVU*) was created. This post-processor was used to obtain and format the relevant parameters that result from the simulation. The speeds and headways of individual vehicles at the two sections for the ten platoons were obtained using the post-processor. This data was then compared with the data obtained from the field.

### **Tests for Consistency**

Analysis of the data was done in three levels of aggregation. First, the data as observed in the field was visually compared with the model output for each platoon. Thus, any significant differences in the way individual platoons were progressing in the field were also observed. If the platoons were not behaving in a reasonably consistent manner, any attempt to calibrate the model would be made more difficult. Secondly, the data from all the platoons was then combined and the measures of effectiveness (MOE's) from the field and the model were compared at each section using the one-dimension Kolmogorov-Smirnov (K-S) test to check if the distributions for each data set were comparable. However, headways and speeds of vehicles within a platoon are interrelated and not completely independent. Hence, it was not completely correct to compare the speeds and headways of the platoons independently. Finally, the two-dimensional K-S test was performed for each platoon.

**First Level Comparisons - Accumulated Averages** In the first comparison, the average speeds and average headways of each platoon were computed and compared for the field data and the model. Table 2-1 summarizes the results of the comparison. Figure 2-2 compares the average speeds and average headways observed at Section A and Section B in the field. From the figure, it can be seen that while average speeds at Section B are consistently higher than the average speeds at Section A, the same is not observed for headways. Compared to Section A, five platoons have higher average headways at Section B, one platoon has the same headway at both sections and the remaining four platoons have lower average headways at Section B. This inconsistency in the manifestation of the behavior of the platoon highlights the difficulty in accurately modeling the field conditions.

Figure 2-3 compares the average speeds observed in the field with the average of the speeds predicted by the model at Section A and Section B. While the average speed values were very similar at Section A, the model was slightly underestimating the speeds for most platoons at Section B. As can be seen from Table 2-1, the model data was consistently having a higher average headway and lower average speed as compared to the field data. The important point to be noted, however, is that the standard deviation calculated for the speeds observed in the field were much higher than the standard deviation for speeds obtained from the model. However, when comparing the field headways with model headways at Section A and Section B (Figure 2-4), it is clearly seen that the model tended to overestimate the headways. This was more pronounced in Section B. Thus, it appears that while NETSIM, using default values, was reasonably accurate at predicting speeds along the link, the comparison of headways was less favorable.

**Second Level - One-Dimensional Distributions** The next level of data analysis involved combining the data from all the platoons and comparing the distributions. For each of the

distributions, the minimum value, maximum value, mean, median, mode, and 85th percentile value were calculated. It is generally expected that speeds will have a normal distribution. A preliminary study of the calculated characteristics of the distributions as suggested by Adolf May<sup>10</sup> indicated that the speed distributions are indeed normal. The speed distributions were then observed graphically as shown in Figure 1-5. While the speed distributions observed in the field appear normally distributed, the speed distributions for the model are not indicative of a normal distribution. A chi-square test was conducted to see if the speed distributions were normal in nature. The results of a chi-square test, however, indicated that the speed distributions were not normally distributed.

Once the speed distributions were found to be not normal according to the chi-square test, the one-dimensional K-S test was performed to see if the field distributions matched the model distributions. The K-S test is applicable to unbinned distributions that are functions of a single independent variable, that is, data sets where each data point can be associated with a single number" (5). The K-S test yields a statistic that is the significance level for the null hypothesis that the data sets are drawn from the same distribution. Small values of the statistic indicate that the cumulative distribution function of the first set is different from the second.

The results of the K-S test comparing the combined field distributions with the combined model distributions for speeds and headways at Section A and Section B are illustrated in Table 2-2. The K-S values indicate that the model distributions are not similar to the field distributions. One interesting result is that even though the cumulative real-world average speed agrees better than the headway average to model prediction, the distribution of model headways is more consistent with real-world behavior than the speed distribution. This is an illustration that cumulative average comparison can yield deceptively close agreement even though the distributions are quite different.

**Third Level - Two-Dimensional Distributions** As stated earlier, the two measures of platoon dispersion, speeds and headways are not necessarily independent variables. The two-dimensional K-S test is appropriate for comparing two samples with two variables in each sample. Given x and y coordinates of the first sample as  $n_1$  values in arrays  $x_1[1 \dots n_1]$  and  $y_1[1 \dots n_1]$ , and likewise for the second sample,  $n_2$  values in arrays  $x_2$  and  $y_2$ , the two-dimensional, two sample K-S test gives a K-S statistic analogous to the one-dimensional test.

The two-dimensional K-S test was performed. The simulations of each of the ten platoons with ten runs for each platoon were compared with the real platoons. The results of the comparison are summarized in Table 2-3. Table 2-3 illustrates the values for each of the K-S tests performed between the data from simulation runs and data obtained from the field. Small values indicate that the two distributions are significantly different. (Care should be taken when comparing the values in the table. The K-S test does not indicate which distribution is most similar to the field data. It only suggests which distribution is less different than the other distributions with the field data. Also, values greater than 0.2 are inherently inaccurate due to simplifications made to reduce the computational complexity (4). However, in such cases the implication that the two distributions are not significantly different is still correct.)

On examining Table 2-3, it is seen that the minimum value of the statistic is 0.0 for Platoon 9 with random seeds 2 and 8. This implies that simulation runs from random seed 2 and 8 are significantly different from the field data. On the other hand, the maximum value of 0.738 is for Platoon 6 with random seed 2. This value implies that the distribution is not significantly different from the field data. Figure 2-6 and Figure 2-7 graphically illustrate the differences and similarities in the two distributions. Figure 2-6 compares the simulation result of Platoon 9, random seed 2 with the field data. The differences in the two distributions are clearly illustrated.



Figure 2-7 on the other hand compares the simulation result of Platoon 17, random seed 5 with the field data. This simulation run was chosen because, as mentioned earlier, when the value of the K-S statistic is greater than 0.2 may not be very accurate. Also, for the purpose of graphical illustration, this run appeared closest to the field data. These two figures graphically illustrate the significance of the K-S test.

Visual observations to obtain a qualitative comparison revealed that the platoons in the field were more closely bunched together than those simulated by the model. The speeds at Section B also seemed to be higher than simulated by the model. Overall, it appears that NETSIM is simulating the platoon dispersion reasonably well for some platoons while not simulating other platoons very well. This behavior appears to be correlated to platoon size where better comparisons are obtained for smaller platoons. However, it cannot be said that the model is doing consistently better for smaller platoons. The presence of heavy vehicle in the platoon does not seem to adversely affect the simulation result. On the contrary, platoons with heavy vehicles seems to be closer to the field data than the platoons without a heavy vehicle. This observation could not be explained due to lack of more data.

### **Calibration**

Based on the results of the statistical tests, it is clear that the model utilizing the preliminary inputs was not accurately simulating the dispersion of the platoon. A thorough analysis of the inputs was performed and a few runs were made to see if the model results could be brought closer to the field data. However, no parameter was found that could modify the speed and headway distributions in the model to bring them closer to field observation.

### **Conclusions**

This paper has illustrated the steps involved in the validation and calibration of microscopic simulation models. Even for the relatively simple validation case of platoon dispersion in interrupted flow on a single link illustrated in this paper, the data requirements and interaction of the various traffic flow components is quite complex. The objective of this research was not just to accurately calibrate the NETSIM model to illustrate the platoon dispersion phenomenon, but also to illustrate the systematic approach to the validation and calibration process of the TRAF family of microscopic simulation models.

The validation tests conducted on platoon dispersion in NETSIM indicated that the comparisons between real-world and simulation results were inconclusive. For relatively small platoons, the comparisons were better than for the larger platoons. Because the car following logic, lane changing logic, and the input and embedded parameters constitute a large parameter space, attempts at calibration failed to improve overall comparisons. However, validation is an iterative process and the results of this research may evoke future discoveries of calibration procedures or modifications to the NETSIM model. Further research will include an extension of the simple case of platoon dispersion to the effect it has on operations on downstream intersections with different signal control, considering other traffic flow components within NETSIM, and increasing the complexities of the scenarios by simulating arterials and networks.

**Table 2-1 Comparison of Average Observed Headways and Speeds and Model Headways and Speeds**

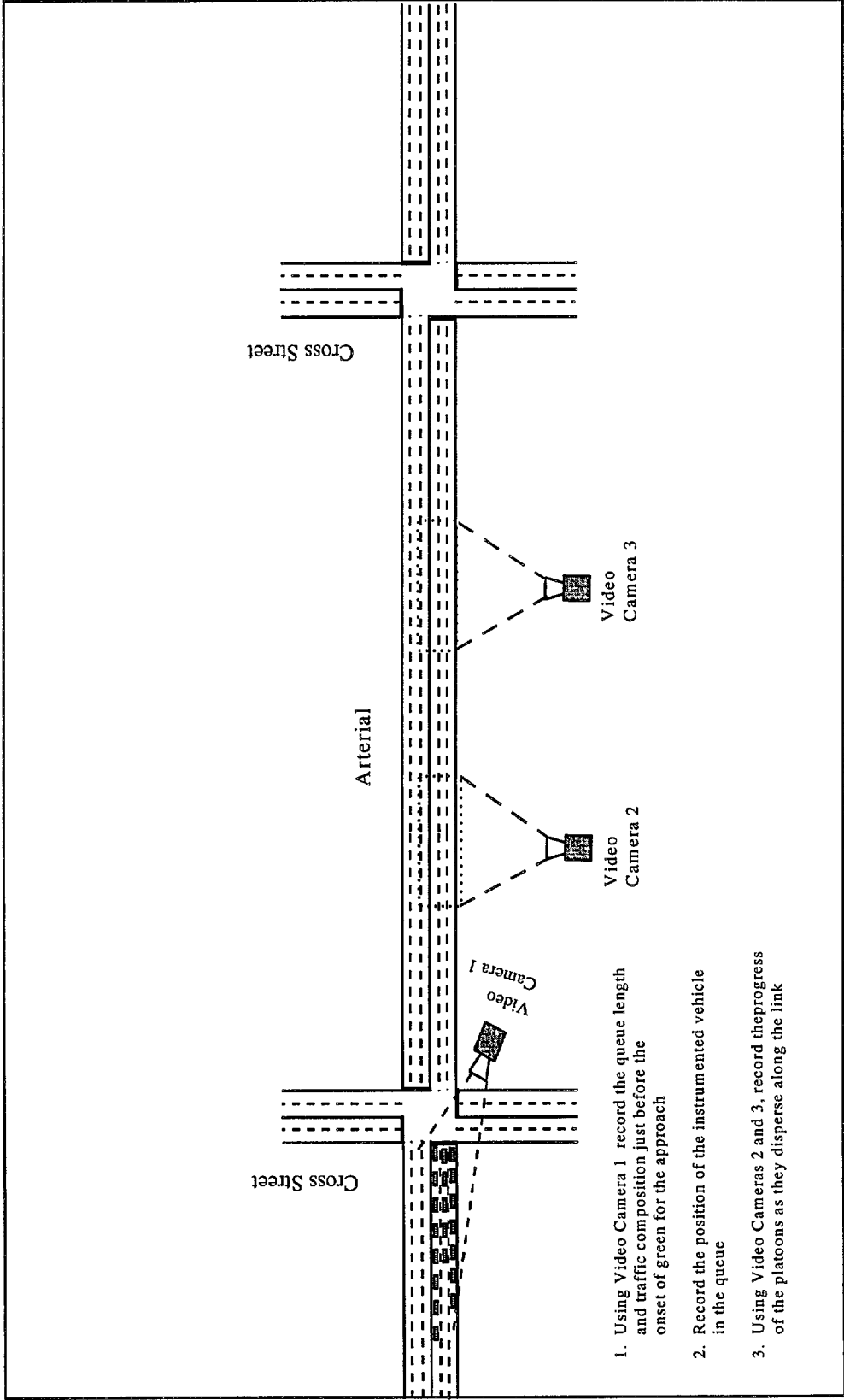
Platoon Number	Platoon Size	Section A				Section B			
		Headway Field (seconds)	Headway Model (seconds)	Speed Field (m/sec)	Speed Model (m/sec)	Headway Field (seconds)	Headway Model (seconds)	Speed Field (m/sec)	Speed Model (m/sec)
2	14	1.8	2.3	17.9	17.9	2.5	3.6	21.6	19.4
3	14	2	2.4	19.9	18.1	1.5	3.6	22.3	18.7
6	14	1.3	2.6	17.0	18.0	1.4	4.1	22.2	18.7
9	23	1.9	2	17.9	17.2	1.9	2.7	21.7	18.0
11	17	2.2	2.9	18.1	18.5	2.1	4.2	19.2	19.1
12	15	2.2	2.3	18.8	17.8	2.6	3.4	21.4	18.4
13	15	1.6	2.4	17.7	17.9	2.3	3.8	19.2	18.9
14	22	1.9	2.1	18.1	17.0	1.7	3.1	19.9	18.1
17	14	2.4	2.4	18.8	18.3	2.6	3.8	20.9	18.9
19	14	1.7	2.5	16.8	17.9	1.9	3.7	19.3	18.8
Average		1.9	2.4	18.1	17.8	2.1	3.6	20.8	18.7
St. Dev.		0.32	0.25	0.90	0.46	0.44	0.45	1.27	0.44

**Table 2-2 Results of One-Dimensional K-S Test for Comparing Field Values with Mode% Values (prob values)**

	Section A	Section B
Speeds	$3.553 \times 10^{-23}$	$1.982 \times 10^{-28}$
Headways	$6.733 \times 10^{-2}$	$1.023 \times 10^{-5}$

**Table 2-3 Results of Two-Dimensional K-S Test For Comparing Field Values with Model Values (Prob Values)**

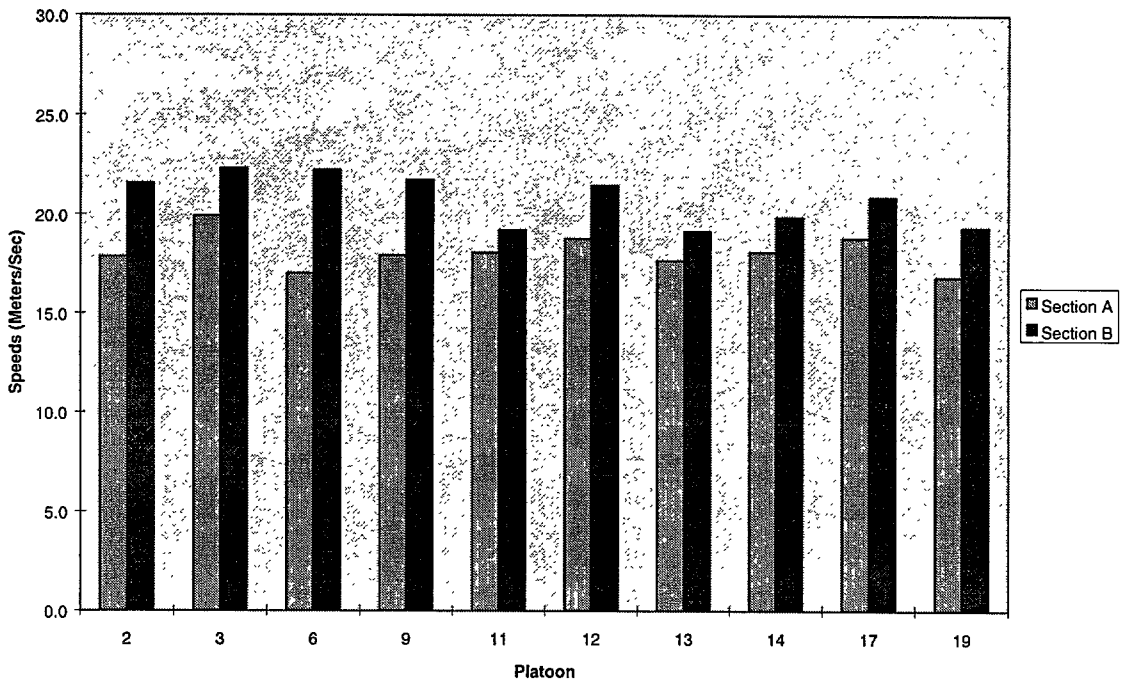
Platoon Number	Random Seed 1	Random Seed 2	Random Seed 3	Random Seed 4	Random Seed 5	Random Seed 6	Random Seed 7	Random Seed 8	Random Seed 9	Random Seed 10
Platoon 2	7.97E-02	1.28E-01	2.96E-01	1.99E-01	4.75E-02	1.52E-02	1.55E-02	2.73E-02	4.15E-03	4.22E-01
Platoon 3	2.96E-01	1.52E-02	2.75E-02	9.83E-04	1.52E-02	4.17E-03	2.07E-03	4.79E-04	8.40E-05	8.13E-03
Platoon 6	4.22E-01	7.38E-01	5.76E-01	1.29E-01	5.78E-01	1.99E-01	2.05E-03	4.21 E-03	1.97E-04	1.99E-01
Platoon 9	3.00E-06	0.00E+00	7.00E-06	3.49E-04	3.49E-04	1.11E-03	5.30E-05	0.00E+0	6.29E-04	5.34E-03
Platoon1 1	1.07E-01	5.82E-06	2.33E-01	1.08E-01	5.82E-01	2.68E-02	5.14E-03	1.47E-03	2.33E-01	7.27E-01
Platoon 12	1.62E-01	3.47E-01	6.52E-02	3.95E-02	6.52E-02	6.52E-02	2.29E-02	3.69E-03	3.47E-01	1.29E-02
Platoon 13	3.65E-03	3.47E-01	2.41 E-01	2.41 E-01	4.79E-01	7.01 E-03	1.62E-01	6.53E-02	1.04E-01	6.53E-02
Platoon1 4	3.97E-02	2.00E-06	3.83E-03	1.05E-02	3.83E-03	8.71 E-02	1.00E-06	1.00E-06	3.86E-03	6.44E-03
Platoon 17	2.97E-01	1.29E-01	2.98E-01	8.13E-03	1.99E-01	4.17E-03	8.22E-03	2.75E-02	3.50E-05	4.78E-02
Platoon 19	1.28E-01	2.96E-01	1.28E-01	2.74E-02	1.99E-01	4.75E-02	1.28E-01	4.87E-02	4.13E-03	1.51 E-l-m



1. Using Video Camera 1 record the queue length and traffic composition just before the onset of green for the approach
2. Record the position of the instrumented vehicle in the queue
3. Using Video Cameras 2 and 3, record the progress of the platoons as they disperse along the link

**Figure 2-1 Positioning of the Video Cameras at the Site**

Average Observed Speeds at Section A and Section B



Average Observed Headways at Section A and Section B

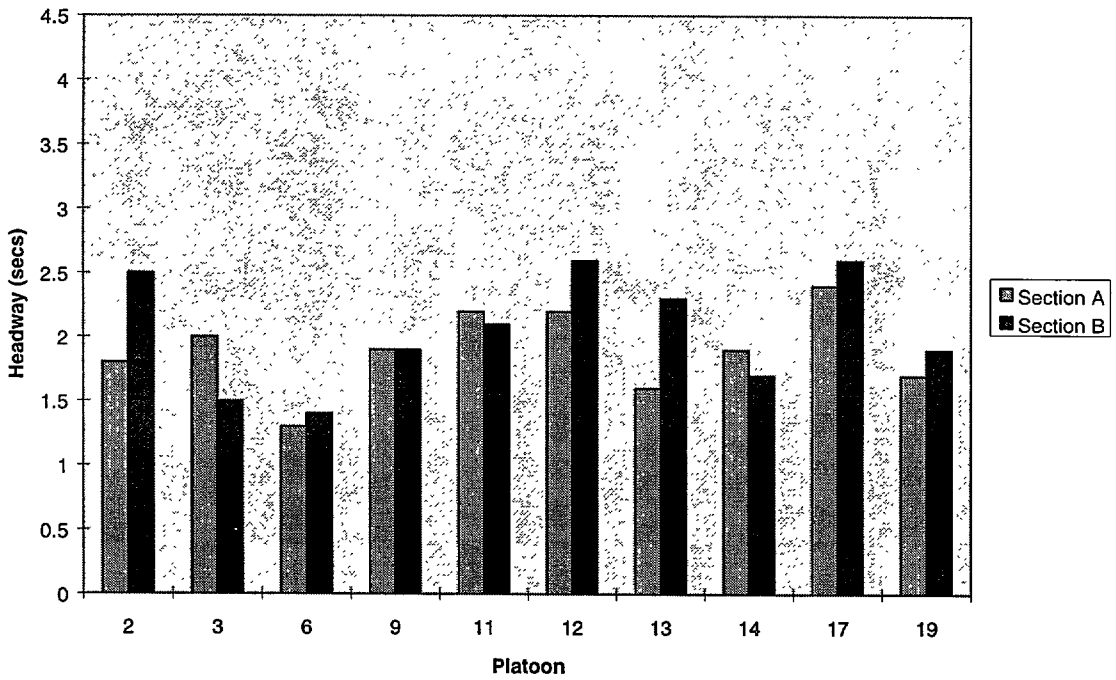
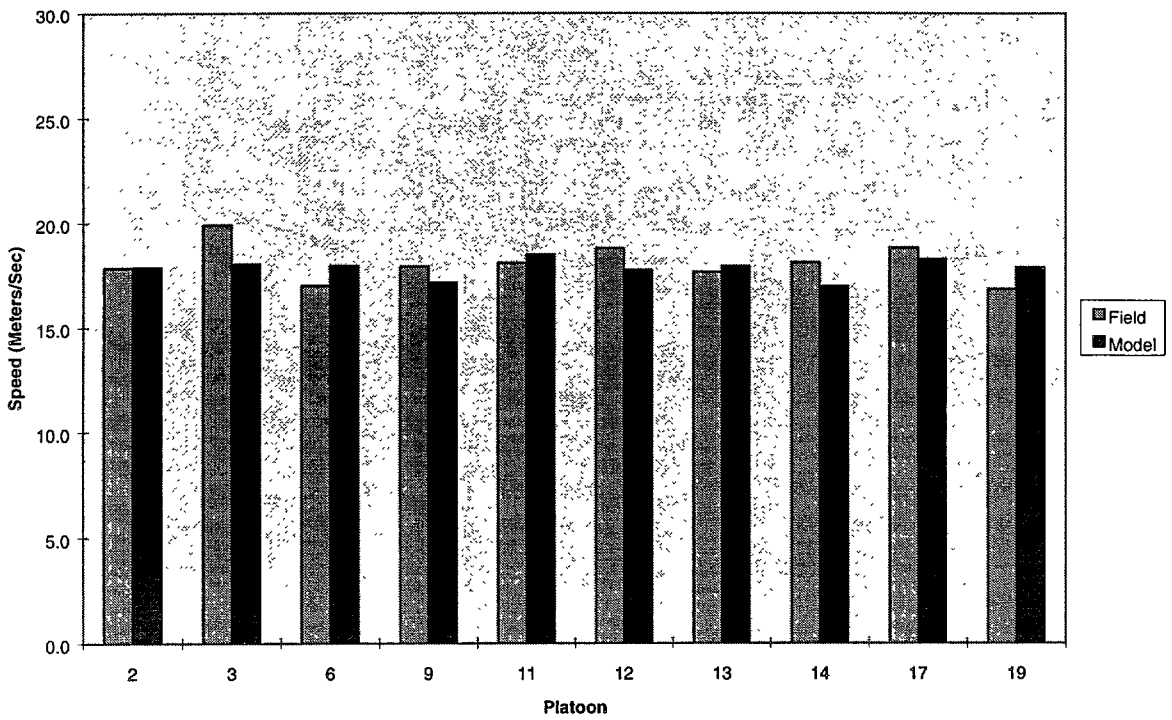
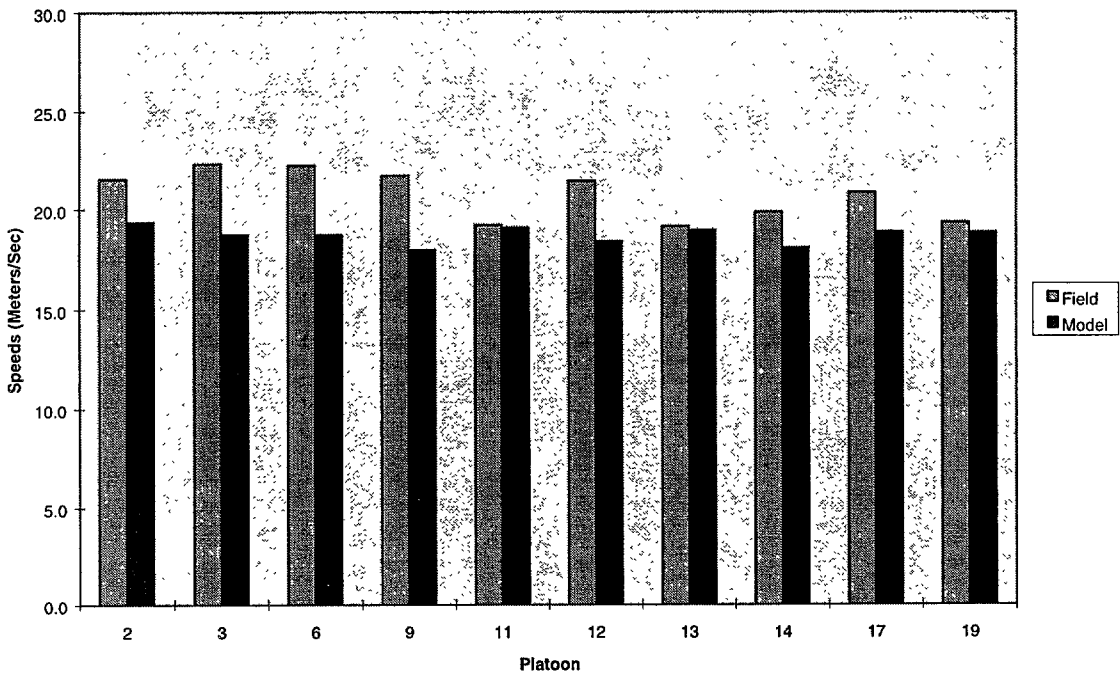


Figure 2-2 Speeds and Headways Measured in the Field at Section A and Section B

**Field vs. Model-Speed (Section A)**

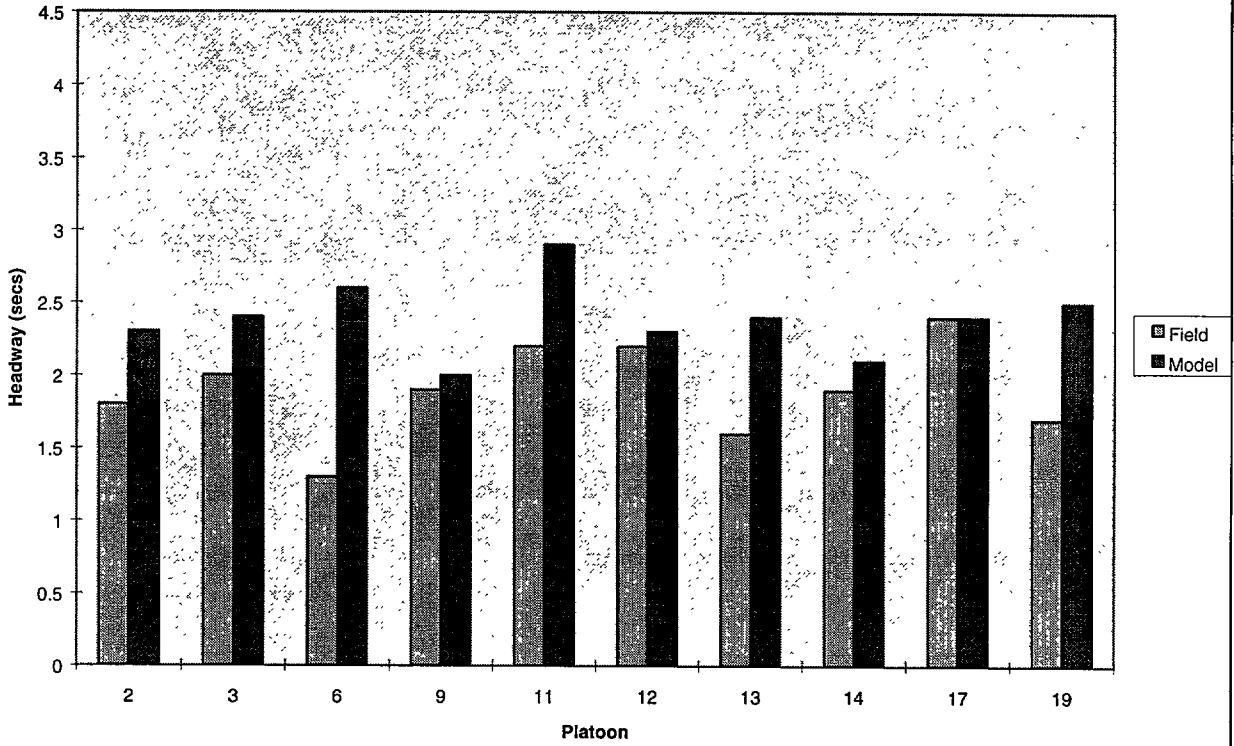


**Field vs Model-Speed (Section B)**



**Figure 2-3 Comparison of Field and Model Speeds at Section A and Section B**

Field vs. Model-Headway (Section A)



Field vs. Model-Headway (Section B)

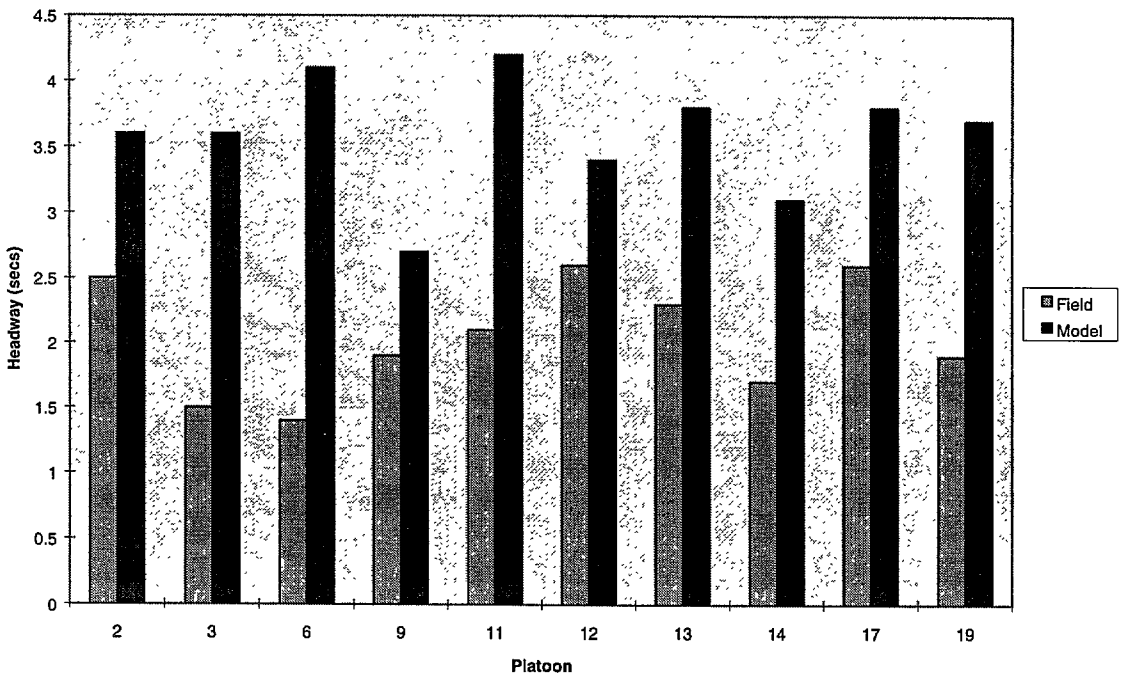
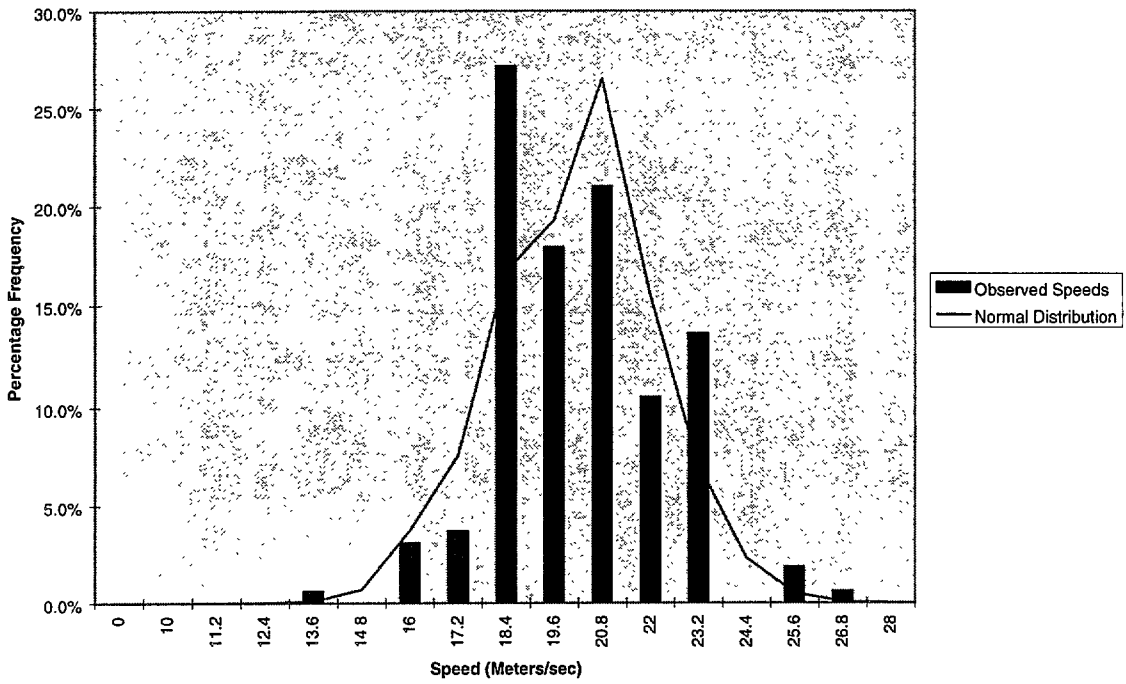
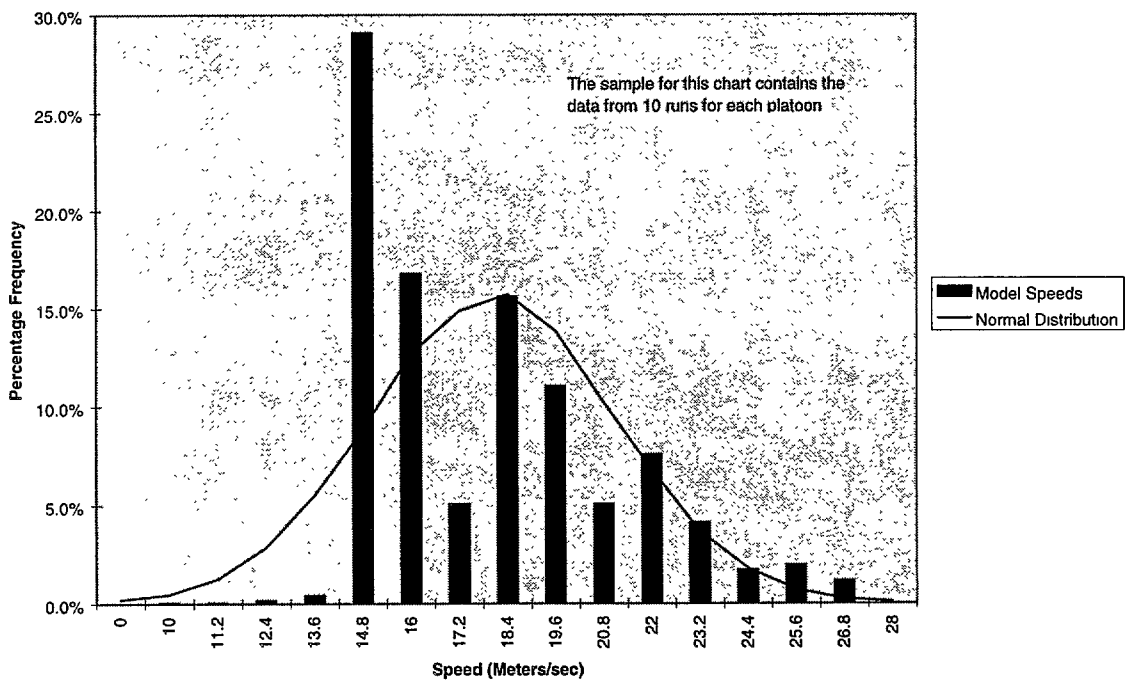


Figure 2-4 Comparison of Field and Model Headways at Section A and Section B

**Observed Speeds - Section B**



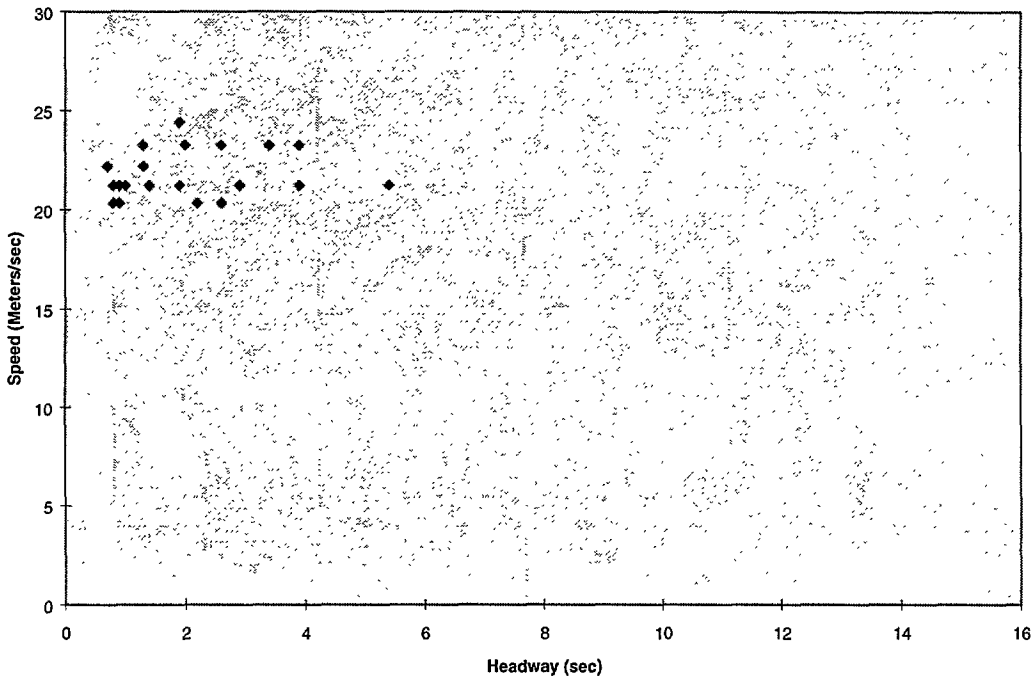
**Model Speeds - Section B**



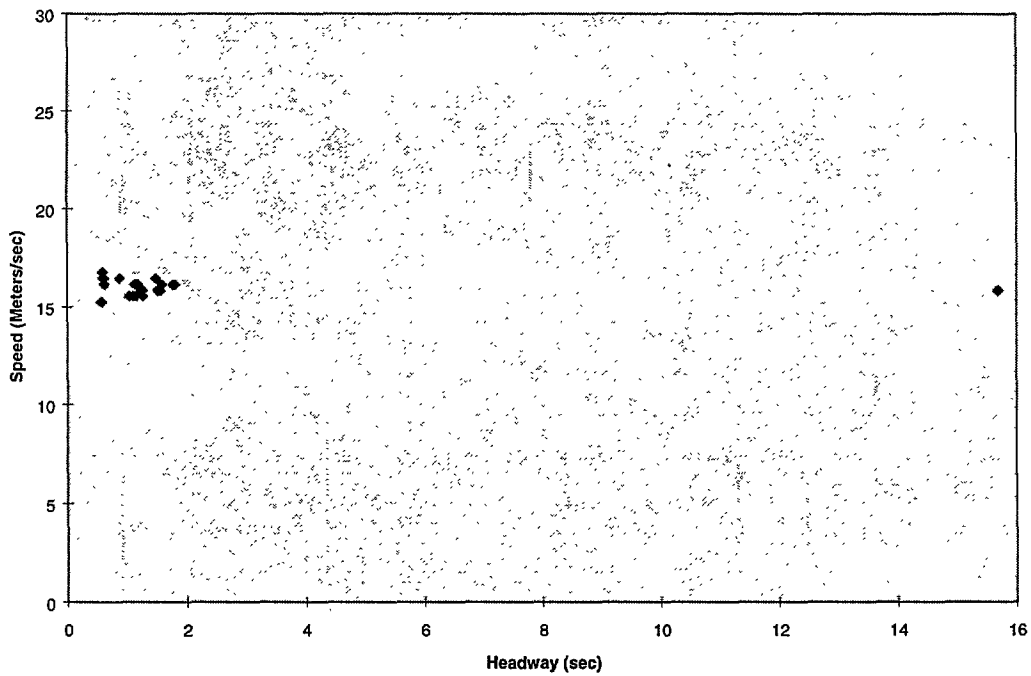
**Figure 2-5 Comparison of Field and Model Speeds with Normal Distributions at Section B**



Speed-Headway Distribution (Field Data, Platoon 9, Section B)

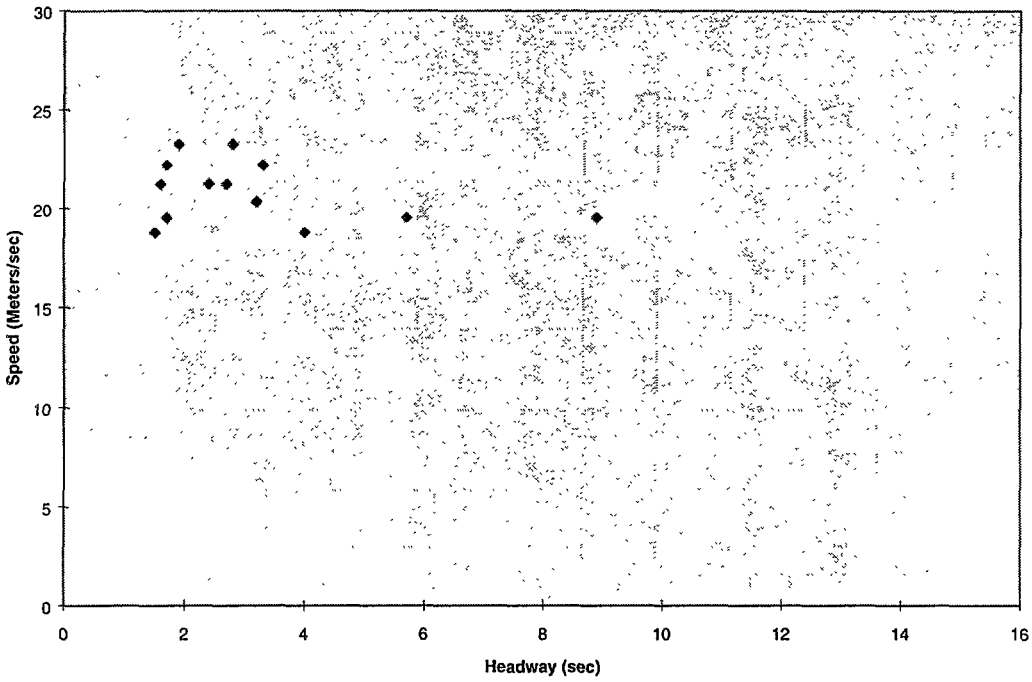


Speed-Headway Distribution (NETSIM Simulation, Platoon 9, Section B, Random Seed #2)

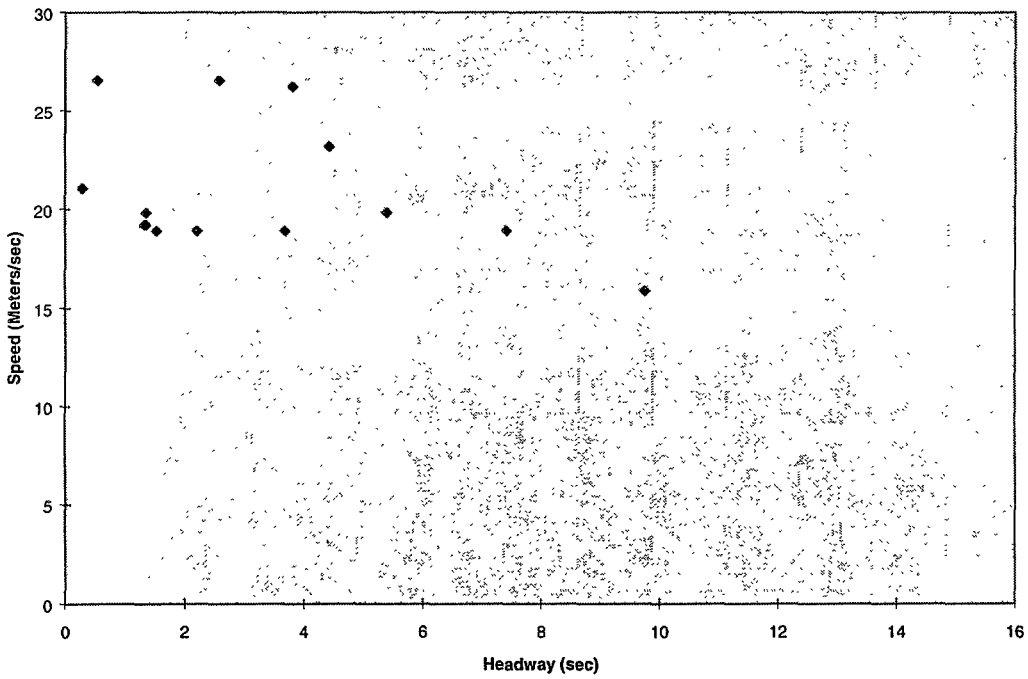


**Figure 2-6 An Example of K-S Test Result Indicating Inconsistency Between Field Data and Model Data**

Speed-Headway Distribution (Field Data, Platoon 17, Section B)



Speed-Headway Distribution (NETSIM Simulation, Platoon 17, Section B, Random Seed #5)



**Figure 2-7 An Example of K-S Test Result Indicating Consistency Between Field Data and Model Data**

## **Section 3. Illustration of FRESIM Validation**

FRESIM (FREeway SIMulation) is currently the most extensive, micro-computer based microscopic traffic simulation for modeling freeway operations. FRESIM is a member of the TRAF family of models used with the PC-based traffic simulation analysis system, TSIS (Traffic Software Integrated System). It has been integrated with NETSIM, its arterial counterpart in the combined simulation package CORSIM (CORridor SIMulation). This is a very powerful package that can be used for modeling many traffic situations including planned geometric changes, incidents, and ITS (Intelligent Transportation Systems) traffic management strategies.

In order to provide an accurate simulation of a given scenario, CORSIM must be validated so it will give a realistic representation of what will happen in the field. There are no current guidelines for validating and calibrating CORSIM for any type of scenario. There are a number of parameters and variables that can be modified and adjusted to change the way the simulation behaves, but there are no specifications for making these adjustments. The research described in this paper investigates this problem of validation and calibration. Simulated scenarios and respective real-world data are both qualitatively and quantitatively studied.

The validation and calibration plan for the TRAF models is divided into different stages. The corresponding methodology is discussed in Section 1. The stages differ with increasing complexity, with stage one looking at simple freeway weaving sections. Later stages include more complex scenarios with lane adds/drops, combined scenarios, and complex integrated networks which are examined in the final stage. This paper presents the investigation and results of stage one and builds a framework for future stages.

The goal of the research presented in this paper is to lay a foundation for traffic simulation calibration and validation. This foundation includes an in-depth look into existing data inventory, data collection needs, calibration parameters, and other problems inherent to the study of microscopic traffic simulation models. This research is the beginning of an ongoing and iterative process of validation and calibration for a wide range of scenarios cumulating in a flexible, inexpensive, microcomputer based, microscopic traffic simulation that can be used throughout the transportation industry for a wide range of applications.

### ***Data Requirements***

Investigation of FRESIM parameters is critical to the analysis and discussion of validation and calibration. The preliminary work before stage one of validation revolves around identification of the parameters with a focus on classification of the input and output sections of the simulation.

The paper *Traffic Model Validation and Data* included in this document discusses several simulation programs including the TRAF family of models. For each of the models, a data requirements matrix was developed that illustrated and categorized both the input and output variables. The matrix is broken down into descriptive data that is not calibrated, such as link geometry; basic calibration data that can be adjusted or calibrated based on primary observations, such as freeflow speed; and advanced calibration data that intimately deal with micro-models within the simulation, such as car following sensitivity factors. The data is further divided into network-based data, link-based data, and vehicle-based data.

### ***Conceptual Validation***

Conceptual validation is focused on the study of the underlying logic and equations. This kind of study is important in determining logic flaws or anomalies that may lead to complications with

analysis In the case of FRESIM, the primary simulation control resides within the car-following logic. Anomalies resulting from the logic can seriously hamper any attempts at validation. Conceptual validation is the process of ensuring that a model performs as theoretically expected for its intended purpose. A model can be considered conceptually validated when it has been tested and shown that adjustment of the calibration factors of the model give a basic expected response, and output of the model is in accordance with accepted theory. The goal of conceptual validation, is to qualitatively identify anomalies that exist within the model that may or may not affect operational validation. Anomalies may include, but are not limited to: inconsistencies with the output, vague calibration parameters, fundamental differences between model vehicle behavior and real-world vehicle behavior, and peculiarities of the logic used in the basic models. Conceptual validation is a continuing process that is done in parallel with quantitative validation of the simulation. In this study, the car following model was examined and followed by a study of the user-adjustable FRESIM parameters. Finally, qualitative analysis was performed with graphical animation output files.

### Car-Following Model

The car following logic within FRESIM determines the acceleration of each vehicle for each time step. This determination is based on the logic dictated by the Pitt car-following model and is dependent on many environmental factors A full description of the model can be found in the KLD report on INTRAS.<sup>12</sup> This is an older model and hence, was developed in the customary U.S. set of units. Rebuilding the model in the international system of units would not be prudent at this stage.

The acceleration of each vehicle is dictated by:

$$a=2 \frac{[x_1 - y - L - 10 - v(k+T) - bk(u_1 - v)^2]}{[T^2 + 2kT]} \quad (1)$$

The term  $b$  is included to allow high relative closing speed behavior to be observed empirically and has been calibrated to be:

$$b = \begin{cases} 0.1 & \text{for } \#10 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Including driver reaction time  $c$ , the position and speed are:

$$y_1 = y + vT + \frac{A(T-c)}{2} \text{ and } v_1 = v + a(T-c), \text{ where } c < T \quad (3)$$

random assignment to vehicles. When a vehicle is created in FRESIM, it must be designated a car following sensitivity factor. To accomplish this, a random number between one and ten is drawn. This number then corresponds to the car following sensitivity factor that is stored in the matching bin. The default for these factors is consecutive integers from six to fifteen. The ten parameters are assigned to ten different driver types that are uniformly generated by the vehicle generation module. The TSIS User's Guide<sup>15</sup> states:

*"The car-following model in FRESIM is based on the premise that drivers desire to follow the car in front of them at a given value of the time headway between them. The time headway, however, differs from driver to driver. The distribution of time headways is stored in the ZFOLK array, which designates the factors for driver types that determine the desired car following distance."*

The car following sensitivity factors (CFSF) translate into desired time headways for each of the ten driver types. If FRESIM were run on a long single-lane pipe segment, thus precluding any lane changing, the vehicle headway distribution should, after some time, reach equilibrium and identically reflect the CFSF distribution. In a highly interactive traffic environment where lane changing is occurring, the CFSF are no longer obviously correlated in a direct way to the distribution of headways actually produced by FRESIM. This is due to the fact that when lane changes occur, new headway relationships are produced between leaders and followers in both lanes involved. Although the CFSF directly interact with the car following logic, this lack of direct correlation to any output parameters makes the CFSF more abstract and difficult to precisely calibrate.

### **Other User Adjustable Parameters**

Other parameters that are not tied into the car following behavior also affect the results that FRESIM produces. These parameters include: vehicle acceleration factors, emergency deceleration factors, acceleration lag times, percentage of cooperative drivers, and mean start up queue delay. These parameters are even more abstract than the CFSF due to the fact that they are not directly used in the car following logic. For this reason, they are not discussed or analyzed in detail at this level (stage) of validation.

### **Qualitative Validation**

Qualitative analysis has led to some significant discoveries between real traffic flow and uncalibrated simulated traffic flow. These discoveries are not based on any form of model examination or data analysis, rather they are simply based on visual observations of traffic flow patterns and vehicle interactions using several generic test scenarios. Many of these observations, or anomalies, are inherent to the simulation code itself, and cannot be addressed by any of the input variables. One of the most prominent observations is the lane-speed variation. Figure 3-1 shows time-speed scatterplots that illustrate the speeds by lane in the real world data and in the simulation. For the real-world case, the speeds in the left lane are generally higher than in the right lane. This generally follows the real-world hypothesis that slower moving vehicles stay to the right. In the simulated case, speeds in the left and right lane are not different. Unfortunately, there is no way to correct for this phenomena with the simulation input. Analysis of Figure 3-1 also indicates that there are a higher number of lane-changing vehicles in the simulation as opposed to the real world. This is another observation that may have an effect on the validation and calibration study. Some of the other most noteworthy qualitative observations include:

- In high-volume merging sections within the simulation, some vehicles will stop in the roadway to wait for an opening in the traffic stream
- The simulated case shows all vehicles trying to enter a freeway near the same point
- Entry volumes are more uniform in the simulation than real-world data

Given:

$k$	car following parameter (driver sensitivity or desired headway, s)
$L$	length of the leading vehicle (ft)
$T$	scanning interval (sec)
$a$	acceleration of the follower in the interval $(t, t+T)$ (ft/sec <sup>2</sup> )
$b$	constant
$c$	lag (sec)
$x$	position of leader at time $t$ (ft)
$y$	position of follower at time $t$ (ft)
$u$	speed of the leader at time $t$ (ft/sec)
$v$	speed of the follower at time $t$ (ft/sec)
$x_l$	position of the leader at time $t+T$ (ft)
$y_l$	position of follower at time $t+T$ (ft)
$u_l$	speed of the leader at time $t+T$ (ft/sec)
$v_l$	speed of the follower at time $t+T$ (ft/sec)

note: 1 ft = 0.305 m

### **Calibration and Validation Factors**

This model has two factors for calibration and validation. The two factors are  $k$ , the car following parameter or driver sensitivity, and  $c$ , the acceleration/deceleration lag time. The sensitivity factor  $k$ , is proportional to the time headway that the following vehicle tries to achieve. The lag time affects the time it takes for a following vehicle to react to changes in speed or position of the leading vehicle.

### **Discussion of Related Models**

Over the years, traffic flow research has produced many car-following theories and models. It is useful to compare different car following models to show the similarities and differences between the logic, output, and calibration parameters. The most popular and widely used car-following theory used today is the general form of the GM car-following model.

As discussed by May<sup>13</sup> and Rothery<sup>14</sup>, the models developed by GM were followed up by an extensive set of field tests for calibration and validation. A total of five models were developed based on the premise that driver response is a function of stimuli and the adjustable driver sensitivity parameter.

Future direction of the calibration and validation plan will lead to a tool where different models such as the GM models can be used in the simulation. Currently, problems with the code structure are an impediment to this procedure. With proper structural modifications, however, analysis with different models will play an important role in future CORSIM validation research.

## **FRESIM Calibration Parameters**

### **The Car Following Sensitivity Factors**

There are a number of parameters that affect the behavior of vehicles in the simulation and thus, affect the output. The goal of calibration is to modify these parameters such that the simulation output better conforms to real world data. This section discusses the basic parameters available to the user for calibration. Quantitative effects of parameter modification are discussed in a later section describing operational calibration.

The primary calibration parameter is the car-following sensitivity parameter, which is illustrated as ' $k$ ' in the Pitt car following model. In FRESIM, the car following sensitivity is specified by the user as ten integer parameters. The ten integer sensitivity factors are put into ten bins for

random assignment to vehicles. When a vehicle is created in FRESIM, it must be designated a car following sensitivity factor. To accomplish this, a random number between one and ten is drawn. This number then corresponds to the car following sensitivity factor that is stored in the matching bin. The default for these factors is consecutive integers from six to fifteen. The ten parameters are assigned to ten different driver types that are uniformly generated by the vehicle generation module. The TSIS User's Guide states:

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Other parameters that are not tied into the car following behavior also affect the results that FRESIM produces. These parameters include: vehicle acceleration factors, emergency deceleration factors, acceleration lag times, percentage of cooperative drivers, and mean start up queue delay. These parameters are even more abstract than the CFSF due to the fact that they are not directly used in the car following logic. For this reason, they are not discussed or analyzed in detail at this level (stage) of validation.

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- The simulated case shows all vehicles trying to enter a freeway near the same point
- Entry volumes are more uniform in the simulation than real-world data

- In the real-world case, vehicles tend to clump together

It should be noted that these observations and/or anomalies may have significant impact on the accuracy of the simulation. For instance, a stopped vehicle in a simulation can give end results that are widely different from what actually happens in the field. It is difficult to directly address problems such as stopped vehicles through calibration, however, problems such as uniformity of headways and speeds can be indirectly addressed; thus, these are the specific areas that validation and calibration concentrate on. Future modifications to the models and/or program code will be needed to address other problems such as the lane bias.

## ***Operational Validation***

### **Real-World Data**

In order to perform a quantitative validation with a simulation, real world data must be used to build a test case. Results from simulation runs with the test case are compared with real world data to determine the agreement between the real world and the simulation. For microscopic analysis of FRESIM, detailed real-time car trajectories are ideal. This is the kind of data that was collected in the mid 1980's by JHK & Associates in the Washington D.C. and Los Angeles metropolitan areas. The data collection and reduction effort is described by Smith".

### **Calibration Test Scenario**

To perform qualitative and quantitative tests between simulated and real world data, scenarios were built in FRESIM to represent the situations where the data was collected. The section used in this paper is located at the intersection of the Baltimore Washington Parkway, NB at I-95 in Prince George's County, Maryland. The total time of the scenario is 3600 seconds.

To make an accurate simulation file from this case, volumes were obtained from the data file. Input volumes and ramp volumes were read and summarized in 5-minute intervals from the data file. These volumes and turning percentages were inserted into 12 time intervals for the FRESIM simulation input file. A graph depicting the traffic volumes along with the on-ramp and off-ramp volumes is shown with the geometric layout in Figure 3-2. The input file was then run through CORSIM to obtain an output animation file that can be run in TRAFVU. TRAFVU is the graphical interface that plays back vehicle animation files created by CORSIM.

### **Aggregate Quantitative Results**

Validation begins with examination of results on the most aggregate level and moves through stages into more detail. For initial comparison of the simulated and real world results, aggregate means and standard deviations are used. These give general indications of how the real world and the simulation compare. They do not, however, give any indication of how the variables perform over time, what patterns are created, or any major deviations.

Several significant traffic variables were studied between the two runs. These variables for both the real data and the simulated data are shown in Table 3-1. The aggregate parameters were grouped by compiling the average vehicle speeds, accelerations, and headways into a sorted database. The mean and standard deviation were then computed for each of the traffic variables. At this level, results are more illustrative than conclusive, and no comprehensive inferences can be made from these variables.

### **One-Dimensional Results**

After examination of the aggregate parameters, the next level of analysis involves looking at the variables on a one-dimensional binned histogram basis. To concentrate the analysis, only the most descriptive variables, the headway and speed were chosen for study. The speeds were measured by calculating the mean speed of each vehicle that passed through the study area.



The headways were measured at a point midway through the weaving section. The speeds were binned into 1 m/s increments, and the headways were binned into 0.1 second increments. These graphs are depicted in Figure 3-3. There were few vehicles with high headways such as 26 seconds, so the headway graph depicts the majority of vehicles that have headways of less than five seconds. The last bin in the graph indicates the number of vehicles that had headways greater than five seconds.

At this level some initial conclusions can be made about the speeds and headways. The speeds in the simulation do seem to generally follow the same distribution as the real world speeds. The headways, however, do not seem to follow the real world pattern. The real world patterns seem to concentrate around 1.2 seconds, while the simulated pattern concentrates around 1.8 seconds. The simulated case also shows a wider peak of headways than the real world.

## **Two-Dimensional Analysis**

To further determine how the parameters perform over time, a two-dimensional analysis was studied and illustrated in Figure 3-4. The first graph shows the real world mean vehicle speeds versus their respective entry time to the section which reveals patterns over time. The dips in speeds at the beginning (500 seconds), middle of the simulation (600 seconds), and the latter part of the simulation (3000-3600 seconds), may be due to the increased mainline volumes during their respective time periods.

The second graph depicts the real world headway measurements over time. Due to the lack of extremely low or extremely high volumes, the headways do not fluctuate much over time. Although this graph gives more detail than the binned histogram, it does not give the best display for analysis of the headway data.

## **Calibration Investigation**

### ***Calibration Elements***

There are several key elements needed to suitably calibrate a simulation. First, representative output variables were chosen to indicate the affinity of the real world data to the simulated results. The speed and headway were appropriately chosen to represent the traffic situation for the test case.

Secondly, the form of the output of the representative variables was chosen such that the output was most easily analyzed to determine the agreement between the simulation and real world. Through examining aggregated output, one-dimensional output, and two dimensional output, it was found that the speeds are best illustrated in a two-dimensional fashion, while the headways are best illustrated by one-dimensional (histogram) analysis.

Thirdly, calibration parameters were chosen that will most directly affect the simulation output. As discussed earlier, the car following sensitivity factors (CFSF) are most directly tied to the car following logic in FRESIM. The car following logic directly controls how vehicles interact with each other, thus affecting both the speeds and the headway.

Finally, a method to quantitatively or statistically compare the output must be chosen based on the type of output data. If the speed output is viewed as time-based individual distributions, the Kolmogorov-Smirnov test (K-S test) would be most appropriate for statistical comparison. The probability constant generated by a K-S test ranges from zero to unity and indicates the agreement between two distributions. If two distributions are exactly identical, then the probability is one. The K-S test returns a zero probability for distributions that are entirely different from one another. This probability gauge was used for comparing speed distributions between FRESIM runs. More information about the K-S test can be found in many statistics handbooks<sup>17</sup>.

The headway output, on the other hand, is a binned one-dimensional data set. In this case, a K-S test is inappropriate, therefore a chi-square test is used. The chi-square test is a technique that can be used to assess statistically the likelihood that a measured distribution has the attributes of a mathematical distribution. The chi-square test can also be used to assess statistically how closely the measured distribution is similar to another measured distribution<sup>17</sup>.

### **Random Seed Variance**

When vehicles are generated in the code, a random number string is used to induce internal traffic variation. The random numbers are generated from a starting user-selected number or random seed. This allows two simulation runs to be identical if the same random number seed is used. However, if a different seed is used, the two runs will give different results due to the fact that the same vehicles are not generated at the same time. Theoretically, the two runs should be different but statistically similar. The purpose of studying the random seed variance is to see the magnitude of the effect of the random seed on the variables in question: the headway and the speed.

To perform this study, ten runs identical except for the random seed, were run through FRESIM, and results of the headway and speeds were collected. Examination of the speed results showed widely different results between the ten runs. It can be seen in Figure 3-5 that the drop in speed at time 400-600 seconds is explicit in random seed #6, but is not apparent in random seed #4. This drop in speed in the real case may be due to a higher through movement, causing a higher density just past the weaving section. The drop in speed is apparent in three of the ten default cases. This observation reveals there are significant differences due to the random variability within the simulation.

To quantify the differences due to randomness in the simulation, a K-S test was done with each of the time-speed scatterplots. Table 2-2 shows the differences between the probability of the ten default test runs. These show agreement with the qualitative observations, with the K-S probability of #6 at 1.5E-05 and the probability of #4 at 5.0E-10. Although the probability is a non-parametric value between zero and one that cannot indicate absolute differences, it does show that #6 is closer to the real world data than #4.

The headway data collected from the ten runs does not indicate such a variability due to the random seed. A chi-square test was performed to determine the difference of the test runs to the real world data and it was found that it did not fluctuate as much as the speed runs. Table 2-2 also lists the chi-square values for each of the default headway runs. Figure 3-6 shows that although the random seed does not significantly change the headway, the simulated headway is significantly different from the measured real world headway.

### **Calibration**

Calibration is needed if the output generated from the simulation is significantly different from the real world data. In the random seed tests, it was shown that a great deal of variance between the speed profiles is solely caused by pure randomness in the simulation. It was also illustrated that some of the random seed runs looked very similar to the real world data. These findings suggest that the speed variations in the real case are included within the randomness of the simulation. Attempting to calibrate the speed variations would be futile in this example.

The headway output, however, shows less variance due to the random seed and a consistent difference between the simulation and the real world data. For this reason, calibration was undertaken to bring the headway histogram into better agreement with the real world data.

The car following sensitivity factors theoretically represent the desired driver headway distribution (x10). The highest headway probability in the real world is concentrated between 1 and 1.3 seconds, while the highest headway probability in the simulation is concentrated between 1.4 and 2 seconds. This indicates that the headway distribution needs to be lowered and narrowed to better match the real world. Due to the abstraction and lack of direct

correlation of the CFSF to the measured headways, there is no real strategy for modifying the factors to increase agreement.

Several cases were examined and the ones that came in best agreement were case C3, C4, and C5. Case C3 used the following CFSF: [5,5,5,5,5,5,5,5,5,5], and had a chi-square value of 665. Case C4 used the following CFSF: [5,5,6,6,7,7,8,8,9,9], and had a chi-square value of 297. Case C5 used the following CFSF: [5,5,5,5,5,6,7,8,9,10] and had a chi-square value of 322. These are illustrated along with the real and default case in Figure 3-7. The numbers in brackets represent the ten car following sensitivity factors

While lowering the CFSF distribution lowered the measured headways, it had a detrimental effect on the speed correlation. In general, the speed profile increased and lost any peaks and valleys as illustrated in Figure 3-8. This may be because when drivers tolerate smaller headways, their speed loses sensitivity. Unfortunately, this has revealed a cause and effect dilemma, where improving one output parameter degrades another output parameter.

The next level of analysis beyond two dimensional profiles would be three dimensional contour plots of the key variables over time and space. This kind of analysis would hopefully be further illuminating, showing spatial variations in combination with temporal variations. Advanced statistical measures such as pattern matching would be used for case comparisons, and their use will be more critical in later stages of validation.

### **Calibration Discussion**

Conclusions of this exercise illustrate difficulties with the calibration process, and problems inherent to the code of FRESIM and calibration factors. Specific highlights that have been uncovered and addressed by this effort include: the strong effect of the random seed on speed output, headway disagreement between the real world and simulation, and the dilemma with output parameter tradeoff between headway and speed. Despite the difficulties, stage one of the calibration process has met with some success. Real world speed variations have been replicated in FRESIM, and the effects of some major parameters have been made visible. Examination of the equations and parameters has led to discoveries that will steer future stages of calibration.

As mentioned in the introduction, the validation and calibration process for FRESIM is in its infancy and no steadfast guidelines have been established. There are many stages of calibration with stage one focusing on calibrating the actions of drivers in a simple weaving section. This process for stage one will be extended and expanded in later stages involving lane drops, incidents, high-volume conditions, combined scenarios, and eventually to large corridors.

### **Summary and Conclusions**

The importance of microcomputer-based simulations to traffic engineering and the development of intelligent transportation systems has been realized in this research. This paper has introduced the underlying traffic flow theory that the microscopic, microcomputer-based freeway simulation program, FRESIM, is based on. The importance of validation to microscopic simulations has also been discussed. Appropriate data sets, models, and documentation have been presented to illustrate the stage one scenario in the process of validation and calibration.

The most important conclusion that can be drawn from this research deals with the variance caused by the random seed in FRESIM. It has been shown that a great deal of variance in the simulation output is directly affected by the randomness of the simulation alone. This conclusion should be taken as a caution for any users of FRESIM. It should be understood that a single output is not necessarily representative of all possible results that could come from a given simulation input. For comprehensive simulation results, an "envelope" of several outputs

should be created using several random seeds. This will convey a more accurate idea to the user of how much variance is inherent to the simulation for the given scenario.

A general conclusion is the realization of the nature of FRESIM and the effects of various input variables on the simulation output. FRESIM is currently the most extensive, complete, microscopic, micro-computer based simulation tool available to transportation engineers and intelligent transportation system practitioners for research and test development. The results presented in this paper, combined with the extensive real-world database of vehicle trajectories, are invaluable to any researcher who works with microscopic freeway simulation models. Properly configured and calibrated, FRESIM can prove to be a very inexpensive, yet highly prolific tool for research, operational test development, ATMS, dynamic traffic assignment, and many other areas in the ITS arena. This research has set the groundwork for the continuing process of validating and calibrating CORSIM.

The data assimilated in this study is currently being combined in a database and plans are being made for future data collection specifically for calibration and validation of CORSIM. Eventually, a database management system with all the assimilated data and validation tools will be available on-line for use by researchers, developers, and practitioners to validate CORSIM for specific scenarios.

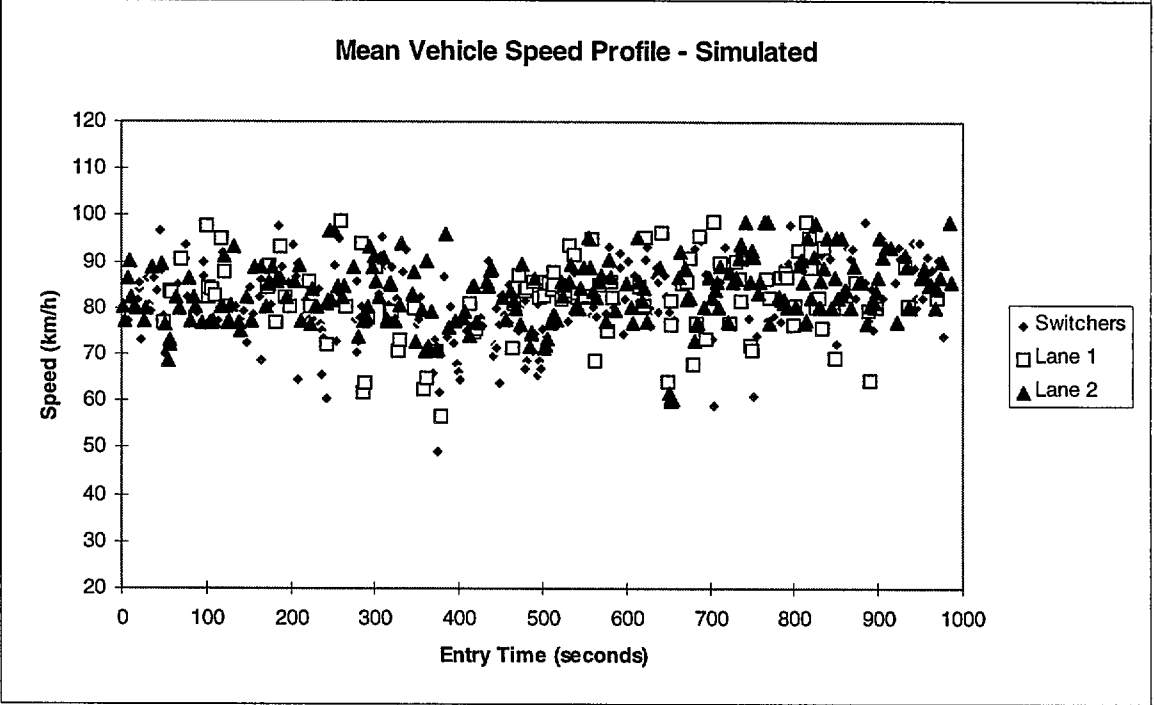
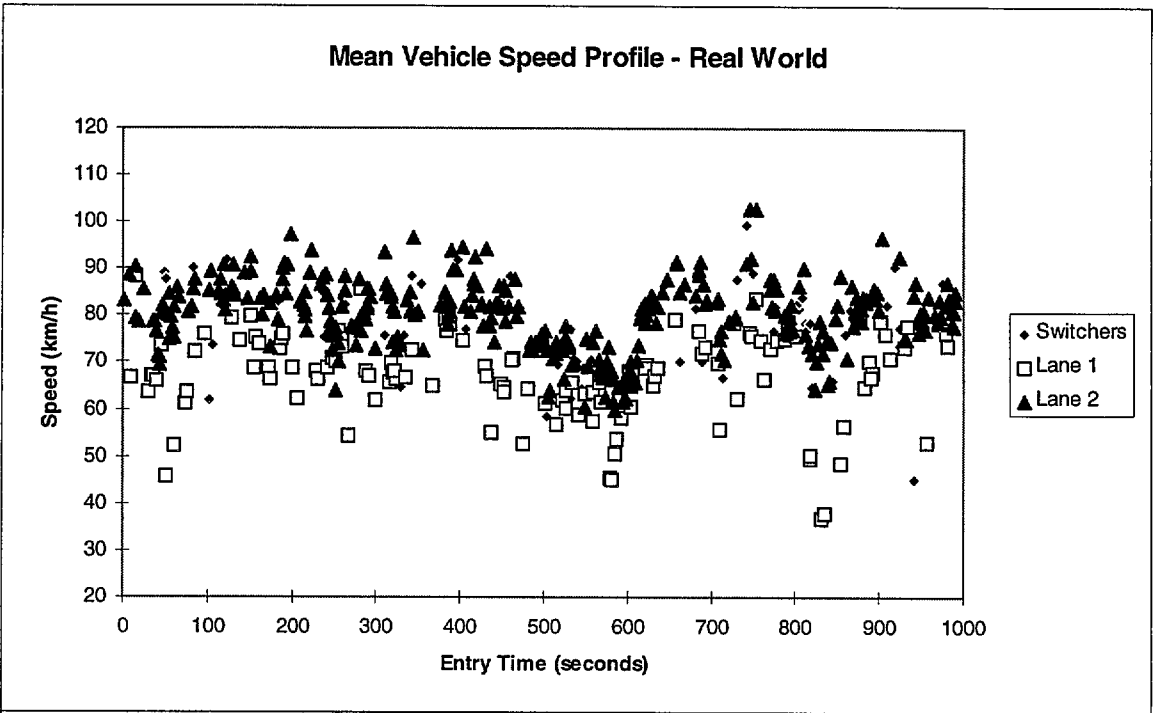
Stage one of the validation methods has been explored and established in this research. Future research by a variety of professionals for an assortment of different applications using the extensive traffic database will help to further extend the validation techniques. Validation is an interactive process and the results may prompt future modifications to the FRESIM model. Eventually, standard validation routines will be integrated with later versions of CORSIM to help automate the process, and make microcomputer simulation an easy and popular tool for a vast array of applications.

**Table 3-1 Aggregate Data Results**

<b>Aggregate Parameter</b>	<b>Real Data</b>	<b>Simulated Data</b>
Mean speed	19.94 m/sec	20.11 m/sec
Stdev of speed	3.07 m/sec	2.93 m/sec
Mean acceleration	0.82 m/sec <sup>2</sup>	0.48 m/sec <sup>2</sup>
Stdev of acceleration	0.25 m/sec <sup>2</sup>	0.22 m/sec <sup>2</sup>
Mean jerk	0.59 m/sec <sup>3</sup>	0.23 m/sec <sup>3</sup>
Stdev of jerk	0.17 m/sec <sup>3</sup>	0.11 ft/sec <sup>3</sup>
Mean headway	2.54 sec	2.52 sec
Stdev of headway	2.33 sec	1.65 sec

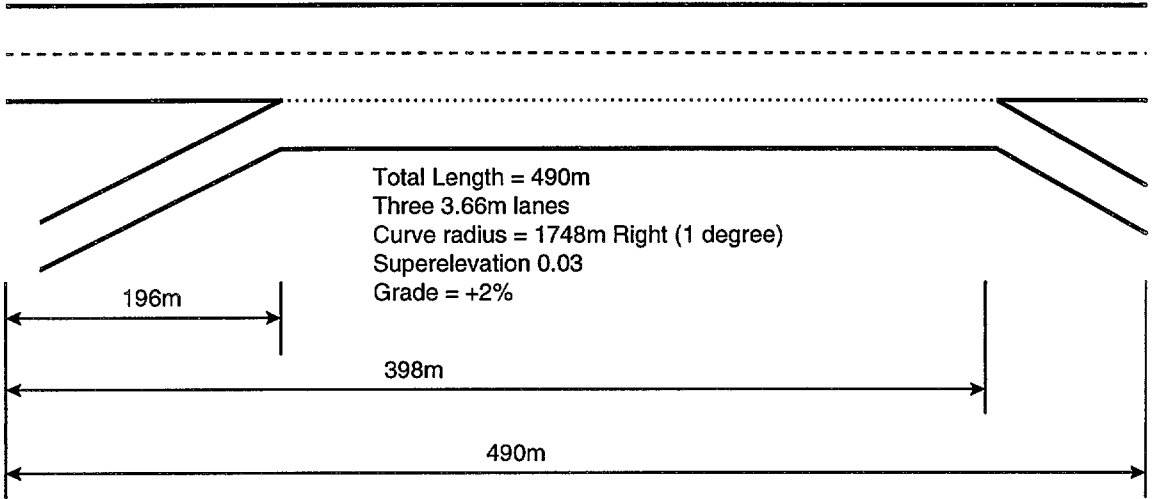
**Table 3-2 Random Seed Output Comparison**

<b>Case Number (random seed)</b>	<b>K-S Probability (speed comparison)</b>	<b>Chi-Square (headway comparison)</b>
1	5.2E-8	1803
2	2.8E-8	1642
3	8.9E-7	1713
4	5E-10	1876
5	2.7E-09	1489
6	1.5E-5	1886
7	8.5E-7	1458
8	3E-15	1670
9	2.6E-6	1579
10	1.3E-11	1790

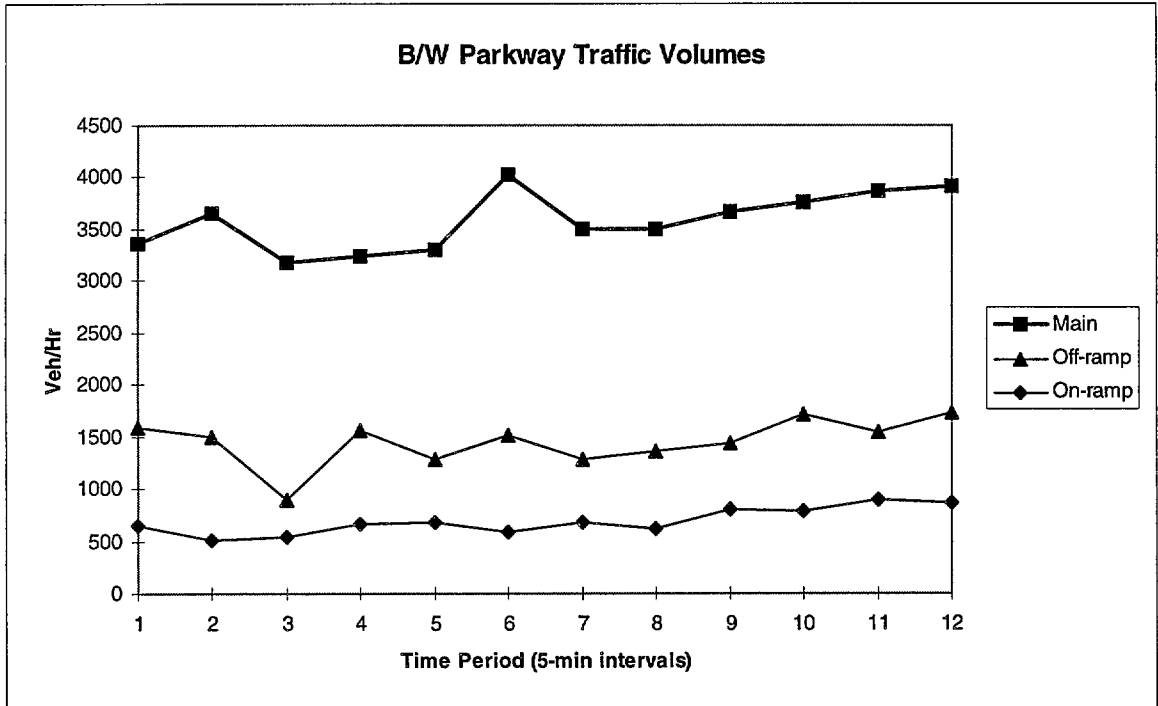


**Figure 3-1** Two Dimensional Speed Scatterplots Aggregated by Lane

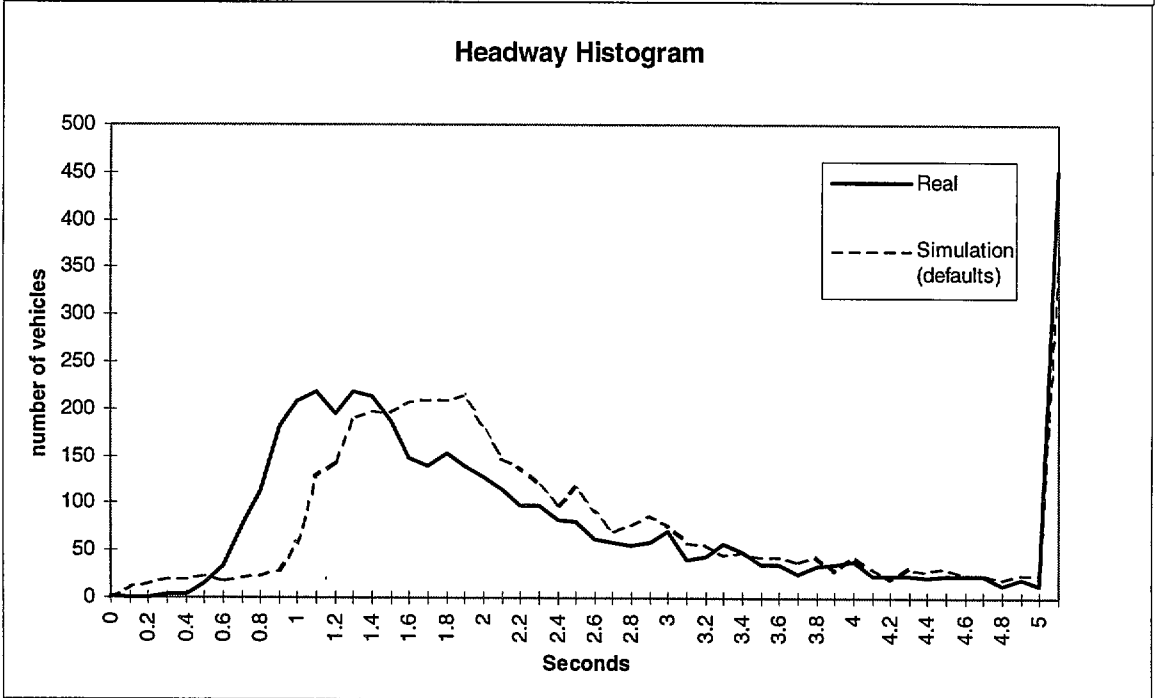
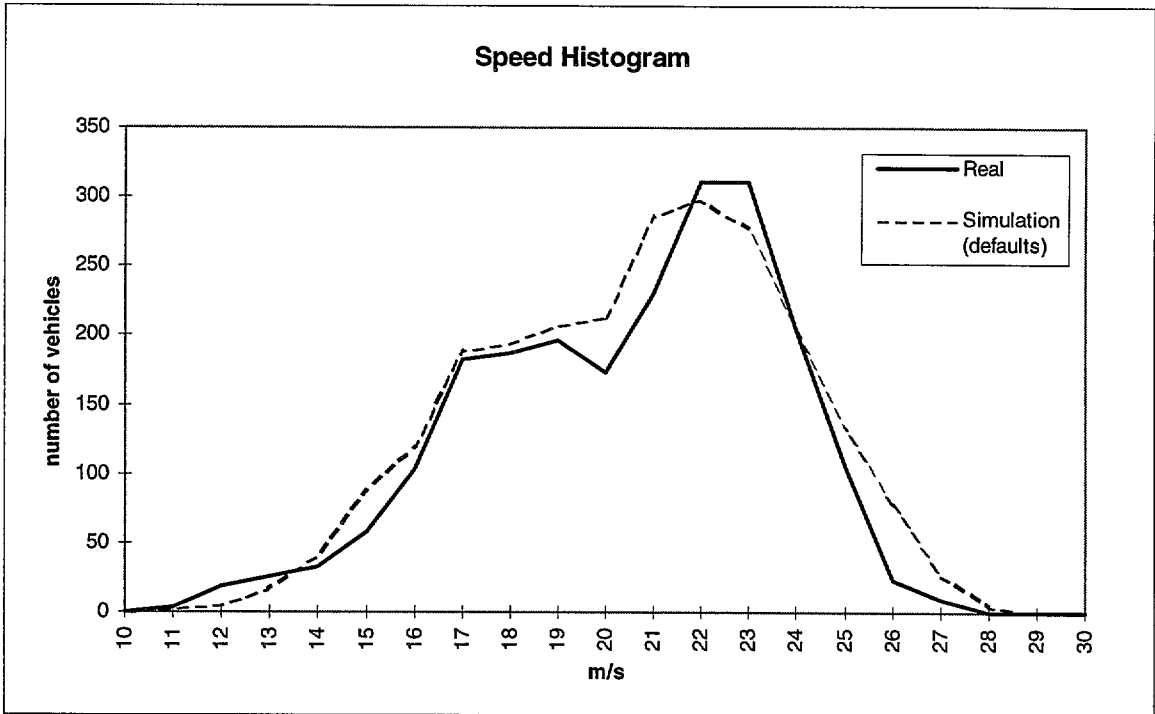
### B/W Parkway Geometrics



*note: not to scale*

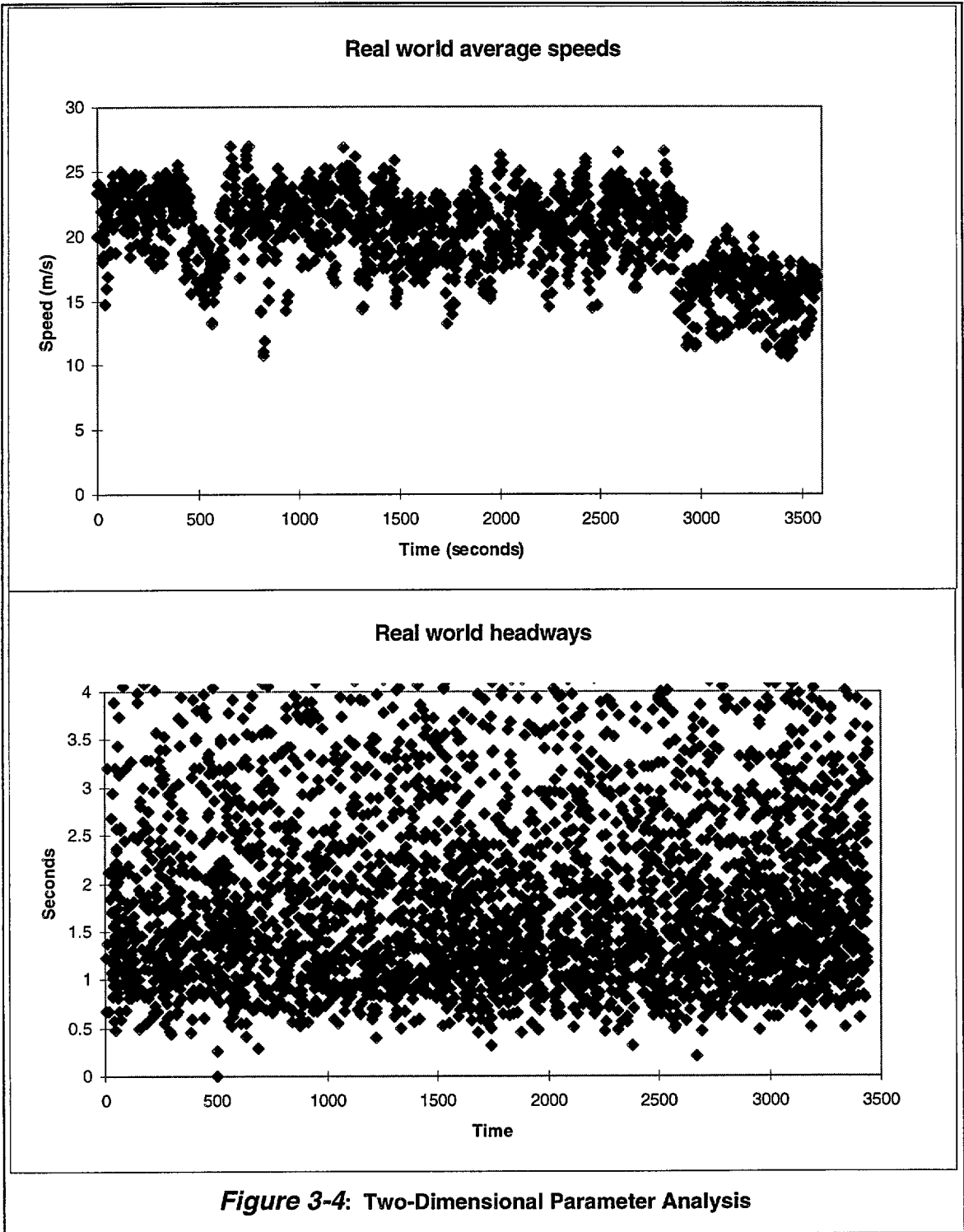


**Figure 3-2 Test Scenario Description**

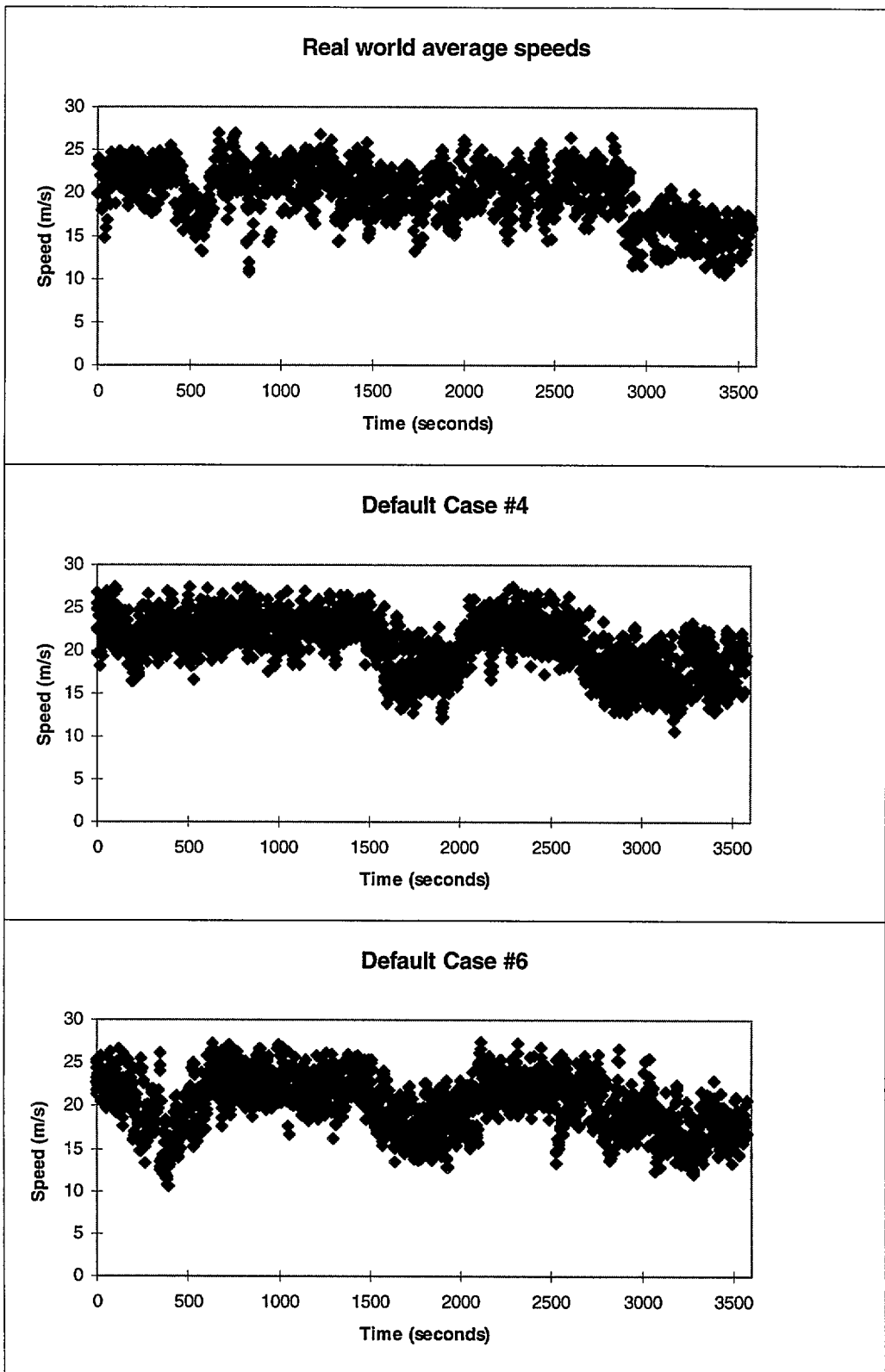


**Figure 3-3 One-Dimensional Parameter Analysis**





**Figure 3-4: Two-Dimensional Parameter Analysis**



**Figure 3-5** Random Seed Analysis with Speed Data

Random Seed vs. Real Headways

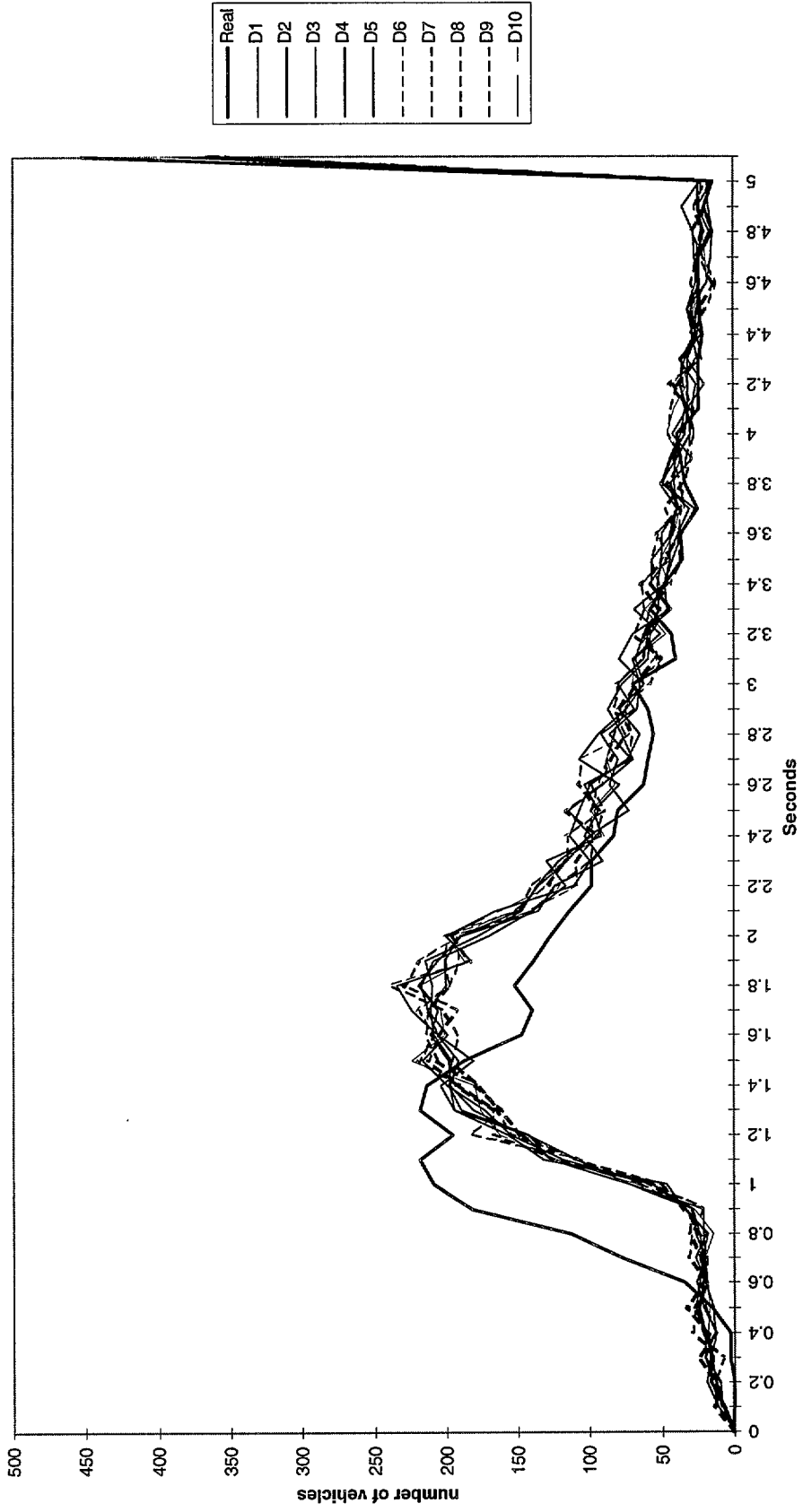


Figure 3-6 Headway Histogram: Real vs. Random Seeds

### Headway Histogram: Calibration Trials

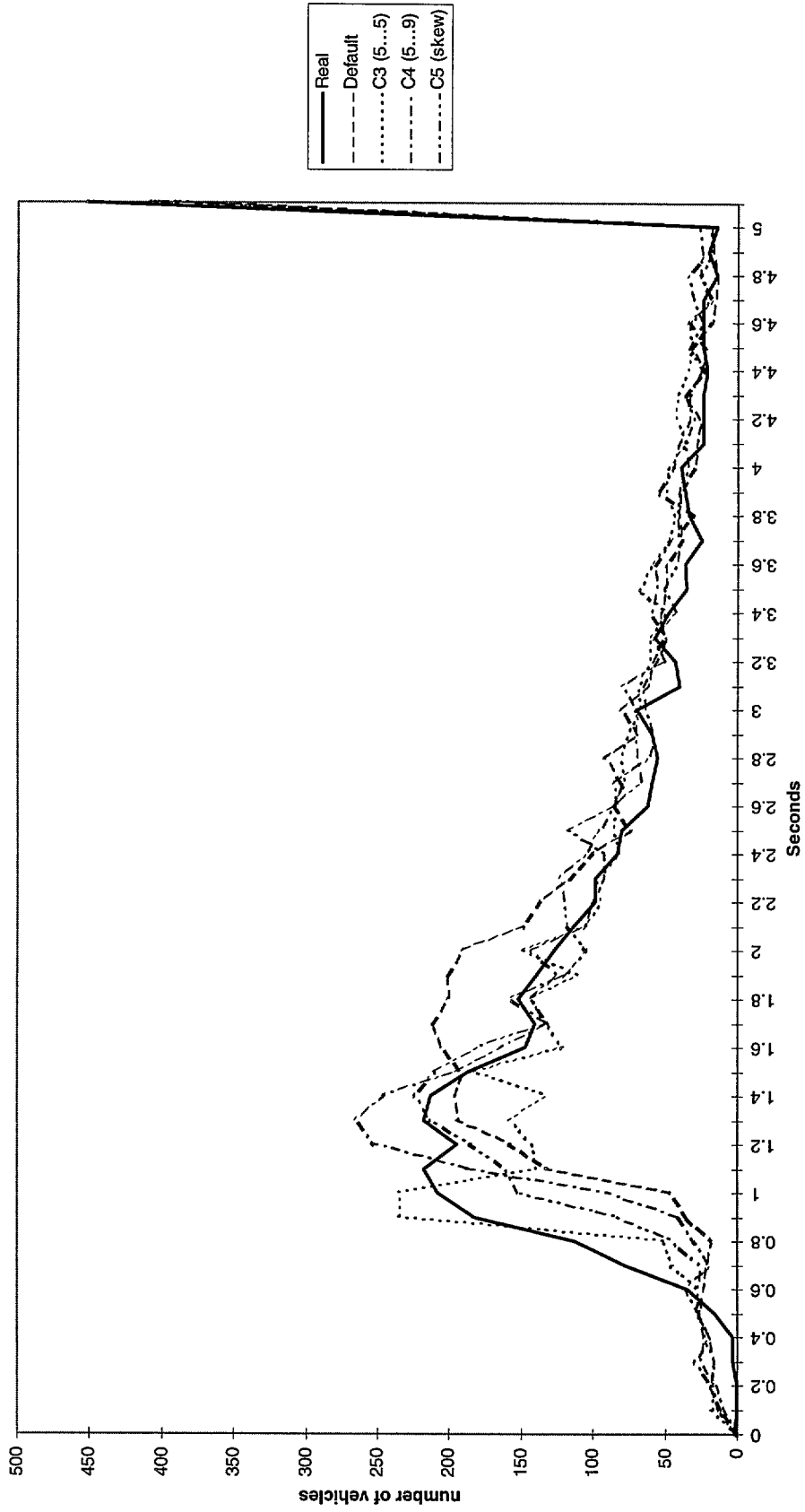
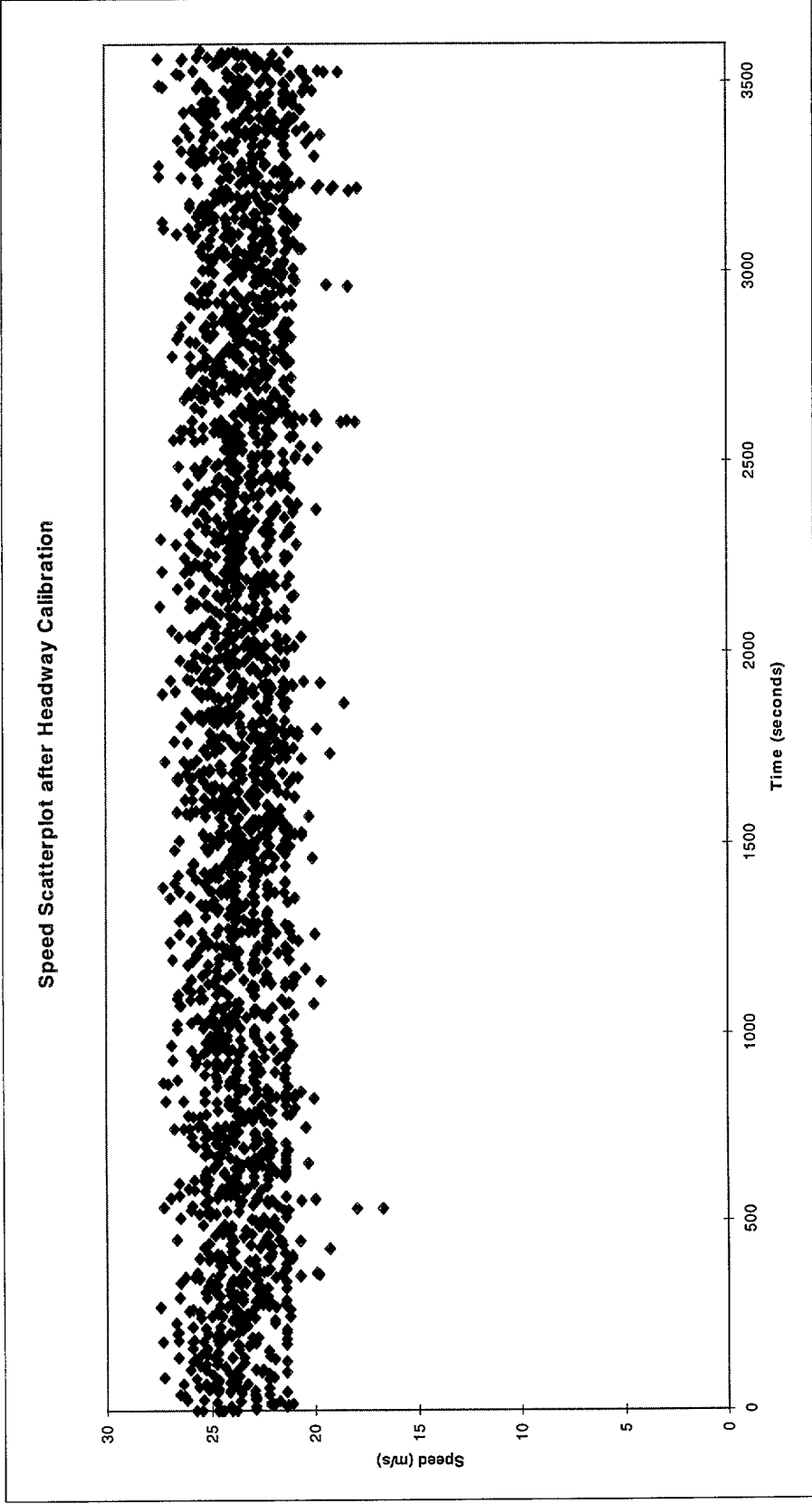


Figure 3-7 Headway Calibration Histogram

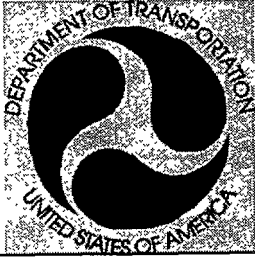


**Figure 3-8** Speed Scatterplot after Headway Calibration

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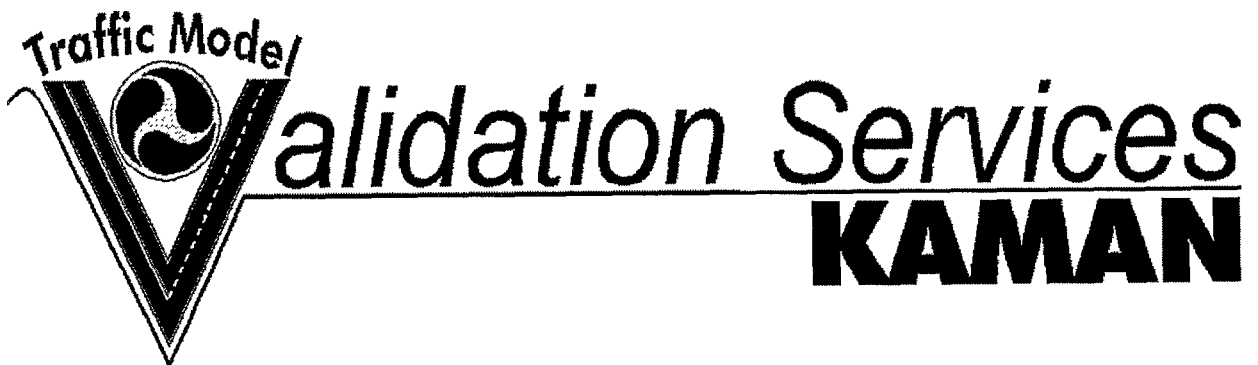


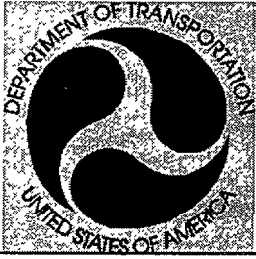
# Work Plan for Phase II

*Task H*

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Draft





# Work Plan for Phase II

*Task H*

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## Forward



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## **Section 1. Preliminary Work Plan**

This section describes the work planned for Phase 2 of the contract, which consists of six tasks. The tasks and a brief description of what Kaman personnel expect to accomplish for those tasks is presented below. The contract is scheduled for 28 months culminating in the final report to be delivered in the 28th month. The attached schedule is structured to provide greater detail for the first 12 months of the program. As the tasks progress, the specifics for the rest of the contract will be developed and forwarded to FHWA.

### ***Task I - Detailed Work Plan***

The detailed Work Plan will consist of a more refined schedule of events for the Phase 2 tasks and a list of potential sites for data collection. Prior to two months after approval to begin Phase 2, a Draft Work Plan for Phase 2 will be delivered to FHWA. The Final Work Plan will be delivered four months after the start of Phase 2.

### ***Task J - Data Collection and Reduction***

Barton-Aschman, the University of Colorado, the University of Texas, and Kaman traffic engineers will investigate potential sites in Washington D. C., Denver, Dallas/Ft. Worth, Seattle, Colorado Springs, Florida, California and other optimal locations. Presently, it is planned that about 40 sites will be proposed for freeway and urban street interrupted flow and uninterrupted flow scenarios as discussed in the Data Acquisition for Traffic Model Validation paper produced for Task D of Phase 1. These sites will be culled down to between 15 to 20 for actual data collection. The selection of these sites will also be determined by the Small Scale Traffic Simulation Testbed models that are to be calibrated, so that data collection can be tailored to the traffic parameters under study. Approval from the appropriate traffic authorities will be obtained and coordination for equipment installation arranged for each site. Prior to the start of data collection at each location, a test plan describing the equipment setup, test procedures and parameters to be investigated will be coordinated with FHWA traffic engineers. A draft working paper describing the proposed data collection and reduction process, including the site selection criteria, will be delivered to FHWA on or prior to ten months after the start of Phase 2.

The testing will begin several months after the start of Phase 2 and continue for about 18 months (depending upon the resources available to continue testing). The data from the first few test sites will be used to refine the models developed in the Small-Scale Traffic Simulation Testbed. The data from the remaining sites will be used to calibrate and validate the traffic models (from the Small-Scale Traffic Simulation Testbed or CORSIM or both) and provide suggestions for future model refinements. In addition, the collected data will be used to populate the database developed in Task K and will be available to FHWA through the Validation Services System for Traffic (VaSST) web site.

### ***Task K - Database for Traffic Models***

The database was described in the working paper produced for Task F - Database Management System, Vendor Recommendations and Preliminary Design. The Validation Services System for Traffic (VaSST) described in that paper will eventually be available on the world wide web. Initially, however, the VaSST will be used as a testbed for storing the collected traffic data, techniques, and automated methods for performing the validation and calibration of traffic models. Access to the database will be limited to selected beta users within FHWA, the

Kaman Team, and others approved by FHWA. The beta testers will exercise the system and provide feedback for improvements. This process will acquaint the users with the object-oriented nature of the selected database management system. Results of the testing and a description of the system will be provided in a working paper to be delivered on or before 15 months into Phase 2.

A large portion of the work on the VaSST system will be performed during the first eight months of the Phase 2 effort. The intent is to quickly get the VaSST system up and running, so that selected users can access the system. Once the VaSST system is operational, we anticipate a low level of effort to insert data, make modifications, and maintain the system. The VaSST system could be installed at FHWA, however, initially it will be housed at Kaman with access to it through the web site.

### ***Task L TRAF Model Validation and Calibration***

As alluded to in the Phase 1 working papers presented in this compendium, it became clear to Kaman and FHWA that validation and calibration of the TRAF family of codes in their present form was not going to be possible. As a result, FHWA and Kaman traffic engineers agreed that a small-scale traffic simulation testbed was required. This testbed will be used to explore various traffic models and to mature the validation and calibration methods. Another advantage of the testbed is that there will be an in-depth understanding of the source code and full control of the implemented traffic parameters so direct comparisons to collected traffic data can be made. The testbed will also permit various models to be compared in a controlled environment to assist in recommending enhancements to the models in the TRAF codes

The initial models to be investigated will be for car-following and lane changing. Some of the areas of investigation for car-following will be queue discharge, free-flow conditions, stopping in queue and psycho-physical implementation. Some of the elements to be considered in the lane-changing models are mandatory, discretionary, and random rules. Other parameters to be investigated in the models involve on/off ramp geometrical aspects and sequential versus event simulation structures. The data obtained from the first several traffic sites will be used to help develop the various models. In fact, the selection of the initial set of sites will be tailored to gather detailed data for the model development. Once the models are completed, the data from the remainder of the test sites will be used for their verification and calibration.

The development of the initial models will be expedited so that within the first several months of the Phase 2 effort, prototypes of the car-following and lane changing models will be available to influence the data collection task. As the models become more mature, calibration and validation of the models will be the primary focus of this task. In addition suggestions for modifications to the CORSIM code will be produced based on the Small Scale Traffic Simulation Testbed model results. Once modified CORSIM is available, validation and calibration will be performed on it. However, it is not certain when the modified CORSIM code will be produced. If it not available within this contract schedule, the Small Scale Traffic Simulation Testbed models will be used.

On or before 19 months into Phase 2, a working paper describing the models, the validation and calibration of the models from the Small Scale Traffic Simulation Testbed (and enhanced CORSIM, if available), and recommendations for other model modifications will be delivered to FHWA. All the models and test data will be accessible through the VaSST web site. A more detailed outline of the model development will be provided in the Draft Phase 2 Work Plan to be delivered two months into the Phase 2 effort

### ***Task M - Draft Final Report and Software***

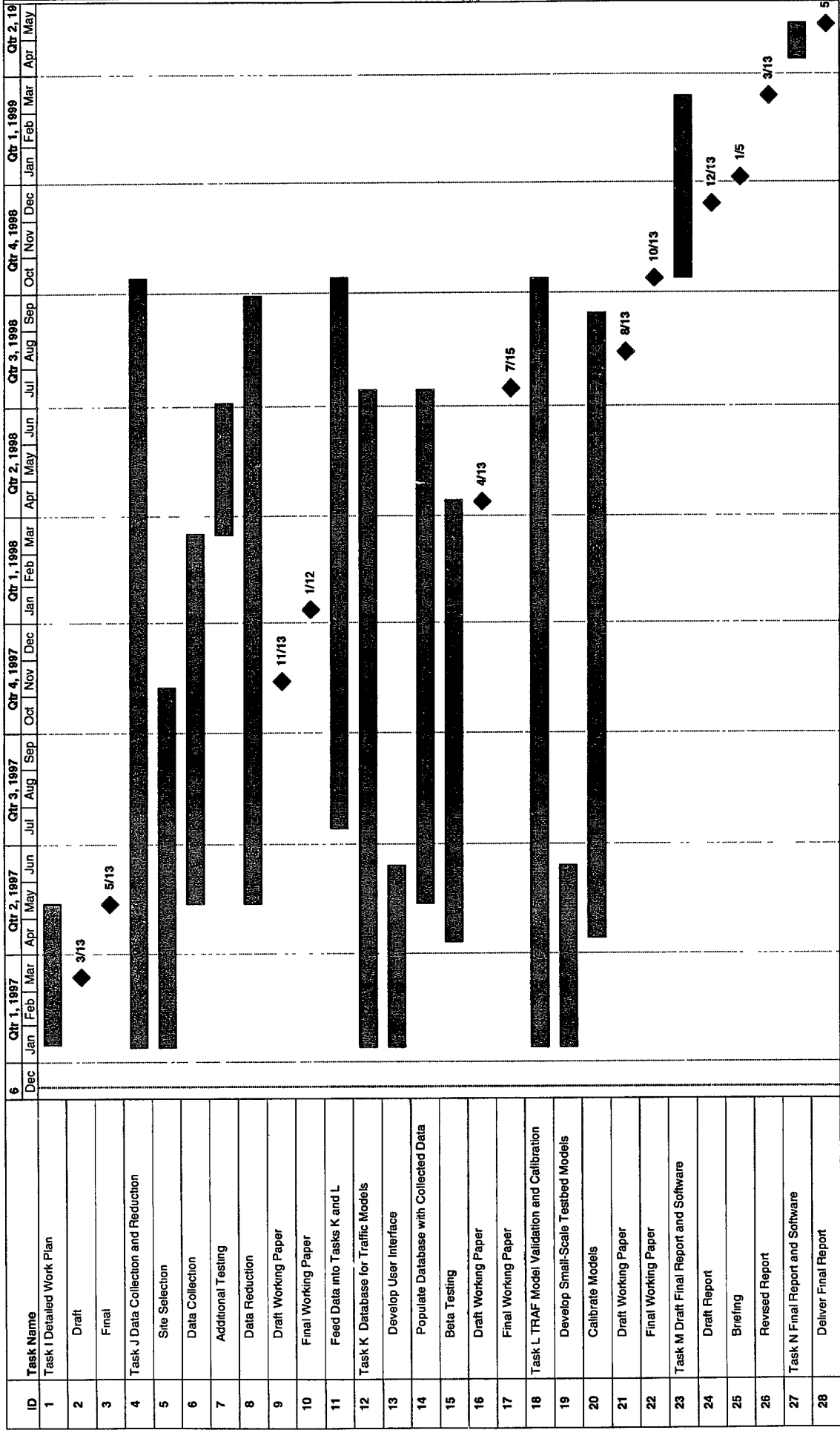
A draft final report summarizing all the tasks in Phase 1 and Phase 2 (Tasks A through L) will be delivered to FHWA on or before 23 months. The report will consist of four volumes:

- Volume 1 will describe the literature review, current practice, and data requirements.
- Volume 2 will describe the field studies, existing data sources and the DBMS,
- Volume 3 will describe the procedures for validation and calibration of the traffic models. This volume will also contain the results of the validation and verification of the Small Scale Traffic Simulation Testbed and TRAF family of models.
- Volume 4 will be a report summarizing the work performed and the results of the entire project.

A briefing will be held between the Kaman Team and FHWA personnel to discuss the draft report. A listing of all the software developed for this project will also be delivered to FHWA. Any software not available on the VaSST web site can be delivered to FHWA upon request.

### ***Task N - Final Report and Software***

On or before 28 months into the Phase 2 effort the final report will be delivered to FHWA. It will incorporate the changes suggested by FHWA to the Draft Final Report delivered for Task M.



Project: Work Plan MPPP  
Date: Wed 12/1/96

Task Progress

Task Milestone Summary

Rolled Up Task Rolled Up Milestone

Rolled Up Progress