
Simulation and Analysis of a Proposed Replacement for the McCook Port of Entry Inspection Station

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16. Abstract The Westa (<u>Weigh Station</u>) model is a detailed simulation of truck, car, and bus traffic around inspection stations. This study used Westa to model current operations at the McCook Port of Entry inspection station on Interstate I-29 in South Dakota and a proposed replacement for the station. The project was funded by the Federal Highways Administration (FHWA) Joint Program Office (JPO) for Intelligent Transportation Systems (ITS), with support from the FHWA Office of Motor Carriers (OMC) Size and Weight team. The study was performed for the South Dakota Department of Transportation (SDDOT) and the South Dakota Highway Patrol (SDHP) as a pilot test of the accuracy and applicability of the Westa model. The measures of effectiveness for the base case scenario confirm congestion at the McCook weigh station. The high arrival rate for trucks relative to the average rate for weighing a truck causes the queue on the entrance ramp to fill up, causing the station operator to close the scale and wave traffic by without weighing. Overweight trucks and trucks with safety or credential problems may be missed when that happens. The weigh-in-motion (WIM) scale in the proposed replacement station is very effective in reducing the number of trucks that must be weighed at the static scale. If only trucks measured over 70,000 pounds gross weight are directed to the static scales, the reduction in the number of trucks that have to wait in the queue leads to significant reductions in the average queue length, the time spent in line by trucks, and the frequency of queue overflow. The proposed operating policy of weighing only a portion of the trucks weighing over the threshold leads to even greater reduction in queue lengths and station transit time, and completely eliminates station closings. The scenarios were repeated with the traffic load increased by 20% and by 30%, in accord with a forecast of growth in the number of trucks from the trucking industry. As expected, the results showed increasing congestion for each scenario as the traffic levels increased. However, the proposed replacement station with the WIM scale was able to handle the increased traffic loads with few problems, both for the scenario where 20 percent of the trucks over the WIM threshold were weighed and the scenario where all trucks over the WIM threshold were weighed.			
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Executive Summary

This paper documents a study of a proposed replacement for the McCook Port of Entry inspection station near the point where traffic enters South Dakota on northbound Interstate I-29. Current operating policy and traffic levels result in frequent occasions where the queue of trucks threatens to back up onto the highway, and the scales must be closed to avoid overflow. The South Dakota Department of Transportation (SDDOT) is considering building a replacement station nearby, using a low-speed Weigh-in-Motion scale within the station to pre-screen the trucks. Trucks weighing less than a specified threshold value may bypass the static scale on a special bypass lane.

The study used the Westa (Weight Station) simulation model to represent the current and alternate scenarios. Westa is a detailed simulation of truck, car, and other traffic around inspection stations. Model development and the current analysis were funded by the Federal Highways Administration (FHWA) Joint Program Office (JPO) for Intelligent Transportation Systems (ITS), with support from the FHWA Office of Motor Carriers (OMC) Size and Weight team. The study was performed for SDDOT and the South Dakota Highway Patrol (SDHP) as a pilot test of the accuracy and applicability of the Westa model.

Data defining the base (current) scenario were collected at the McCook station by SDDOT and SDHP and were provided to Mitretek. Mitretek designed alternate scenarios based on descriptions from SDDOT. Mitretek ran multiple iterations of the base and alternate scenarios, using varying levels of traffic demand.

The measures of effectiveness for the base case scenario confirm congestion at the McCook weigh station. The high arrival rate for trucks relative to the average rate for weighing a truck causes the queue on the entrance ramp to fill up occasionally, causing the station operator to close the scale and wave traffic by without weighing. Overweight trucks and trucks with safety or credential problems may be missed when that happens.

The WIM scale in the proposed replacement station is very effective in reducing the number of trucks that must be weighed at the static scale. Given the distribution of weights by vehicle class supplied by SDDOT, the majority of trucks would be measured as weighing under the 70,000 pound threshold, even accounting for some error in the WIM scale measurement. If all trucks measured over the threshold are directed to the static scales, the reduction in the number of trucks that have to wait in the queue leads to significant reductions in the average queue length, the time spent in line by trucks, and the frequency of queue overflow. The proposed operating policy of weighing only a portion of the trucks weighing over the threshold leads to even greater reduction in queue lengths and station transit time, and completely eliminates station closings.

Mitretek ran the scenarios again with the traffic load increased by 20% and by 30%, in accord with a forecast of growth in the number of trucks from the trucking industry. As expected, the results showed increasing congestion for each scenario as the traffic levels increased. However, the proposed replacement station with the WIM scale was able to handle the increased traffic loads with few problems, both for the scenario where 20 percent of the trucks over the WIM threshold were weighed and the scenario where all trucks over the WIM threshold were weighed.

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Introduction

1.1 General Description of the Problem

There are over 600 commercial vehicle inspection stations (weigh stations and ports of entry) in the United States. Nearly 160 million trucks are weighed and about 1 million vehicle/ driver safety inspections are conducted each year at these sites¹.

Three inspection functions are performed at these inspection stations: vehicle weighing to determine whether a truck is over the legal weight limit, vehicle safety inspection, and driver credential inspection. The latter two inspections are performed for a small selected subset of trucks while those trucks are parked and not obstructing other truck traffic, but the first function (weighing) can cause large queues to form.

When the queue of trucks waiting to be weighed threatens to back up onto the mainline, the weigh station scales must be closed temporarily to further truck entry. When this happens, overweight and unsafe trucks may avoid inspection and enforcement. At some busy weigh stations, such as the McCook Port of Entry on Interstate I-29, this condition occurs regularly. Other weigh stations can handle current traffic loads but expect growth in truck traffic to overwhelm the current facilities. An additional problem caused by long queues is the lost time spent waiting in line by the majority of trucks that are of legal weight.

1.2 Westa Program

The Federal Highways Administration (FHWA) Joint Program Office (JPO) for Intelligent Transportation Systems (ITS) funded the development of the Westa simulation program by Mitretek Systems. Program development has also been supported by the FHWA Office of Motor Carriers (OMC) Size and Weight team. The name Westa is a contraction of “weigh station,” and the purpose of the program is to estimate the benefit of technological approaches to solving congestion problems at weigh stations and similar facilities.

Westa is a detailed simulation of truck, car, and other traffic around inspection stations. It is written in the C++ computer language and runs on most IBM-compatible personal computers. It does not depend on any other commercial software. A description of the approach and algorithms used in Westa is presented in section 2 of this paper. A more complete system description and documentation of input values is presented in the Westa Systems Description and User’s Guide².

Following initial program development, the JPO and OMC desired to test the program in some real situations, to evaluate whether the model is capable of representing actual weigh station configurations and alternatives with sufficient accuracy and credibility to be of use to weigh station operators and planners. During January 1998, the JPO sent a letter to all state departments of transportation, offering to fund a Westa study of a weigh station. The following month, JPO, OMC, and Mitretek selected three states for pilot projects, based on responses from the eleven states that responded. The three states chosen were Indiana, South Dakota, and Arkansas. The criteria for selection were (a) immediacy of the problem at a weigh station, (b) availability of data for modeling the station, and (c) likelihood of the state being able to implement the required changes within the next few years. The third requirement opens the possibility for follow-up analysis to assess the accuracy of Westa’s predictions.

During the following year, Mitretek visited the sites, collected data from various sources, built and validated base case scenario models, built alternative scenarios, and analyzed the results. This report documents the study of the McCook Port of Entry weigh station performed for the state of South Dakota. Figure 1-1 shows the location on this station on Interstate I-29 near the southeastern border of the state.

South Dakota



Figure 1-1. Location of McCook Port of Entry

1.3 Study of the McCook Port of Entry Weigh Station

This paper documents a study of the current condition at the McCook Port of Entry weigh station and a replacement station proposed by SDDOT. The replacement station would use a Weigh-in-Motion (WIM) scale within the station to pre-screen the trucks³. A low-speed WIM scale within the station is preferred by many weigh station operators to a high-speed WIM scale on the highway mainline because it is more accurate and because it gives them a chance to look quickly at each truck.

SDDOT and SDHP proposed using the WIM scale to check for axle weight violations as well as gross weight violations. Those trucks violating axle weight limitations and ten percent of the trucks exceeding gross weight limits but not axle weight limits would be sent to the static scale. The latter ten percent would be randomly chosen for permit checks. The remaining ninety percent of trucks

over the gross weight threshold, and all trucks measured under the gross weight threshold, would be directed to proceed on a bypass lane directly back to the highway.

WIM scales are not considered as accurate as static scales, with standard deviations ranging from 3% to 8% of actual truck weight⁴. Therefore the threshold must be set lower than the legal limit to increase the probability that an overweight truck will be measured as being overweight. Necessarily, this means that some underweight trucks will also be directed to the static scales. Setting the threshold at any level greater than the weight of a half-full truck substantially reduces the number of trucks that must be weighed on the static scale.

Figures were not available defining the proportion of South Dakota trucks over gross weight that are also over axle weight limitations. Mitretek first assumed a lower bound figure of ten percent, and modeled the proposed new station with 20% of the trucks over the WIM threshold directed to the static scales (ten percent axle weight violations and ten percent random checks). Mitretek then modeled as a second alternate scenario the upper bound with all trucks over the WIM threshold directed to the static scales.

1.4 Increased Traffic

SDDOT also asked Mitretek to model the same scenarios with increased truck traffic, reflecting expected growth forecasted by Team 2000⁵. Mitretek ran each of the three scenarios with the current traffic load, and then with 120% of the current traffic load, and with 130% of the current traffic load.

Section 2

Description of the Westa Model

2.1 Overview of Westa

Westa (Weigh Station model) is a PC-based tool designed for modeling truck weigh stations on highways or any vehicle inspection or toll-collection station. It is a micro-level simulation program for evaluating operational performance under various traffic scenarios, inspection capabilities, and station configurations. It quantifies the effectiveness of advanced capabilities for (1) increasing enforcement of weight, safety, and customs regulations; (2) increasing vehicle throughput; and (3) reducing station queue lengths, delay to vehicles, and the time the entire station or components of the station are closed because of queue overflow. While Westa was originally developed to model trucks, it has been adapted to represent other vehicle types as well. Simulations run very quickly, producing animated graphics and writing statistics to permanent files. Westa is an object-oriented program written in the C++ computer language.

Westa simulates the behavior of each truck, car, or bus, from its creation at an origin, through each stage of its progress through the inspection or toll collection station and/or on the mainline, to the point where it leaves the simulation beyond the station. Vehicles may be routed depending on weight according to static or Weigh-in-Motion (WIM) scales or such user-defined characteristics as use of a pre-clearance transponder, preferred carrier or commuter status, safety status, or credential status.

Westa models inspection and toll collection facilities with a series of straight or curved one-lane links. Multiple lanes are modeled as parallel single lanes with defined rules for lane switching. Each vehicle moves along a series of links from an origin to a final destination. A link may branch forward to two others, allowing for multiple paths, and two links may merge into the same link. Upon arrival at a branching link, a vehicle is routed based upon its characteristics or the status of the links ahead. The user may define the combination of characteristics to be checked at each branch.

2.2 Vehicle Movement

Vehicle movement is calculated on the basis of a user-specified time-step value. Westa accepts time-step values as small as one-tenth of a second. Each vehicle moves according to its speed-dependent acceleration and deceleration abilities as well as those of the vehicles ahead of it. A vehicle's maximum acceleration rate decreases linearly with velocity, but its maximum deceleration rate is constant. Each vehicle attempts to accelerate to the maximum allowed speed for the link it is on, but decelerates for slower-moving vehicles ahead of it, a slower speed limit on the link ahead, or a required stop ahead. Vehicles will speed up or slow down as necessary for a merge.

Each vehicle has a maximum and a comfortable deceleration rate. If the user does not specify otherwise, Westa uses a default uniformly distributed maximum deceleration rate that ranges from 0.68g to 1.00g for cars and from 0.40g to 0.50g for trucks. Westa considers all simulated deceleration rates in excess of 0.30g for cars and 0.20g for trucks as hard braking, and reports this information as part of the traffic safety statistics. The comfortable deceleration rate defaults to 30 percent of the maximum value. The user may also specify maximum acceleration rates. The default maximum acceleration rate is generated from a uniform distribution with a range of 0.15g to 0.30g for cars and 0.06g to 0.12g for trucks.

When following another vehicle, a vehicle will keep a distance and speed such that if the vehicle ahead were to come to a stop at its maximum deceleration, the following vehicle would be able to stop with its preferred deceleration and avoid a collision. Only vehicles designated as being driven by aggressive drivers may exceed the speed limit on a link. No vehicle may move in reverse.

2.3 Vehicle Characteristics

When a vehicle is generated at an origin, the values of its characteristics or attributes are determined. Some characteristics are built into the model, but the user may define any other characteristics and the probability of occurrence as described below.

2.3.1 Vehicle Class

The first thing determined for a new vehicle is its vehicle class. Many other characteristics depend on the vehicle class. Westa recognizes the 13 vehicle classes defined by the FHWA. The following table defines the 13 classes. The proportion of vehicles of each class entering the simulation on each origin lane is defined in the input file (see section 3).

Class	Description
1	Motorcycles
2	Passenger Cars
3	2-axle 4-tire trucks (pickup trucks)
4	Buses
5	2-axle 6-tire single unit trucks
6	3-axle single unit trucks
7	4 or more axles, single unit trucks
8	4 or fewer axles, single trailer trucks
9	5 axles, single trailer trucks
10	6 or more axles, single trailer trucks
11	5 or fewer axles, multi-trailer trucks
12	6 axles, multi-trailer trucks
13	7 or more axles, multi-trailer trucks

Table 3-1. FHWA-Defined Vehicle Classes

2.3.2 Built-in Vehicle Characteristics

The following characteristics are specified in the input file for each vehicle class. Mitretek has customized the default values to use data provided by SDDOT, as described in section 3.

- Weight.** Given its vehicle class, a vehicle's weight (in pounds) is picked randomly, given minimum and maximum values and the percentage of vehicles falling into ten equally spaced bands between the minimum and maximum. For example, figure 2-1 below shows the distribution of weights for vehicle class 9 (5-axle trucks with single trailers), obtained from data provided by SDDOT. A different distribution is used for each class. Automobile weights are chosen the same way, using specified weight distributions for vehicle class 2.

Weight Distribution for Class 9 Trucks

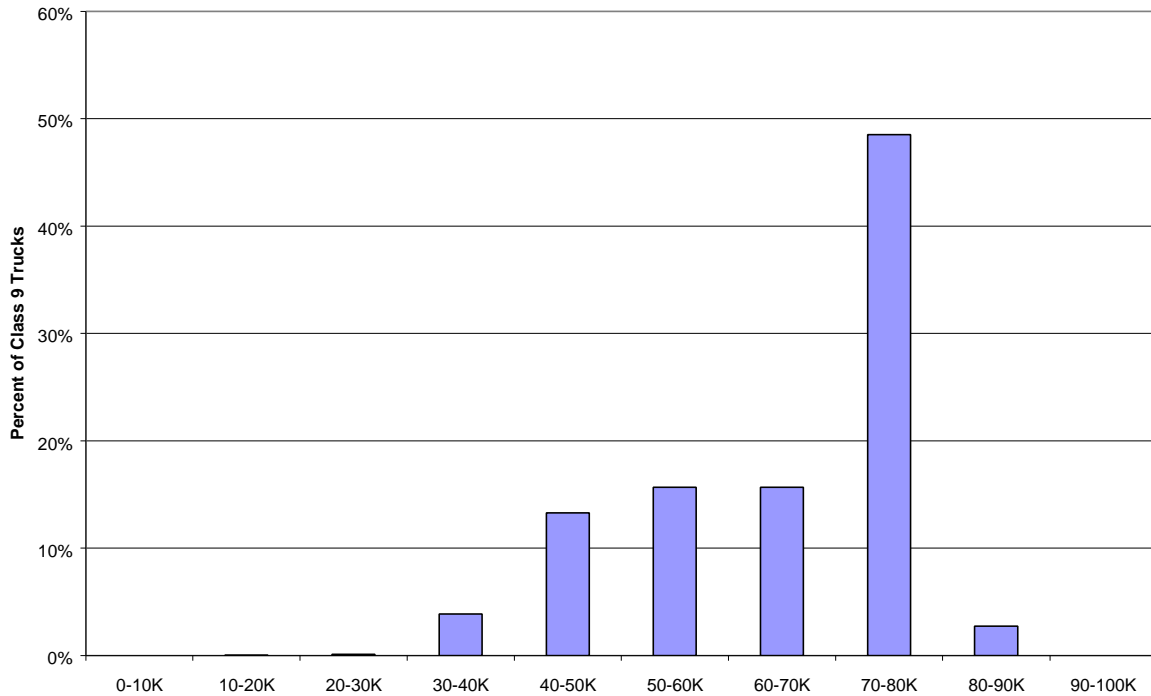


Figure 2-1. Distribution of Weight for Vehicle Class 9

- **Length.** Given its vehicle class, the length of a vehicle (in feet or meters) is picked randomly, given minimum and maximum values and the percentage of vehicles falling into ten equally spaced bands between the minimum and maximum. Automobile weights are chosen the same way, using specified length distributions for vehicle class 2.
- **Maximum acceleration rate.** This rate (in feet/sec² or meters/sec²) is randomly chosen from a uniform distribution between the specified minimum and maximum for the vehicle class. The default minimum is 0.15g for cars and 0.06g for trucks, and the default maximum of 0.30g for cars and 0.12g for trucks.
- **Maximum deceleration rate.** This rate (in feet/sec² or meters/sec²) is randomly chosen from a uniform distribution between the specified minimum and maximum for the vehicle class. The default minimum is 0.68g for cars and 0.40g for trucks, and the default maximum is 1.00g for cars and 0.50g for trucks.

2.3.3 User-Specified Characteristics

The user may specify any characteristic relevant to the study. Examples are presence of transponder, safety status, carrier status, customs status, hazardous materials (HAZMAT) status, type of violation, and driver credential status. A characteristic could be defined solely to predetermine whether a vehicle will turn left or right at a certain branch point. The value of each user-defined characteristic is either true or false. The user specifies in the control file the probability that the characteristic will be true for each vehicle. That probability may depend on the value of previously defined

characteristics. For example, the user may specify that overweight trucks are more likely to be unsafe than legal weight trucks or trucks owned by a “preferred” carrier are less likely to be pulled over for inspection than other trucks. These characteristics form the basis for routing vehicles at branch points. The value of these characteristics may be set or reset as the result of tests performed at branch points during the simulation. The service time for a vehicle at a branch point may also depend on a specified combination of its characteristics.

The vehicle characteristics defined for the South Dakota model are described in Section 3. The South Dakota model also specifies a characteristic named “car” so that cars may be displayed on the screen with a different color than trucks. For other purposes, cars are simply vehicle class 2.

2.4 Driver Characteristics

The driver-characteristics component of Westa provides a means of simulating variations in driver behavior, including speeding, aggression, and perception/reaction times. Simulation of these variations can help study traffic safety concerns such as the safety implications of merge and diverge maneuvers in the vicinity of the inspection facilities. Westa does not predict traffic crashes, but provides statistics on hard braking incidents that can be used as a surrogate for the level of risk exposure at inspection facilities. Westa’s safety module is most relevant as a planning decision support system. The user can test the viability of different operational scenarios, and make a decision on the preferred scenario based on the relative magnitude of simulated risk exposure (i.e., hard braking incidents). Westa accepts two primary sets of input data on driver attributes: aggressiveness and perception-reaction time.

2.4.1 Driver Aggressiveness

Driver aggressiveness is a primary safety concern. Aggressive driving behaviors have been associated with a number of high-risk attributes, including the acceptance of short gaps or headway, sudden acceleration and deceleration, and/or speeding. In a Westa simulation, aggressive drivers travel up to 20% higher than the specified speed limit for each link. Aggressive drivers also require shorter headways when deciding whether to change lanes or decelerate for a slow-moving leader. That is because they anticipate that they and other drivers will decelerate at the maximum deceleration rate, while a normal driver will expect braking at a more comfortable deceleration rate. Westa’s default value for the proportion of aggressive drivers is 20 percent. This percentage is the same across all vehicle classes.

2.4.2 Driver Perception-Reaction Time

Westa uses perception-reaction time (PRT) information in executing the vehicle-following logic described below. Westa uses a Weibull distribution to generate PRT values for individual drivers. The probability density function of the Weibull distribution is $f(x) = k\lambda^{-k}x^{k-1}\exp(-x/\lambda)^{-k}$; where k and λ are non-negative shape and scale parameters, respectively, the mean $\mu = \lambda/k\Gamma(1/k)$, and $\Gamma(k) =$ gamma function of k . The default values for λ and k parameters of the Weibull distribution are 1.35 seconds and 2.00 seconds, respectively. These parametric values of the Weibull distribution correspond to an average PRT value of 1.20 seconds. Figure 2-2 below illustrates the distribution of PRTs across drivers.

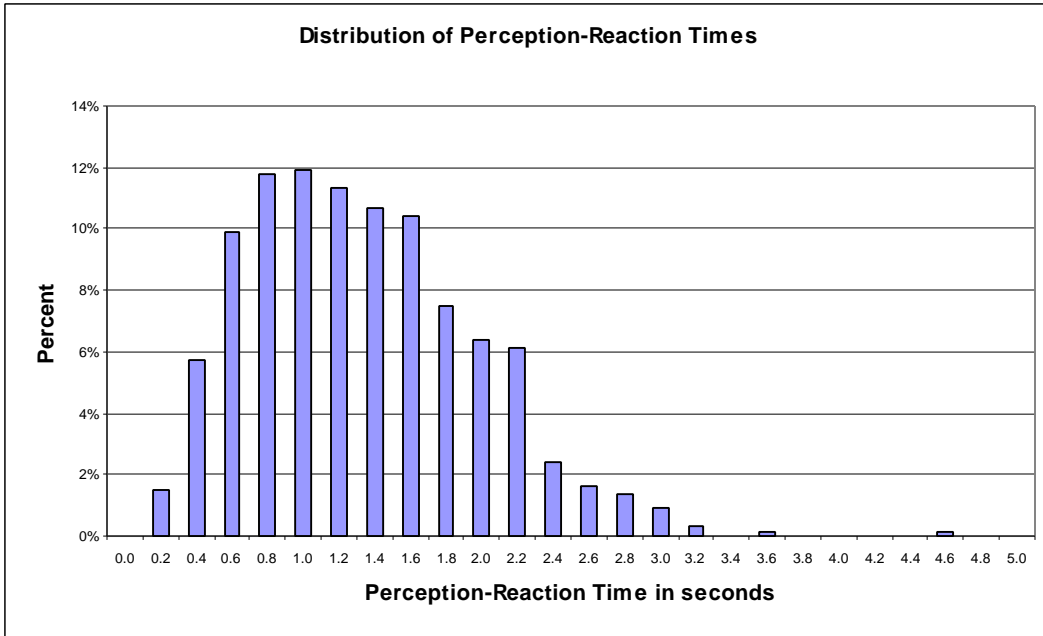


Figure 2-2. Distribution of Driver Perception-Reaction Times

2.4.3 Vehicle-Following Logic

Westa’s vehicle-following logic governs drivers’ decisions to change speed and to change lanes. The primary components of the logic include the gap acceptance principle of drivers during a merge or lane change maneuver and the spacing maintained between vehicles in the traffic stream. The size of the gap accepted during a merge or the spacing maintained in the traffic stream depends on whether a driver is aggressive or non-aggressive. A block diagram of the vehicle-following logic is shown in Figure 2-3.

Two safety regimes are assumed in the vehicle-following logic. The first safety regime, maximum acceleration for a merge or lane change maneuver and maximum deceleration for a stopping distance, is assumed for aggressive drivers. The second safety regime, comfortable acceleration for a merge and comfortable deceleration for a stopping distance, is assumed for non-aggressive drivers. The default values for maximum and minimum acceleration/deceleration rates for cars and trucks are documented in Section 3.2.

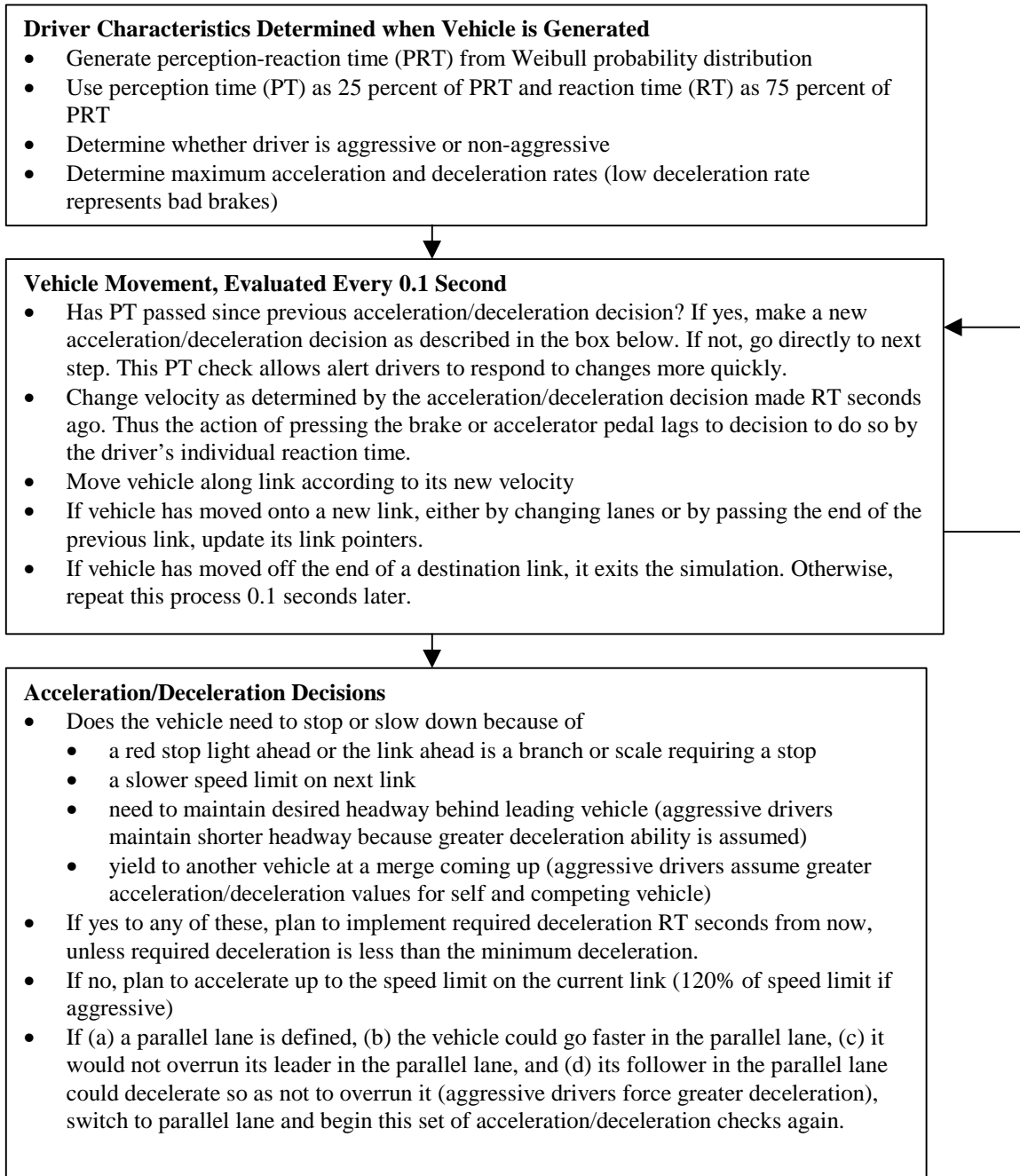


Figure 2-3. Block Diagram of Vehicle-Following Logic

2.5 Link Types and Traffic Signals

Westa can model seven types of links: origin, transit, destination, scale, branch, parking lot, and building. The location and length of each link are determined by the x and y coordinates of its start and end points, specified in the input file. All links other than parking lots may be straight or curved. Westa can also represent two types of traffic signals: fixed timing plan and actuated. This section describes each link type and signal type.

2.5.1 Origin

Vehicles are created on an origin link. Characteristics pertaining to each vehicle, such as weight, length, presence of transponder, safety status, and credential status, are determined at the origin based on vehicle information data specified in the control file. Any number of origin links may be specified. If more than origin is specified, the percentage of total traffic and the proportions of vehicle classes starting at each origin must be specified. An origin link has one next link and no previous links.

2.5.2 Transit

A transit link functions as a one-lane highway, ramp queue, or any other type of link that does not have multiple exits. Each transit link has one next link and one or two previous links. If there are two previous links feeding into the transit link, one previous link must be specified as the yielding link. Vehicles coming from the yielding link must yield the right-of-way to those coming from the other link.

A transit link may be “closed” when the number of vehicles on it reaches a specified percentage of its capacity. A transit link will also close when the link ahead of it is closed. If there is a branch or scale link feeding into the closed link, the branch or scale link will abandon its switching function and will route vehicles to the non-closed alternative. If both alternatives are closed, the branch or scale link itself will close. When the number of vehicles on a closed link declines to the specified reopening threshold, the link is reopened and the previous branch link resumes its switching function.

2.5.3 Destination

There may be more than one destination link. When a vehicle reaches the end of a destination link, it exits the simulation, its statistics are written to an output file, and on-screen statistics are updated. A destination link is the last link in a vehicle’s journey, unless the vehicle is placed out of service in a parking lot. Each destination link has one or two previous links and no next links. The same merging rules for previous links apply as for transit links. A destination link is never closed.

2.5.4 Branch

A branch link has two next links and one or two previous links. The same merging rules for previous links apply as for transit links. When a vehicle arrives at a branch link, a test is performed, as a Boolean combination of any number of current vehicle characteristics and/or comparisons of current link queue lengths. If the outcome of the specified test is true, the vehicle is routed to the link specified by the test. If the outcome is false, the vehicle is routed to the other link. If a non-zero stop time is specified, each vehicle must come to a stop and must wait for a constant time, or a random amount of time drawn from an Erlang, normal, or uniform distribution with specified parameters. The wait time may be a function of vehicle characteristics. The presence of a transponder, the status of driver credentials, vehicle safety hazmat status, preferred or blacklisted carrier status, and bridge

or axle weight violation status are examples of vehicle characteristics that can be defined by the user and checked with a test. The value of one or more vehicle characteristics may be set or reset depending on the result of the test performed at the branch link. Branch links may be closed or open as described in the previous section.

2.5.5 Scale

A scale link is a special case of a branch link. When a vehicle arrives at a scale, a test is performed that compares the measured weight of the vehicle to the defined weight threshold for the scale. An error in the measurement is modeled by choosing the measured weight as a random variable from a normal distribution with the true weight as the average and a specified percentage of the true weight as the standard deviation. Vehicles that are measured above the scale's weight limit are routed to the link specified by the test, and those that are below the weight limit proceed to the other forward link. A static scale is modeled by assigning a non-zero stop time and a small or zero error term, while a WIM (weigh in motion) scale is modeled by assigning zero stop time and a larger error term. The time taken to perform the weighing is constant or a random number drawn from a normal, uniform, or Erlang distribution.

2.5.6 Parking Lot

A parking lot is a special case of a transit link. The user must specify a third corner point, so that the link is wide enough for diagonal parking. The user also specifies the number of parking spaces. If a vehicle enters an empty parking lot and no service time has been specified, it proceeds directly to the exit. If a waiting vehicle blocks the exit, the entering vehicle proceeds to the empty parking space nearest the exit, pulls into it, and waits. The lot may be treated as a first-in first-out queue, in which case the vehicle cannot pull out of its parking space and proceed to the exit until all vehicles that have entered the lot before the waiting vehicle have exited the lot. Alternatively, no queuing may be specified, in which case the time a vehicle waits does not depend on any other vehicle.

A parking lot is also a special case of a branch link. A test and a wait time may be specified. The wait time begins when the vehicle is first in line to leave the lot if queuing is specified, or as soon as it parks if queuing not specified. If the test results in the vehicle being assigned the characteristic named "OOS", the vehicle is placed out of service. The vehicle remains in the parking lot (occupying a parking space) until the end of the simulation, and its statistics are added into the running totals as if it had finished by leaving a destination link.

2.5.7 Building

A building is not a traveled link at all, but may be specified in the same manner as a link for convenience. It is displayed as a stationary yellow rectangle on the screen with a user-specified label. Examples are an office, an inspection shed, a tollbooth, or a simply a highlighted section of pavement such as a scale. It may overlay other links. It has no active role in the simulation.

2.5.8 Fixed Signal

A fixed signal turns red and green on a fixed cycle. The user specifies the length of the cycle in seconds, the number of seconds the light is green, and whether the simulation begins at the beginning of the red phase or the green phase. A traffic signal serving multiple approaches is modeled as multiple signals, one at the end of each link, with coordinated red and green phases.

2.5.9 Actuated Signal

An actuated signal is defined with pointers to one, two, or three other links. If there are any vehicles on any of the indicated links, the traffic signal is red. Otherwise, the signal is green. In other words, vehicles on the link with the actuated signal must stop until the other link is clear of traffic. An actuated signal may be used to enforce vehicle priority or merging patterns.

2.6 Use of Probability Distributions

Westa uses two independent streams of pseudo-random numbers during the course of the simulation. The first is used for determining vehicle characteristics and arrival times, and the second is used for determining weighing, inspection, toll-payment, and other activities involving delay times. The two streams are independent so that the arrival rate and characteristics of vehicles can be kept identical while station configuration and control strategies are varied.

The following sections describe the probability distributions used in Westa.

2.6.1 Exponential Arrival Rate

The time between the arrival of a vehicle at the origin and the arrival of the next vehicle is drawn from an exponential distribution whose average is the given interarrival rate. Figure 2-4 illustrates the probability of various interarrival times, given an average of 25 seconds. Interarrival times less than the average are most common, but occasional long gaps between arrivals are possible.

The density function for the exponential probability distribution is $f(x) = 1/\alpha \exp(-x/\alpha)$. The parameter α of the exponential distribution is estimated from the empirical interarrival time data as $\alpha = [\sum x]/n$; where x = interarrival time for individual vehicles, and n = number of vehicles observed in the analysis period. The value of the mean and variance for the exponential distribution is α .

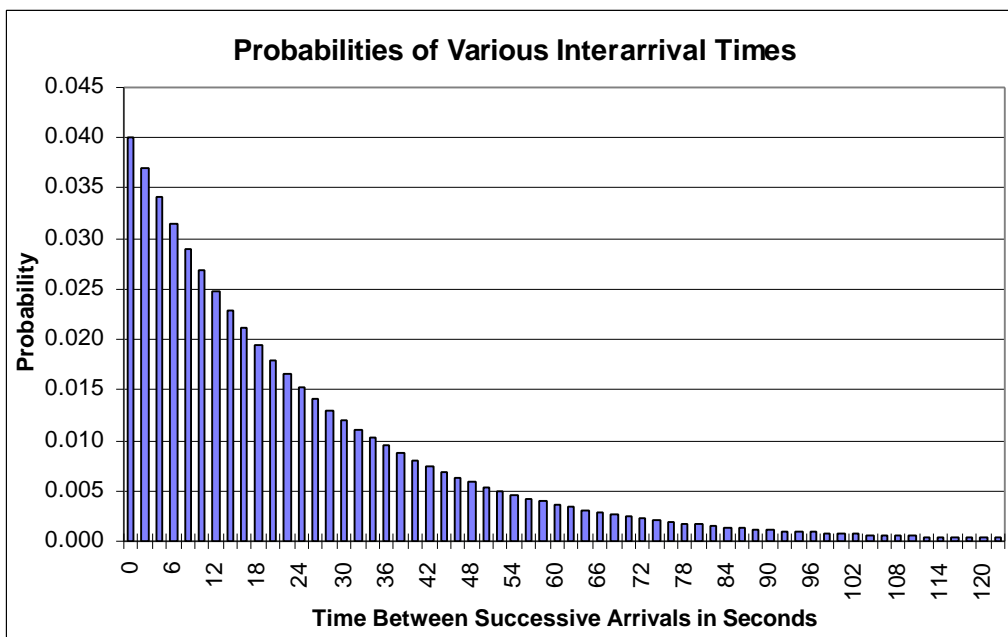


Figure 2-4. Sample Exponential Distribution

The user may specify different average interarrival times for different time periods. The transition between different arrival rates may be gradual or abrupt.

2.6.2 Uniform Distribution for Vehicle Attributes

The user may specify that a certain percentage of vehicles have a certain attribute, or that a certain percentage of vehicles that possess a specified combination of previously defined attributes have the attribute. At the time each vehicle is created, a random number is drawn from a uniform distribution between 0 and 100 percent for each attribute to determine whether the vehicle has the attribute or not. For example, if the user specifies a 20% chance that a vehicle will have a transponder, whenever a vehicle is generated, a random draw of 20 or less means the vehicle has a transponder, and a draw of greater than 20 means the vehicle does not have a transponder.

The density function for the uniform probability distribution is $f(x) = 1/b-a$. The parameters a and b are the lower range value and upper range value, respectively. The mean and variance for the uniform distribution are $(a+b)/2$ and $(b-a)^2/12$, respectively.

2.6.3 Normally Distributed Error for Weight Measurement

The operation of a scale is simulated using a random number from a normal distribution. The density function of the normal distribution is $f(x) = [1/\sqrt{2\pi\sigma^2}] \exp(-(x-\mu)^2/2\sigma^2)$. The average value μ for the normal distribution is the true weight of the truck and the variance σ^2 is chosen by the user to reflect the accuracy of the scale. For example, figure 2-5 below illustrates the probability distribution for the measured weight of a truck weighing 85,000 pounds, on a scale with an error of 5 percent.

Because of the error in measurement, a truck that is overweight may be weighed as being underweight or vice versa. For example, a truck with a weight of 75,000 pounds has a 99% chance of being measured over a threshold of 60,000 pounds, a 90% chance of measured over a threshold of 70,000 pounds, and a 10% chance of being measured over a threshold of 80,000 pounds.

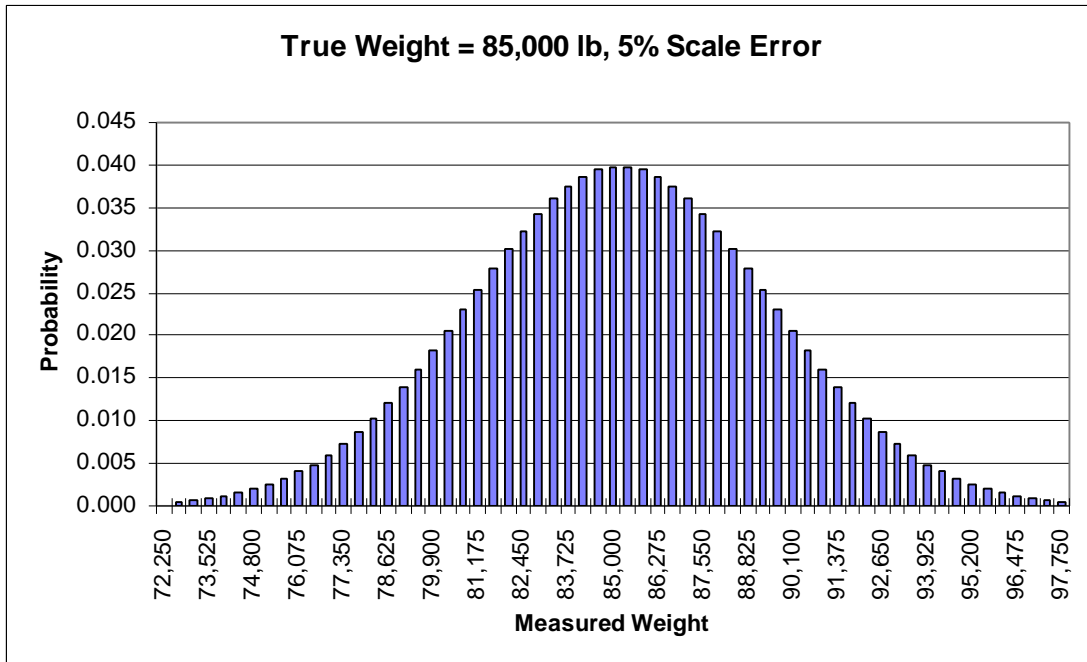


Figure 2-5. Probability of Measured Weight, Using a Normal Distribution

2.6.4 Normal, Uniform, Erlang or Constant Service Times

The time taken to weigh a truck on a scale, perform a safety inspection, write a ticket, or perform any other delay-causing activity is either a specified constant value or a random value drawn from a specified distribution. Random numbers may be drawn from (a) a normal distribution with a specified mean and standard deviation, (b) a uniform distribution between specified minimum and maximum values, or (c) an Erlang distribution with a given average value. Different probability distributions for service times may be specified for different categories of vehicles.

Values drawn from a normal distribution may have a negative value; if a negative value is drawn Westa replaces it with 0.01 times the mean. If the user does not have a large data set on the service times that can be used to select a reasonable probability distribution model, the use of a uniform distribution requiring only the minimum and maximum service-times is recommended.

The probability density function for the Erlang distribution is $f(x) = (\lambda k)^k x^{k-1} \exp(-\lambda kx) / k-1!$; where $\lambda = 1/\mu$, μ = mean value of x , and k = shape parameter and is a positive integer. Westa uses the Erlang distribution with shape parameter $k=4$, since that value has been found to reflect the observed distribution of service times very well⁵. The figure below illustrates the probability of various truck-weighing times generated from the Erlang distribution for $\mu = 25$ seconds.

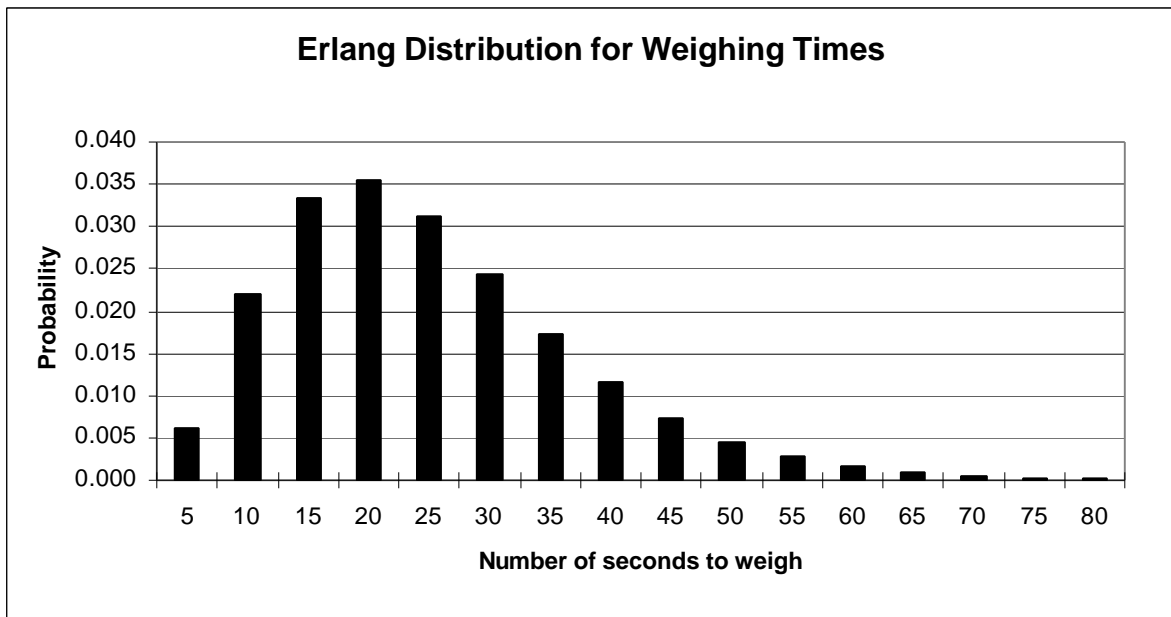


Figure 2-6. Probability of Weighing Times Using an Erlang Distribution

2.6.5 Weibull Distribution of Perception/Reaction Time

The use of the Weibull distribution to represent driver perception-reaction times is presented in section 2.4 and illustrated in figure 2-3. This distribution has been found to be a good match of empirical data on perception-reaction times.

Section 3

Representation of the McCook Weigh Station Scenarios

This section describes the McCook weigh station base case scenario and alternate scenarios and documents the input files defining the scenarios.

3.1 Description of Scenarios

The base case scenario was constructed using data defining current station design and operation. The results of the base case scenario can be compared to current conditions at the station. Section 3.2 documents the input file for the base case.

The first alternate scenario represents the proposed replacement facility and operating policy. The station layout would be similar to the existing layout, except for the addition of a low-speed WIM scale on the station entrance ramp, and a bypass lane between the scale facility and the highway. A branch from the bypass lane to the parking lot would enable the station operator to direct trucks with possible safety or credential problems to the inspection lot. The only trucks sent to the static scale would be trucks that exceed the maximum weight on any single axle, plus a randomly chosen 10 percent of trucks over 80,000 pounds gross weight. The axle weight and gross weight measurements would be performed by the WIM scale on the entrance ramp. This scenario represents a lower bound on the number of trucks weighed. The input file for this scenario is documented in section 3.3.

The second alternate scenario is an alternate operating policy at the proposed station. First, the threshold for gross weight was set to 70,000 pounds rather than 80,000 pounds. The lower threshold allows for error in the WIM scale, reducing the chance that an overweight truck would be measured as under the threshold. It is acknowledged that the gross weight threshold is more simplistic than using thresholds specific to vehicles' axle configurations. Second, all trucks measured by the WIM scale as over 70,000 pounds would be sent to the static scales, rather than a random sample. This scenario is an upper bound on the number of trucks sent to the static scales from a WIM scale. The input file for this scenario is documented in section 3.4.

At the request of SDDOT, Mitretek ran each of the three scenarios again with the traffic load increased by 20% and by 30%. A fact sheet from the trucking industry's Team 2000 predicts that "In the year 2006 ... the total number of miles driven [by trucks] will have grown by 28% and the total volume of ton-miles will have grown by 32%." The arrival rate for each class of vehicles increased proportionately by the same amount. Section 3.5 describes how these scenarios were defined.

In all, nine scenarios were modeled. Table 3-1 summarizes the nine scenarios.

Arrival Rate	Base Case Scenario	First Alternate Scenario	Second Alternate Scenario
Base	x	x	x
120%	x	x	x
130%	x	x	x

Table 3-1. Scenarios Modeled

3.2 Base Case Scenario

For each value or set of values, the source of the information is given. The lines of the input file are shown in bold Courier font, and the commentary follows in Times New Roman font. Any characters following the pound sign (#) in the input file are treated as comments. The complete input file is presented in Appendix A.

McCook 100% Base case scenario

The scenario name is displayed at the top of the screen and included in the output files. The traffic level simulated is 100% of the current traffic load.

runLength: 120 # run for two hours

The scenario runs for two hours, representing the fairly steady truck traffic during the peak period in the late morning. Figures 3-1 and 3-2 depict truck traffic counts taken by SDDOT during March 1998 and June 1998. Both show peak periods for truck traffic in the late morning and early afternoon on weekdays. Truck traffic on weekends is significantly less. Figure 3-3 shows the hourly car and truck traffic averaged across the weekdays in March. Clearly the peak hours for cars correspond to morning and evening rush hours, but the peak hour for trucks is between 10 and 11 a.m.

randomSeed_truck: 101
randomSeed_link: 11

These random seeds initialize the random number generators for vehicle generation and weighing/inspection times. The numbers here were used for the first iteration. Mitretek ran each scenario ten times with a different pair of random seeds for each iteration, and averaged the results together for the results presented in Section 4.

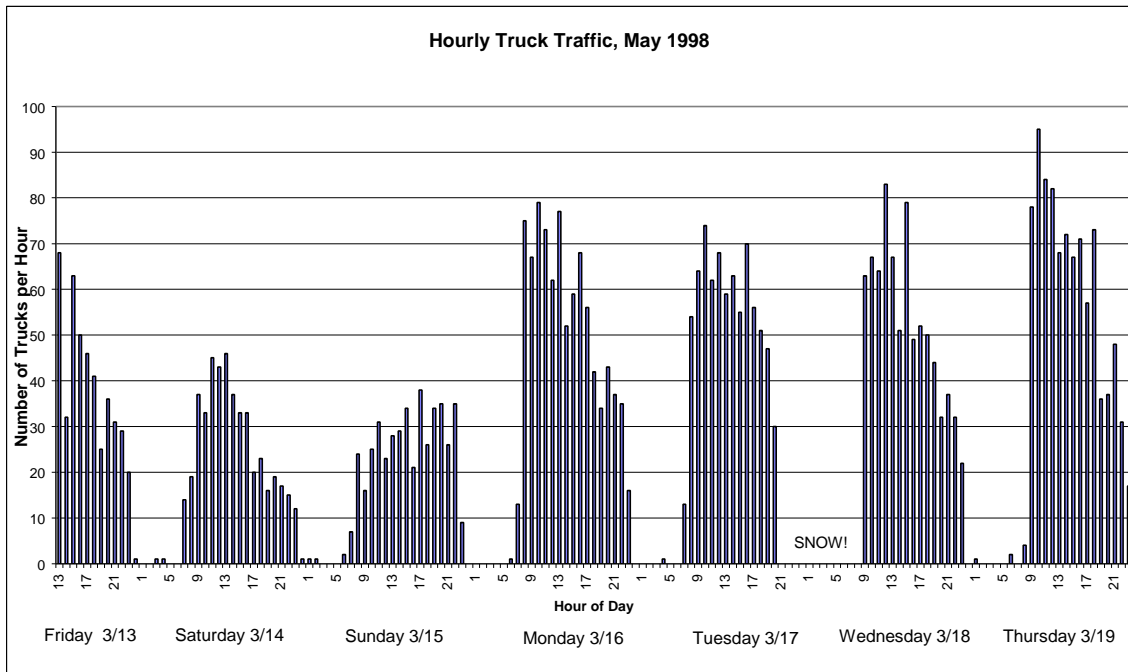


Figure 3-1. Hourly Count of Trucks at McCook Station – March 1998

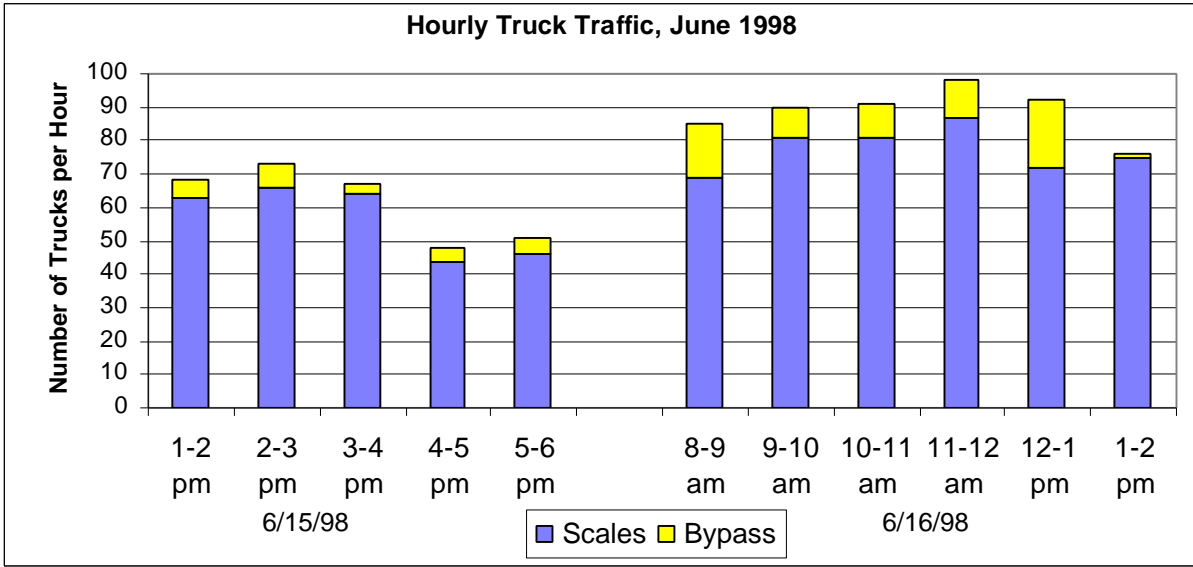


Figure 3-2. Hourly Count of Trucks at McCook Station – June 1998

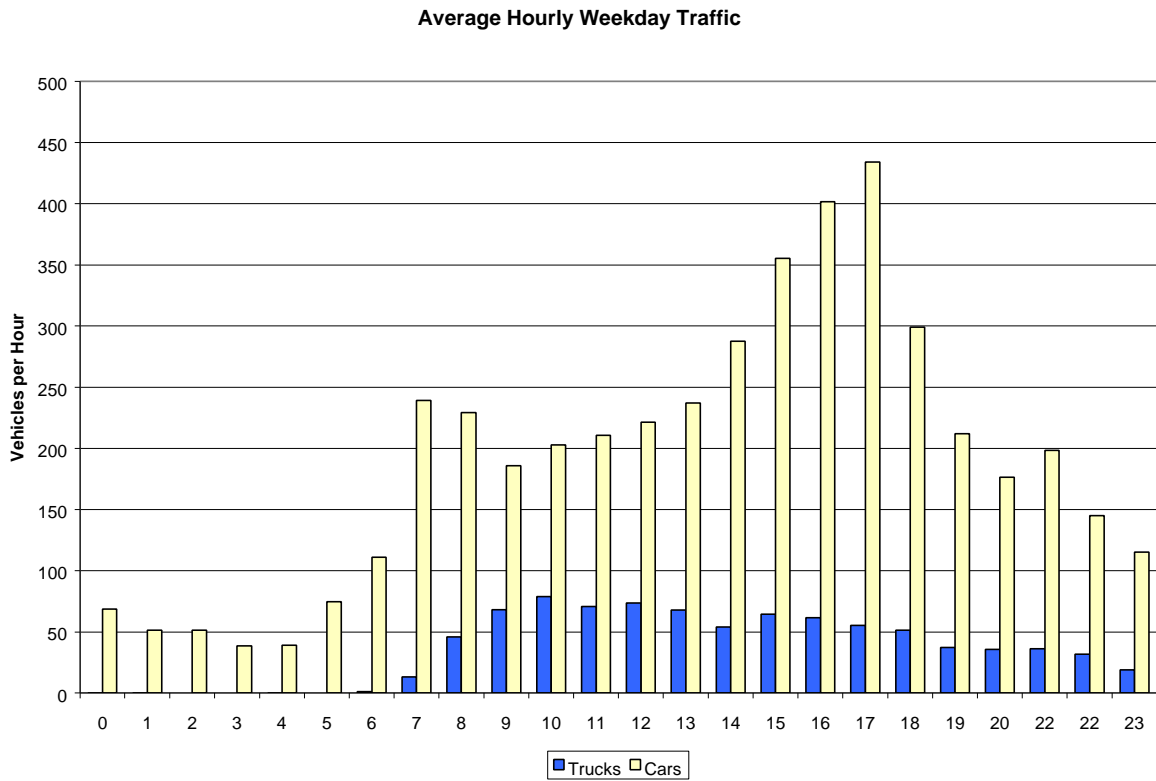


Figure 3-3. Truck and Car Traffic Averaged by Hour across Weekdays

avgCreatTime: 10 # (sec.)

A vehicle is generated every 10 seconds on the average. The vehicle has a 24.4% chance of being a truck (see the truck info section), so a truck is generated every 41 seconds on the average, for an arrival rate of 88 trucks per hour. An arrival rate of 88 trucks per hour is roughly equal to the hourly arrival rate in the morning of March 19, the busiest of the days measured in March 1998 (see figure 3-1). It is also roughly equal to the hourly arrival rate in the morning of June 16, 1998, when additional measurements were recorded by SDDOT (see figure 3-2).

Section 3.4 describes the set of scenarios with higher levels of traffic demand.

maxWt: 80000 # <- maxWt for static scales

The maximum legal gross weight for trucks without a special permit is set at 80,000 pounds per South Dakota regulations. Trucks weighing more than 80,000 pounds are considered overweight.

TimeStep .1

The size of the time step was reduced from one second to 0.1 second to enable detailed modeling of vehicle response to potentially hazardous situations. Driver perception-reaction times vary from 0.8 to 2.4 seconds, and vehicles have a corresponding lag in their behavior. Time steps as small as 0.1 seconds are required to model the effects of these different perception-reaction times.

[TruckInfo]

The following groupings define the distribution of length, weight, and acceleration/ deceleration characteristics for vehicles in each FHWA class. When values for any of these variables are not specified for a class, Westa uses values for the preceding class.

Class 2 Cars

maxAccRange: 2.8 6.3 .009 # (mi/hr/sec)

The maximum acceleration rate for each car is chosen from a uniform distribution between 2.8 and 6.3 mph per second. These values reflect the range of maximum acceleration capabilities for passenger cars reported in the Road Test Digest of Car and Driver magazine. Those acceleration figures are divided by two since the maximum acceleration used on a freeway is less than the maximum value on a test track. The value of 0.009 indicates that the maximum acceleration rate declines at .009 times the current speed (the faster a car is going, the smaller is its maximum acceleration).

maxDecRange: 17.3 20.7 .30 # (mi/hr/sec)

The maximum deceleration rate for each car is chosen from a uniform distribution between 17.3 to 20.7 mph per second. These values are the weighted averages plus and minus two standard deviations for maximum deceleration rates for passenger cars published in Consumer Reports magazine. The value of 0.3 indicates that the normal (comfortable) rate of deceleration is 0.3 times the maximum rate.

weightRange: 0 6000 # (lbs)

weightDistrib: 0.0 0.0 4.1 9.9 31.4 27.3 14.9 6.6 4.1 1.7 # (%)

The minimum and maximum weights serve as end points for the weight distribution. The weight range is divided into ten bins of equal size between the minimum and maximum value, and the percentages give the percent of cars in each bin. In this case, the bin size is 600 pounds. The values of weight distribution for cars reflect the weight range of new cars reported in Consumer Reports magazine. The weight of cars is irrelevant to the McCook model in any case.

lengthRange: 10 20 # (ft)

lengthDistrib: 0.0 0.0 1.7 7.4 19.0 28.9 27.3 10.7 5.0 0.0 # %

The minimum and maximum lengths serve as end points for the weight distribution. The length range is divided into ten bins of equal size between the minimum and maximum value, and the percentages give the percent of cars in each bin. In this case, the bin size is 1 foot. The values of length distribution for cars reflect the length range of new cars reported in the March 1998 Consumer Reports magazine.

Class 3 2-axle 4-tire (Pickup trucks)

maxDecRange: 16.8 18.6 .30 # (mi/hr/sec)

The maximum deceleration rate for light trucks ranges from 16.8 to 18.6 mph per second. These values are the weighted averages plus and minus two standard deviations for maximum deceleration rates for light trucks published in Consumer Reports magazine. The value of 0.3 indicates that the normal (comfortable) rate of deceleration is 0.3 times the maximum rate.

lengthDistrib: 0.0 0.0 96.2 0.0 0.2 1.5 1.9 0.3 0.0

The length distribution for this class and for all truck classes was supplied by SDDOT. Since the maximum and minimum lengths are not specified, the values for the previous class are used. Similarly, since the acceleration and weight characteristics of class 3 trucks are not specified, the values for cars are used. The length and weight of pickup trucks are irrelevant to the model in any case since they are not inspected.

Class 4 Buses

maxDecRange: 16.8 18.6 .30

lengthRange: 30 40

lengthDistrib: 0.0 0.0 96.2 0.0 0.2 1.5 1.9 0.3 0.0

The same deceleration characteristics were used for buses as for small trucks. The distribution of bus lengths came from SDDOT. Bus characteristics are not significant to the McCook model since they are not inspected.

Class 5 2-axle 6-tire single units

The performance characteristics of class 5 trucks were assumed to be the same as for light trucks so they are not specified.

weightRange: 0 100000

weightDistrib: 0.7 23.1 28.6 20.4 14.3 12.2 0.0 0.0 0.7 0.0 # (%)

The weight distribution supplied by SDDOT for "straight trucks" was used for class 5 trucks. A chart of weight distribution for all truck classes supplied by SDDOT is presented in table 3-2.

lengthRange: 0 50 # (ft)

lengthDistrib: 0.0 2.4 64.1 23.6 9.9 0.0 0.0 0.0 0.0 0.0

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 6 3-axle single units

maxAccRange: 1.3 2.6 .009 # (mi/hr/sec)

The maximum acceleration rate for each large truck (class 6 and above) is chosen from a uniform distribution between 1.3 and 2.6 mph per second. These values range around the value of .1g (2.2 mph) considered good acceleration for a loaded truck. The value of 0.009 indicates that the maximum acceleration rate declines at .009 times the current speed (the faster a truck is going, the smaller is its maximum acceleration).

Bin	Straight Class 5	3-axle Class 6	4-axle Class 7	Trailer Class 8	5-axle Class 9	6-axle Class 10	Double Class 11	Double Class 12	7+-axle Class 13
0-10K	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10-20K	0.231	0.000	0.000	0.206	0.000	0.000	0.000	0.000	0.000
20-30K	0.286	0.000	0.096	0.147	0.001	0.000	0.000	0.000	0.000
30-40K	0.204	0.846	0.386	0.088	0.039	0.000	0.019	0.019	0.000
40-50K	0.143	0.154	0.434	0.029	0.133	0.019	0.101	0.101	0.000
50-60K	0.122	0.000	0.084	0.029	0.157	0.113	0.335	0.335	0.000
60-70K	0.000	0.000	0.000	0.176	0.157	0.170	0.424	0.424	0.000
70-80K	0.000	0.000	0.000	0.324	0.485	0.245	0.082	0.082	0.000
80-90K	0.007	0.000	0.000	0.000	0.027	0.245	0.019	0.019	0.000
90-100K	0.000	0.000	0.000	0.000	0.000	0.132	0.013	0.013	0.000
100-110K	0.000	0.000	0.000	0.000	0.000	0.075	0.000	0.000	0.000
110-120K	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.111
120-130K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.222
130-140K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
140-150K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
150-160K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.222
160-170K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.222

Table 3-2. Distribution of Truck Weights by FHWA Class

maxDecRange: 12.8 16.0 .30 # (mi/hr/sec)

The maximum deceleration rate for trucks ranges from 12.8 to 16.0 mph per second. The upper value was supplied by data in the American Trucking Association library. The lower value was based on the assumption that some trucks will have less than optimal brakes. The value of 0.3 indicates that the normal (comfortable) rate of deceleration is 0.3 times the maximum rate.

weightRange: 0 100000 # (lbs)
weightDistrib: 0.0 0.0 0.0 84.6 15.4 0.0 0.0 0.0 0.0 0.0 # (%)

The weight distribution supplied by SDDOT for “3-axle trucks” was used for class 6 trucks.

lengthRange: 0 50
lengthDistrib: 0.0 0.0 0.8 18.7 72.3 8.2 0.0 0.0 0.0 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 7 4 or more axles, single unit
weightRange: 0 100000
weightDistrib: 0.0 0.0 9.6 38.6 43.4 8.4 0.0 0.0 0.0 0.0 # (%)

The weight distribution supplied by SDDOT for “4-axle trucks” was used for class 7 trucks.

lengthRange: 0 50
lengthDistrib: 0.0 0.0 0.0 11.5 50.0 34.6 3.8 0.0 0.0 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 8 4 or fewer axles, single trailer

weightRange: 0 100000

weightDistrib: 0.0 20.6 14.7 8.8 2.9 2.9 17.6 32.4 0.0 0.0 # (%)

The weight distribution supplied by SDDOT for "Trailer trucks" was used for class 8 trucks.

lengthRange: 20 70 # (ft)

lengthDistrib: 0.0 6.8 22.4 35.1 16.4 7.4 6.5 4.2 1.1 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 9 5-axle, single trailer

weightRange: 0 100000

weightDistrib: 0.0 0.0 0.1 3.9 13.3 15.7 15.7 48.5 2.7 0.1 # (%)

The weight distribution supplied by SDDOT for "5-axle trucks" was used for class 9 trucks.

lengthRange: 35 85

lengthDistrib: 0.2 0.6 2.1 10.0 37.1 46.0 3.9 0.2 0.0 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 10 6 or more axles, single trailer

weightRange: 10000 110000

weightDistrib: 0.0 0.0 0.0 1.9 11.3 17.0 24.5 24.5 13.2 7.6 # (%)

The weight distribution supplied by SDDOT for "6-axle trucks" was used for class 10 trucks. Note that the weight range is now 10,000 pounds to 110,000 pounds. The range was changed to reflect the chance of class 10 trucks over 100,000 pounds.

lengthDistrib: 0.0 0.0 0.9 8.8 31.0 27.9 27.4 3.5 0.4 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 11 1.1 % 5 or fewer axles, multi-trailer

weightRange: 20000 120000

weightDistrib: 0.0 1.9 10.1 33.5 42.4 8.2 1.9 1.3 0.0 0.6 # (%)

The weight distribution supplied by SDDOT for "Double" trucks was used for class 11 trucks. The range is from 20,000 pounds to 120,000 pounds.

lengthDistrib: 0.0 0.0 0.9 8.8 31.0 27.9 27.4 3.5 0.4 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 12 6 axles, multi-trailer

weightRange: 20000 120000

weightDistrib: 0.0 1.9 10.1 33.5 42.4 8.2 1.9 1.3 0.0 0.6 # (%)

The weight distribution supplied by SDDOT for "Double" trucks was used for class 12 trucks.

lengthDistrib: 0.0 0.0 0.0 0.0 0.0 0.0 26.4 36.8 36.8 0.0 # %

The length distribution for this class and for all truck classes was supplied by SDDOT.

Class 13 7 or more axles, multi-trailer

weightRange: 70000 170000

weightDistrib: 0.0 0.0 0.0 0.0 11.1 22.2 11.1 11.1 22.2 22.3 # (%)

The weight distribution supplied by SDDOT for "7+ axle" trucks was used for class 13 trucks. The range is from 70,000 pounds to 170,000 pounds.

lengthDistrib: 0.0 0.0 0.0 0.0 0.0 0.0 26.4 36.8 36.8 0.0

The length distribution for this class and for all truck classes was supplied by SDDOT.

ClassDistribution 2 origins

Link	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13
0	0.0	44.6	27.4	0.3	3.5	1.0	0.0	17.0	3.1	0.1	2.3	0.4	0.3
1	0.0	74.0	21.2	0.0	0.8	1.6	0.0	0.8	1.6	0.0	0.0	0.0	0.0

Link 0 and link 1 are the two origin links, where vehicles enter the simulation. Link 0 represents the right lane of northbound I-29 and link 1 is the left lane. These lines in the input file specify the percentage of each vehicle class to enter the simulation on each link. The percentage of each class was taken from the data collected by SDDOT at the McCook facility in March 1998. SDDOT had set up counters in each lane approaching the station. Mitretek used the proportions of traffic in each lane from 10 a.m. to 11 a.m., consistent with the peak truck traffic times described previously. Figure 3-4 shows the percentage of each vehicle class. When links 0 and 1 are defined in the “LinkInfo” section, the percentage of total traffic entering the simulation on each of the two lanes is defined.

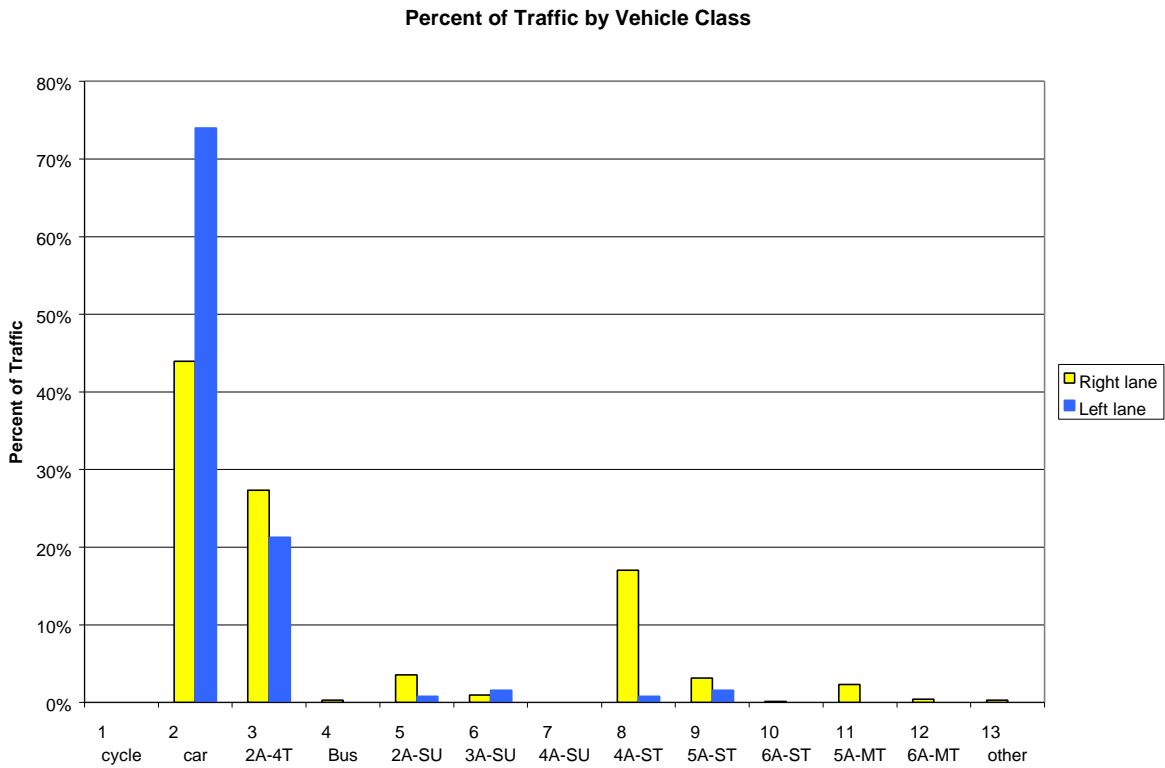


Figure 3-4. Distribution of Vehicle Classifications by Lane on Northbound I-29

[Attributes]

Each attribute (also called a characteristic) of a vehicle is determined at the time it enters the simulation. Some attributes are given other values during the simulation as a result of a test. The probability of each characteristic being set to true is specified. The probability may depend on the value of previously set attributes. The cab and/or trailer of a vehicle may be displayed in a certain color to indicate that a certain attribute is true. Attributes need not be defined in numerical order, and there may be gaps in the sequence of attribute numbers.

```
# name                cab color trailer color % expr    % expr
```

```

# -----
1 "car"          yellow    yellow    100 { c2 }

```

Cars are displayed in yellow. 100% of the vehicles in class 2 are designated as cars.

```

2 "truck"       default    default    100 { ( not c2 ) and ( not c3 ) and ( not c4 ) }

```

Trucks are normally displayed with the default color (blue). If the vehicle is not class 2, class 3, or class 4, there is a 100% chance that the vehicle will be a truck (i.e. all vehicles that are not cars, pickup trucks, or buses are trucks). Pickup trucks (class 3) and buses (class 4) are not treated like trucks since they are not required to stop for inspection.

```

3 "overweight"  default    lightred   owt { }

```

This attribute is true if the vehicle is overweight (over 80,000 pounds). The special keyword "owt" indicates that this attribute is set by comparing the weight to the limit, rather than by drawing a new random value. Overweight trucks are displayed on the computer screen with red trailers.

```

4 "safety check" default    black      2 { 2 }

```

If attribute 2 is true (the vehicle is a truck), there is a 2% chance the vehicle will be pulled over for a safety check. This percentage was the percentage of trucks pulled over for safety reasons as reported by SDDOT. These trucks are displayed with black trailers.

```

5 "credential check" lightred  default    4 { 2 }

```

If attribute 2 is true (the vehicle is a truck), there is a 4% chance the vehicle will be checked for credentials or logbook violations. This percentage was the percentage of trucks pulled over for credential checks as reported by SDDOT. Trucks suspected of credentials or logbook problems are displayed with red cabs (suggesting that the problem is with the driver, not the cargo).

```

6 "fixable"     default    default    100 { 3 } 100 { 5 } 90 { 4 }

```

100% of the trucks with weight (attribute 3) or credential problems (attribute 5) are considered "fixable" in that they are allowed back on the highway after a short time. 90% of the trucks with safety problems (attribute 4) are allowed to leave after the problem is fixed or noted. However, 10% of the unsafe trucks are placed out of service for the remainder of the simulation. These percentages come from data recorded at the McCook station over two days in June, where one unsafe truck was effectively placed out of service each day out of 9 or 10 unsafe trucks.

```

7 "inspected"   lightblue lightblue   0 { }

```

Initially all vehicles have this attribute set to false. However, the vehicles that have been pulled into the parking lot and then released have this attribute set to true, so they will not be counted as bad misses by test 7. Their color is restored to blue from whatever color it was to indicate that it may proceed back to the highway. Because of the order the attributes are defined, trucks with attribute 7 true are displayed with blue cabs and trailers, regardless of their previous colors.

```

8 "OOS"         black     black      0 { }

```

Initially all vehicles have this attribute set to false. However, the trucks that are not fixable (10% of the unsafe trucks) are placed "out of service" and have this attribute set to true after inspection. They are displayed as all black, and they never leave the parking lot.

```

10 "held at scales" default    default    50 { 3 }

```

According to SDHP, half the overweight trucks are held at the scales longer while the driver is summoned into the office to see the results of the scale measurement. 50% of the overweight trucks (attribute 3) have this attribute set to true. It is checked in the specification for service time 1.

```

12 "legal"      default    default    100 { 2 and ( not 3 ) and ( not 4 ) and ( not 5 ) }

```

This attribute is set to true for each truck of legal weight with no credential or safety problems. It is defined so that statistics on the average station transit time for these trucks can be computed and displayed. Overweight trucks and trucks with credential or safety inspections spend much longer in the simulation. These longer times should not be counted when determining how much delay is caused to legal trucks by the weighing operation.

15 "waved through" default lightgray 0 { }

This attribute is initially set to zero for all trucks. It is set to 1 if the truck is waved past the scales when the scales are temporarily shut down (see test 6). The trailers of these trucks are displayed gray.

16 "bad misses" default brown 0 { }

This attribute is set to true when a truck that is overweight or has safety or credential problems is waved past the scales when the scales are temporarily shut down (see test 7). It is defined so that the model can report the number of such trucks. The trailers of these trucks are displayed brown.

[Tests]

Each branch and parking lot link performs a test on each vehicle as it enters the link. The test is a Boolean combination of vehicle attributes. If the value of the test is true, the vehicle leaves the branch link by the alternate link (the second link named in the link file). If the value of the test is false, the vehicle leaves the branch by the main link (the first link named in the link file). More than one branch may perform the same test. If an attribute number is specified in the second part of the test, that attribute is set to true for all vehicles that pass the test.

1 "trucks right" A { 2 } { }

All trucks (not including pickup trucks) take the alternate branch to the right. This test is used twice: first to move any trucks still in the left lane when the station is at hand (link 4) to the right lane (link 6), and then to move all trucks from the right lane onto the station entrance ramp (link 9).

2 "to parking lot" A { 3 or 4 or 5 } { }

All trucks that are overweight (attribute 3) or unsafe (attribute 4) or have credentials problems (attribute 5) take the alternate branch from the scales toward the parking lot. All other trucks take the primary branch back to the highway. This test is applied by link 12 (the scale link). Trucks that have already been inspected bypass the scales on links 13, 14, and 15, so they are not inspected a second time.

3 "safety check" A { not 6 } { 8 }

This test is performed in the parking lot (link 21). All vehicles that are not fixable (not attribute 6) are tagged with attribute 8 (out of service). Those trucks will not leave the parking lot. Otherwise, after waiting the appropriate length of time, they return to the highway.

4 "fix some" A { 6 } { 7 }

Trucks leaving the parking lot go through a branch (link 22) with this test. Since all vehicles leaving the parking lot are fixable, no trucks fail this test. In fact, both exit links are the same. The only purpose of this test is to set attribute 7 (inspected) to true for those trucks, so are not counted as bad misses by test 7.

6 "missed truck" A { 2 } { 15 }

Links 12 and 16 are defined as occupying the same physical space. Link 12 contains a static scale and link 16 does not. When the scales are closed because of queue backup, link 12 closes, and trucks are switched to link 16. Thus the only time a truck traverses link 16 is when the scales are closed. Therefore all trucks on link 16 have attribute 15 (waved through) set to true.

7 "bad miss" A { 15 and (3 or 4 or 5) and (not 7) } { 16 }

This attribute is set to true whenever a truck that is overweight truck (attribute 3) or has safety (attribute 4) or credential (attribute 5) problems has been waved by the scale (attribute 15) and has not already been inspected (not attribute 7). These are the trucks that should have been inspected but were not because of station congestion.

[ServiceTimes]

Service times are specified for scales and branches as probability distributions. Different distributions may be specified for different Boolean combinations of vehicle classes. The types of possible distributions are Normal, Uniform, Erlang, or Constant.

```
# name                            expression    random type parms
# ----                            -----       -
1 "weighing time"                { 10 } Erlang 90 { } Erlang 41
```

The service time distribution was calculated from data recorded at the McCook station by SDDOT on June 15 and 16, 1998. In all, 665 observations were recorded, grouped by 15-second intervals. The distribution of this data is shown in figure 3-5. The plot suggests that the distribution of service times is consistent with an Erlang distribution (see figure 2-6). The average value is 41 seconds. However, for trucks with attribute 10 true (held at scales) the service time was 90 seconds, reflecting the extra time for the driver to be shown the scale measurement.

```
2 "inspection time"    { 5 } Erlang 900 { 4 } Erlang 3000 { 3 } Erlang 1200 # sec.
```

SDDOT recorded the time spent in the parking lot for 67 trucks on June 15 and 16, 1998. The arrival and departure time for each truck was recorded, together with an indication of the reason for detention. Mitretek grouped the overweight, safety, and credential-related causes separately and computed the average time for each one. The results are presented in figure 3-6. Although the number of observations is not large, the data are consistent with the assumption of an Erlang distribution of service time in the parking lot.

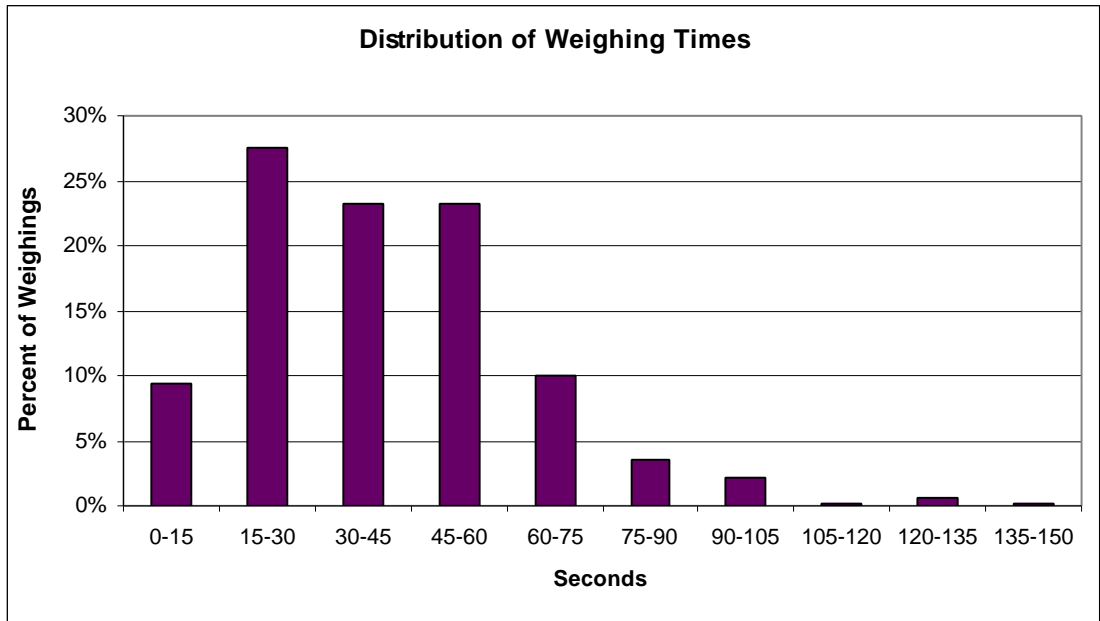


Figure 3-5. Distribution of Time between Trucks on Scale at McCook

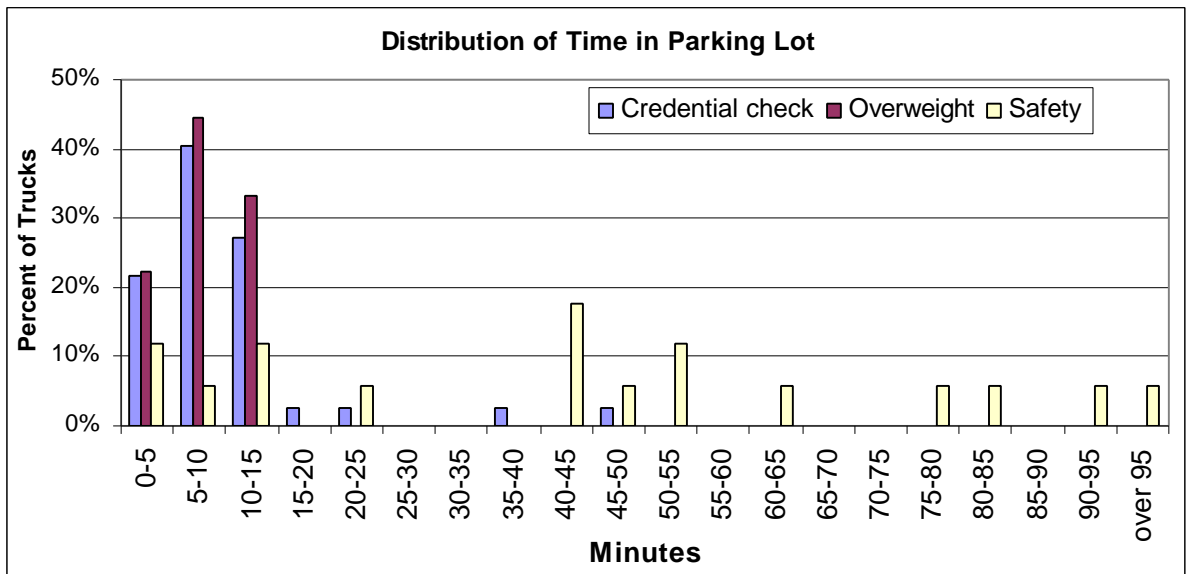


Figure 3-6. Distribution of Time in Parking Lot

[LinkInfo]

This section specifies information for each link in the simulation. The first column is the link number. The second column gives the type of link. The third and fourth columns specify the first and second links following the given link. Two exit links are specified only if the link is a branch or scale; otherwise there is a dash (-). The fifth column specifies the free speed limit in miles per hour. The sixth and seventh columns specify the x and y coordinates (in feet) of the start of the link and the

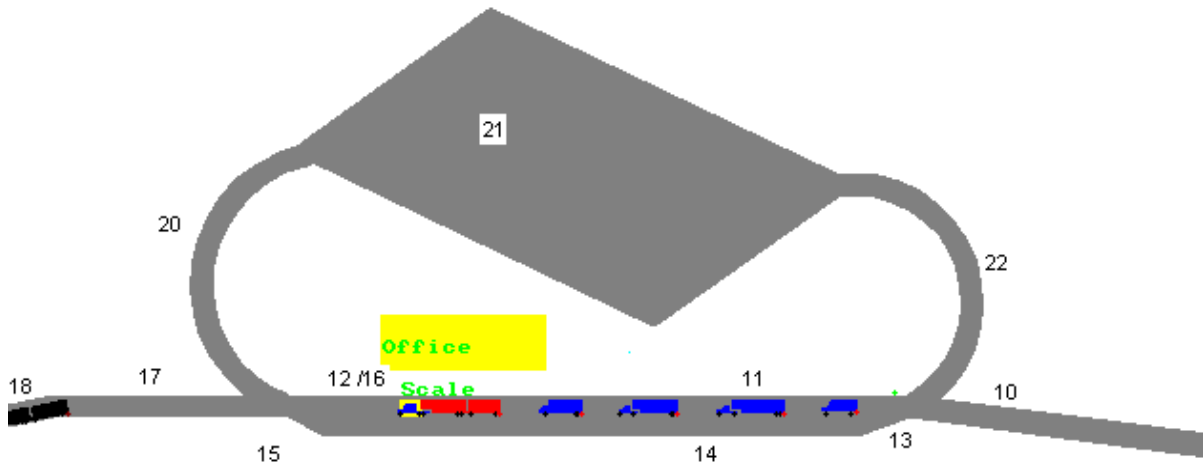


Figure 3-9. Detail of Central Area of McCook Station

Code	Explanation
T	Precedes the test number for a branch link
ST	Precedes the service time number for a branch or scale link
Y	Indicates that traffic on that link must yield when merging with traffic from another link
CC	Precedes the coordinates of the center of curvature for a curved link
PS	Precedes the number of parking spaces for a parking lot
OC	Precedes the x and y coordinates of the opposite corner of a parking lot (the corner directly opposite the corner where trucks enter the lot)
NQ	Specifies that no queuing applies in the parking lot (service time starts as soon as the truck parks, rather than waiting for any other trucks in the lot)
A	Indicates the proportion of arrivals to appear on each origin link
AS	Exit from the link is governed by an actuated signal keyed on the designated link
CL	The link is closed when the designated link reaches the closing threshold (see “C”) and reopens when the designated link reaches the reopening threshold (see “O”)
C	The link closes when the ratio of total truck length to total link length exceeds this fraction
O	The link reopens when the ratio of total truck length to total link length drops below this fraction
LL	Indicates the link number of the corresponding left-hand lane where lane-changing is permitted
RL	Indicates the link number of the corresponding right-hand lane where lane-changing is permitted
Q	The number of trucks in this link is to be included in the queue length count
SC	Indicates that when this link is closed, the station is closed (the simulation keeps track of how long the station is closed).

Table 3-3. Special Link Options in the LinkInfo Section

[LinkInfo]											
#	type	ahead	spd	dimensions				typespecific			
#	----	--	---	-----	-----	-----	-----	-----	-----	-----	
0	Orig	2	-	55	4400	100	3900	100	A .8	LL 1	
1	Orig	3	-	55	4400	80	3900	80	A .2	RL 0	
2	Trans	6	-	55	3900	100	2700	100	LL	3	
3	Trans	4	-	55	3900	80	3200	80	RL	2	
4	Branch	23	5	55	3200	80	2800	80	T	1	
5	Trans	6	-	55	2800	80	2700	100	Y		
6	Branch	7	9	55	2700	100	2200	100	T 1	LL 24	
7	Trans	8	-	55	2200	100	100	100	LL	25	
8	Dest	-	-	55	100	100	0	100			
9	Trans	10	-	35	2200	100	1300	217	Q		
10	Trans	11	-	15	1300	217	1200	230	Q AS	22	
11	Branch	16	12	10	1200	230	920	230	T 1	Q	
12	Branch	17	20	5	920	230	860	230	ST 1	T 2 CL 9 C .5 O .2 SC	
13	Trans	14	-	10	1200	230	1170	220			
14	Trans	15	-	10	1170	220	880	220			
15	Trans	17	-	25	880	220	860	230	Y		
16	Branch	17	17	10	920	231	860	231	T	6	
17	Branch	18	18	35	860	230	730	230	T	7	
18	Trans	8	-	55	730	230	100	100	Y		
20	Trans	21	-	10	860	230	870	370	CC 882	297	
21	Park	22	22	5	870	370	1160	350	ST 2	T 3 OC 970 440 PS 10	
22	Branch	13	13	10	1160	350	1200	230	T 4	CC 1170 287	
23	Trans	24	-	55	2800	80	2700	80			
24	Trans	25	-	55	2700	80	2200	80			
25	Dest	-	-	55	2200	80	0	80			
40	Bldg	-	-	0	910	250	1000	280	"Office"		
41	Bldg	-	-	0	920	224	932	234	"Scale"		

Links 1, 3, 4, 23, 24, and 25 are the left lane of Northbound I-29. Link 1 is the origin link, delivering 20 percent of the vehicles. Link 3 is a long transit link. Any trucks on link 3 may shift right to link 2 if there is sufficient room. Cars may switch lanes at will, given a sufficient gap, but trucks may only shift to the right lane from the left lane.

All trucks that haven't shifted to the right lane by the end of link 4 must take the branch (link 5), which merges with link 2 into link 6 (changes from the left lane to the right lane). Traffic on link 5 yields to traffic on link 2. Cars, buses, and pickup trucks on link 4 continue on to links 23, 24, and 25, bypassing the weigh station. Vehicles completing destination link 25 exit the simulation.

Links 0, 2, 6, 7, and 8 are the right lane of northbound I-29. Link 0 is the origin link, delivering 80 percent of the vehicles. Cars, buses, and pickup trucks on links 2, 6, and 7 may change lanes to the left onto links 3, 24, 25 respectively if there is enough space. Link 6 is the branch link in the right lane. At the end of this branch, all trucks must exit the highway into the station on the ramp link 9. Cars and pickup trucks continue on highway link 7. Vehicles completing destination link 8 exit the simulation.

Link 9 is the ramp into the station, leading to link 10. There is an actuated signal defined for link 10. Whenever a truck is exiting the parking lot on link 22, the actuated signal turns red, forcing trucks on link 10 to wait for the emerging truck. At all other times the signal is green.

Link 11 is just before the scales. Link 11 sends all trucks to the scales (link 12), unless link 12 is closed, in which case link 11 sends all traffic to the other defined branch (link 16). Link 16 and link 12 are defined in the same physical location. However, link 16 does not require trucks to stop.

Instead, it uses test 6 to set attribute 15 true for any trucks crossing it. Thus this link models the operation of the station when the scales are closed.

Link 12 is the scale where test 2 is applied (is the truck overweight or is there a reason for a safety or credential check?) If any of these are true, the truck takes the right branch (link 20) to the parking lot. If no further check is required, the truck takes the left branch (link 17) toward the station exit. Service time 1 defines the distribution of times to weigh a truck and make the safety/credential determination. The parameters for link 12 specify that when link 9 is more than 50% full, link 12 closes. The percentage full is computed by dividing the length of trucks on the link to the link length. Mitretek has found that this procedure detects when the ramp is full of trucks better than judging whether a truck over a loop detector is stopped at the end of the queue or not. When link 12 is closed, link 11 directs all trucks to link 16, which occupies the same space as link 12, but does not require trucks to stop. When the length of trucks on link 9 is reduced to 20% of its length, the scale reopens, and trucks again enter that link.

The definitions for links 9, 10, and 11 include a “Q”. This tells the model to sum the number of trucks on these three links to compute the current queue length.

The scale departure link (link 17) leads to the reentry ramp onto the highway (link 18). Trucks on link 18 must yield to highway traffic on link 7, as both links merge onto link 8.

Links 13, 14, and 15 bypass the static scale. Trucks emerging from the parking lot go directly to link 13, bypassing the scale. Link 15 merges with link 16 onto link 17. Traffic on link 15 yields to traffic on link 16.

The ramp to the parking lot (link 20) leads to the parking lot (link 21). In the parking lot, test 3 (safety inspection) is applied. Service time 2 defines the distribution of times to perform a safety, credential, or weight distribution inspection and to fix the problem. If the truck is fixable, after waiting the appropriate time, it exits the lot on the parking lot exit ramp (link 22). On link 22, the truck’s attribute 7 (inspected) is set to true and the truck goes to link 13 so it is not pulled over at the scales a second time.

Links 40 and 41 are not links at all, but are simply labeled locations shown on the display. Link 40 is the office and link 41 is the scale.

[GraphInfo]

The following lines define the statistics boxes in the lower left corner of the screen. The first four statistics display the current cumulative count of vehicles with certain attributes. A vehicle does not get counted in these statistics until it leaves the simulation, either by exiting a destination link or by being placed out of service in the parking lot. The fifth statistic displays the cumulative average transit time for all underweight trucks with no credential or safety problems that finish the simulation. The last statistic gives the total number of trucks in links defined with a “Q” (i.e. links 9, 10, and 11).

```
Stat "Total number of trucks" Count 2
Stat "Overweight trucks"      Count 3
Stat "Waved through"         Count 15
Stat "Violators missed"      Count 16
Stat "Average time"          Time 12
Stat "Trucks in queue"       Queuelen
```

The following lines define six “views”. These are preset coordinates that can be invoked by pressing a single number key during the simulation.

```
View 1  1817  2857  -237  545
View 2  1160  2701  -237  545
View 3   784  1317   57  457
View 4    48   881  -96  529
View 5   888  1107  135  298
View 6  4160  4501  -36  221
```

[End]

Note: other data collected at the McCook station, including number of trucks in queue, frequency of queue overflow, and number of trucks in the parking lot were not used as input. Instead they were used for validating the output of the model.

3.3 First Alternate Scenario

At the request of SDDOT and SDHP, Mitretek modeled the operation of a proposed station to replace the current McCook facility. The station layout would be similar to the existing layout, except for the addition of a low-speed WIM scale on the station entrance ramp and a bypass lane between the scale facility and the highway. A variable message sign following the WIM scale would direct trucks weighed over a certain threshold to proceed to the static scale, and would direct trucks weighed under that threshold to use the bypass lane. A branch from the bypass lane to the parking lot would enable the station operator to direct trucks with possible safety or credential problems to the inspection lot. Figure 3-10 shows how Westa represents the different configuration.

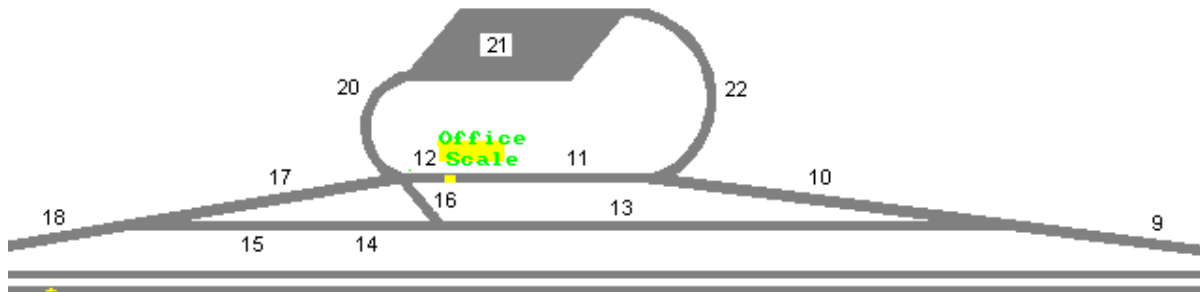


Figure 3-10. Proposed Weigh Station with WIM Scale and Bypass Lane

SDHP further specified that not all trucks weighed over the threshold would be directed to the station scale. Most overweight trucks have special permits granting permission to travel the highway or have extra axles to spread out the extra weight so that the maximum weight per axle is not violated. SDDOT plans to direct a randomly chosen 10 percent of overweight trucks to the static scale for weighing, plus all trucks that are over the maximum axle weight limitations as well as over the gross weight threshold. Data were not available defining the proportion of trucks exceeding gross weight of 80,000 pounds that also exceeded axle weight limitations. As a lower bound, Mitretek assumed a value of 10 percent. Thus 20 percent of the trucks over 80,000 gross weight were sent to the static scales and all other trucks were allowed to bypass the scales.

The first alternate scenario was modeled with the following changes in the input file. First, a new attribute was defined named "axle weight/random." Since ten percent of the trucks over 80,000 pounds gross weight were assumed to be in violation of maximum axle weight limitations, and ten percent of the same group of trucks were randomly selected for weighing, twenty percent of the overweight trucks had this attribute.

```
11 "axle weight/random"  default  default  20 { 3 }
```

A new test was defined to check for this attribute.

```
5 "axle or random"      A { 11 } { }
```

Test 7 was added so that trucks with credential or safety problems could be detected in the bypass lane and sent to the parking lot for inspection. Test 8 was defined to mark trucks that took the bypass lane, and test 9 was defined to mark overweight trucks that took the bypass lane.

```
7 "to parking lot2"     A { 4 or 5 } { }
8 "set bypass"         A { 2 } { 14 }
9 "set heavy bypass"   A { 3 } { 16 }
```

Next, the station entrance ramp (link 9) was changed from a transit link to a branch link. It applied test 5. All trucks with attribute 11 true were sent to the static scale as before. All other trucks were sent to the new bypass link 13. Link 13 is itself a branch, applying test 7. All trucks with safety or credential concerns were directed to link 16 toward the parking lot. Other trucks proceeded to link 14, where their attribute 14 (bypass) was set to true by test 8. On link 15, overweight trucks had their attribute 16 (overweight bypass) set to true by test 9.

```
9 Branch 13 10 35 2200 100 1700 165 T 5
13 Branch 14 16 35 1700 165 915 165 T 7
14 Branch 15 15 35 915 165 600 165 T 8
15 Branch 18 18 35 600 165 480 165 T 9
```

Trucks on link 15 merged with trucks on link 17 onto the highway reentry link (link 18).

3.4 Second Alternate Scenario

After running the previous scenario, Mitretek noted that there was significant unused capacity at the static scales. In fact, the scales were empty most of the time. This unused capacity could be used by the station operators to conduct more thorough safety inspections. On the other hand, it might be possible to weigh more trucks without causing congestion. Therefore Mitretek changed the operating policy suggested by SDDOT, so that all trucks measured by the WIM scale as over 70,000 pounds would be sent to the static scales, rather than 20%. This scenario is an upper bound on the number of trucks sent to the static scales from a WIM scale.

Since a measurement from a WIM scale is not as accurate as a measurement from a static scale, the threshold for sending a truck to the static scale is typically set less than the legal weight limit. For this scenario, Mitretek set the threshold at 70,000 pounds, and assumed the WIM scale had a 5% error rate. This means that the weight of a truck passing over the scale was measured as its simulated weight plus or minus a random number drawn from a normal distribution with mean equal to zero and standard deviation equal to 5% of the simulated weight. The station entry ramp (link 9) was changed from the branch link of the first alternate scenario to a scale link with threshold 70,000 and error .05.

3.5 Increased Traffic Scenarios

At the request of SDDOT, Mitretek ran each of the three scenarios again with the traffic load increased by 20% and by 30%. A fact sheet from the trucking industry's Team 2000 predicts that "In the year 2006 ... the total number of miles driven [by trucks] will have grown by 28% and the total volume of ton-miles will have grown by 32%.⁵⁷" The only change to the input files for the three scenarios was the decrease in vehicle interarrival time, which increased the hourly number of arrivals by 20% or by 30%. The arrival rate for each class of vehicles increased proportionately by the same amount.

avgCreatTime:	8.33	# 20% increase
avgCreatTime:	7.69	# 30% increase

Section 4

Results

Mitretek ran ten iterations for each of the nine scenarios using different random seeds for each iteration. Each iteration produced a summary file, from which the following values were extracted:

- ◆ Total number of trucks
- ◆ Total number of trucks that were weighed
- ◆ Total number of overweight trucks and trucks with safety or credential problems
- ◆ Total number of trucks not weighed when the scales were closed
- ◆ Total number of overweight trucks or trucks with safety or credential problems not inspected because of scale closing
- ◆ Average time to transit the station spent by legal weight trucks
- ◆ Average queue length for the static scale
- ◆ Total time during the simulation that the scales were closed because of queue overflow
- ◆ Total seconds of hard deceleration (greater than 0.2g) for trucks
- ◆ Total seconds of hard deceleration (greater than 0.3g) for cars

The results are presented and plotted for each scenario. For each measure of effectiveness, a table presents the average value $\Sigma x_i/10$ and the standard deviation $\sqrt{(\Sigma x_i^2/10)}$. The table then presents the statistical significance from two χ^2 (chi-square) tests. The first χ^2 test compares the results the ten iterations of an alternate scenario against the ten iterations of the base scenario with the same traffic volume. The second χ^2 test compares the results for the ten iterations of a scenario with increased traffic levels against the ten iterations of the same scenario but the base traffic volume. Thus it is apparent which changes are due to the different station configuration or operating policy and which changes are due to increased traffic levels. If the level of significance is greater than 90% or 95%, there is high confidence that the alternate scenario does indeed make a significant difference to the average value of the measure of effectiveness. If the level of significance is less than 90%, it cannot be said that the alternative scenario has a different result than the base scenario.

Following each table, a plot shows the average value across the 10 iterations for each scenario. The averages for the three traffic volumes for the base case scenario are blue squares, the averages for the first alternate scenario are red squares, and the averages for the second alternate scenario are green squares. Each plot also features vertical bars indicating one standard deviation above and below the average for each scenario. If the standard deviation is large in relation to the difference between the average value for the base scenario and the average value for an alternate scenario, then the difference in the average value is not likely to be statistically significant. In general, the smaller the standard deviation, the more likely results are to have high values of statistical significance.

4.1 Average Scales Closed Time

Table 4-1 and figure 4-1 present the average time (in minutes) the scales were closed because of queue backup. The amount of time represented by the simulation was two hours.

The key input values driving this result were the arrival rate of trucks and the average time to weigh a truck. Based on data collected by SDDOT when the scales were closed twice during the two days of observation, the results obtained from the base scenario do not seem unreasonable. SDDOT has confirmed that the results are consistent with their experience.

Minutes scales are closed	Base	Base	Base	Alt. 1	Alt. 1	Alt. 1	Alt. 2	Alt. 2	Alt. 2
	100%	120%	130%	100%	120%	130%	100%	120%	130%
Mean	2.71	8.38	11.40	0.00	0.00	0.00	0.00	0.00	0.00
Std. Deviation	1.96	3.30	4.08	0.00	0.00	0.00	0.00	0.00	0.00
Statistical Significance:									
Compared to base case same volume				100%	100%	100%	100%	100%	100%
Difference is Significant?				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume		100%	100%		N/A	N/A		N/A	N/A
Difference is Significant?		Yes	Yes		N/A	N/A		N/A	N/A

Table 4-1. Statistics for the Number of Minutes the Scales are Closed

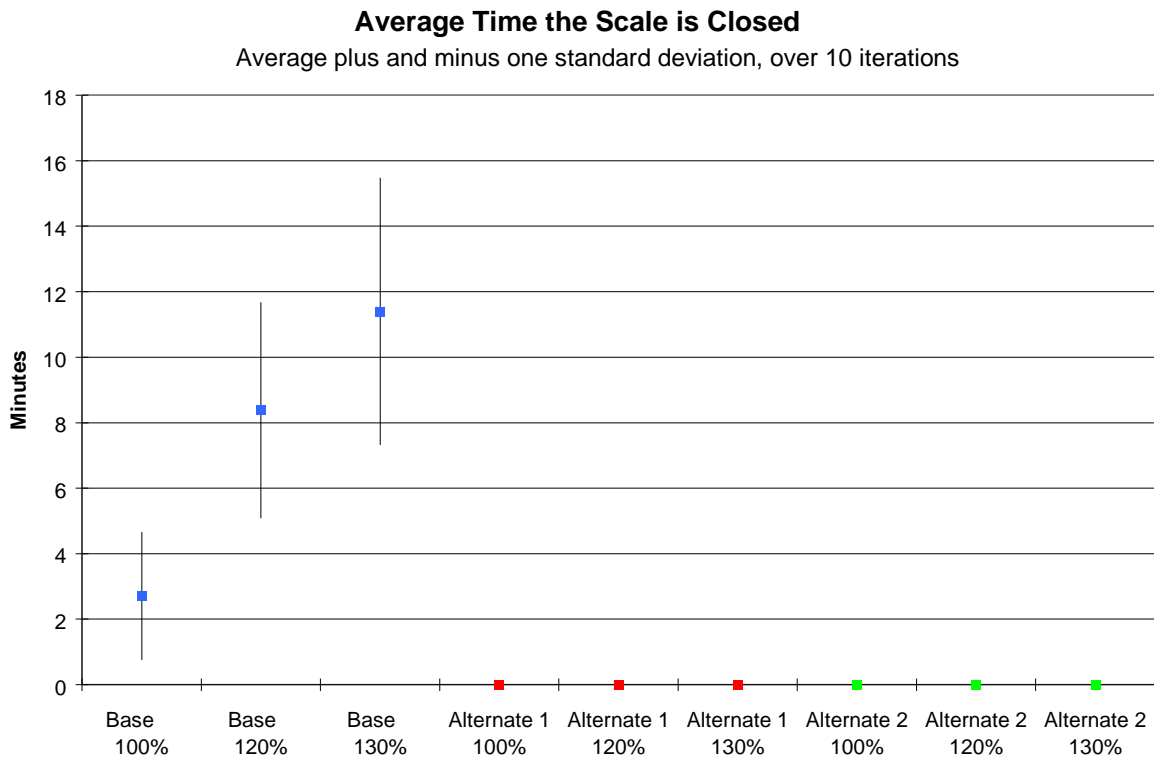


Figure 4-1. Average Time Scales are Closed

For the base case scenario, increasing traffic volumes clearly led to more times the scales were closed. This result is consistent with basic queuing theory, comparing the arrival rate of trucks to the service rate. Under the highest growth scenario, the scales were closed nearly ten percent of the time.

The WIM scale for the first alternate case effectively removed over 95% of the trucks from the static scales, so there was no backup of trucks waiting to be weighed. In other words, the arrival rate of trucks to be weighed was well below the rate at which they could be weighed. Therefore the time the station was closed was reduced to zero. It should be noted that if the queue of trucks waiting for the static scale were to back up past the point where the bypass lane diverged from the entrance ramp, then underweight trucks would be stuck briefly in the queue as well. However, for this scenario the queue backup never extended so far as to cause the scales to close.

The second alternate case, with all trucks measured over the 70,000 pound gross weight threshold sent to the scales, likewise did not experience sufficient backup to close the scales. The reduction in the number of trucks to be weighed was so significant that further reduction was not necessary to prevent queue backup.

4.2 Average Number of Trucks Weighed

Table 4-2 and figure 4-2 show the average number of trucks weighed for each scenario. For the base case scenarios, this number did not increase with traffic volume. This fact suggests that the effective maximum number of trucks that can be weighed had already been reached, and any additional traffic was spilled over as bypasses (see table 4-3 and figure 4-3). In fact, the number weighed decreased slightly, since the scales were closed more frequently to empty out the queue.

Number weighed	Base	Base	Base	Alt. 1	Alt. 1	Alt. 1	Alt. 2	Alt. 2	Alt. 2
	100%	120%	130%	100%	120%	130%	100%	120%	130%
Mean	116.20	113.60	110.60	0.60	0.60	0.90	44.70	54.10	56.70
Std. Deviation	4.39	5.46	5.23	0.84	0.84	0.99	7.50	8.81	9.58
Statistical Significance:									
Compared to base case same volume				100%	100%	100%	100%	100%	100%
Difference is Significant?				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume		74%	98%			0%	52%	98%	99%
Difference is Significant?		No	Yes			No	No	Yes	Yes

Table 4-2. Statistics for Number of Trucks Weighed

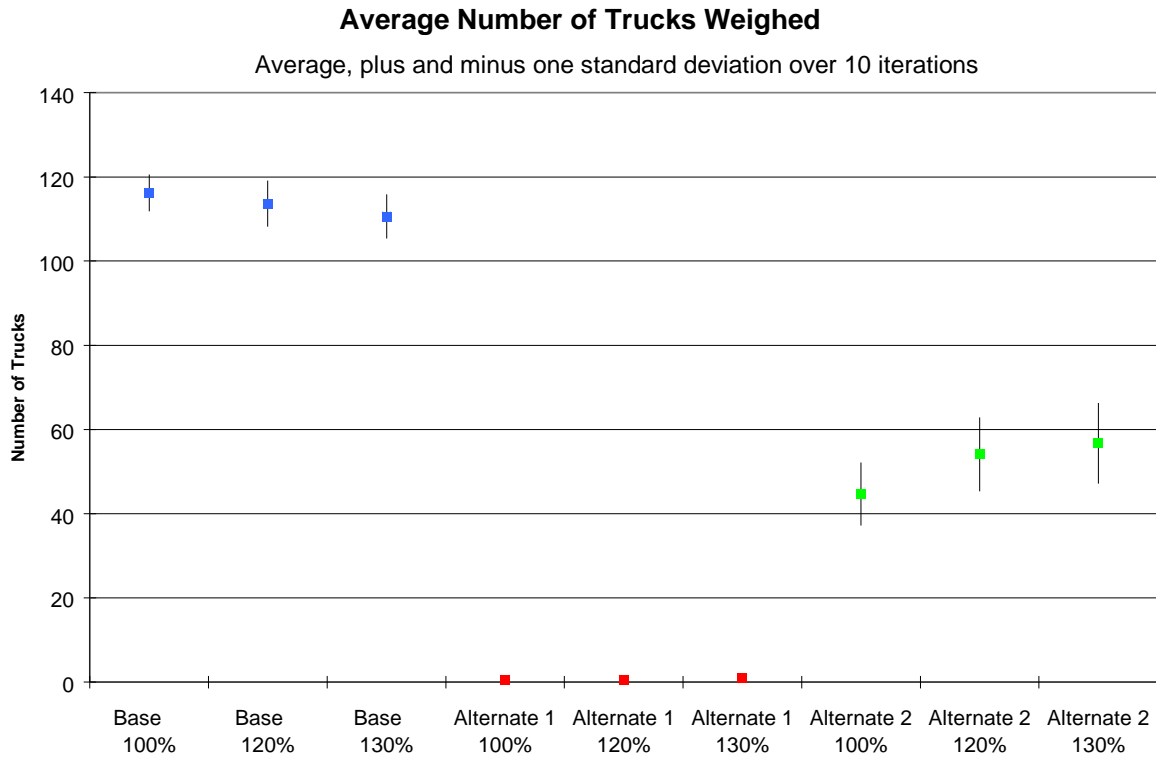


Figure 4-2. Average Number of Trucks Weighed

The effective maximum number of trucks that can be weighed in an hour is a function of the average time to weigh a truck (including the longer time spent by some overweight trucks) and the time between trucks from when one truck begins to leave the scale to when the next truck is in place ready to be weighed.

The number of trucks weighed for the first alternate scenario with a WIM scale was almost zero because only one percent of the trucks were over 80,000 pounds gross weight, and only 20% of those were sent to the static scales. The number of trucks weighed for the second alternate scenario is much greater than for the first alternate scenario because all trucks measured over 70,000 pounds gross weight by the WIM scale were sent to the static scale. For this scenario the increase in number weighed with traffic volume is evident. The difference is statistically significant because of the small standard deviations.

4.3 Average Number of Trucks Bypassed

Table 4-3 and figure 4-3 show the average number of trucks that bypassed the static scale for each scenario. For the base case scenarios, this is the number of trucks that were waved past the scales when the scales were closed. For the first alternate scenario, this number is all legal weight trucks plus 80% of the overweight trucks. For the second alternate scenario, this number is all trucks measured under the 70,000 pound WIM threshold.

For the base scenario, this number increased as the traffic level increased. More frequent long queues caused the scales to close more frequently, and more trucks bypassed the scales during those times. For the first alternate scenario, most trucks bypassed the scales, and the number to do so is directly proportional to the total traffic load. For the second alternate scenario, the number of bypasses is less because all trucks weighted over 70,000 pounds were sent to the static scales. In this scenario as well, the number to do so was directly proportional to the total traffic load. All differences were statistically significant.

Number bypassed	Base 100%	Base 120%	Base 130%	Alt. 1 100%	Alt. 1 120%	Alt. 1 130%	Alt. 2 100%	Alt. 2 120%	Alt. 2 130%
Mean	32.40	68.90	89.10	159.00	191.50	206.60	115.80	138.70	151.20
Std. Deviation	12.88	13.19	16.78	12.53	13.05	10.59	9.92	6.07	9.02
Statistical Significance:									
Compared to base case same volume Difference is Significant?				100%	100%	100%	100%	100%	100%
				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume Difference is Significant?		100%	100%		100%	100%		100%	100%
		Yes	Yes		Yes	Yes		Yes	Yes

Table 4-3. Statistics for Number of Trucks Bypassed

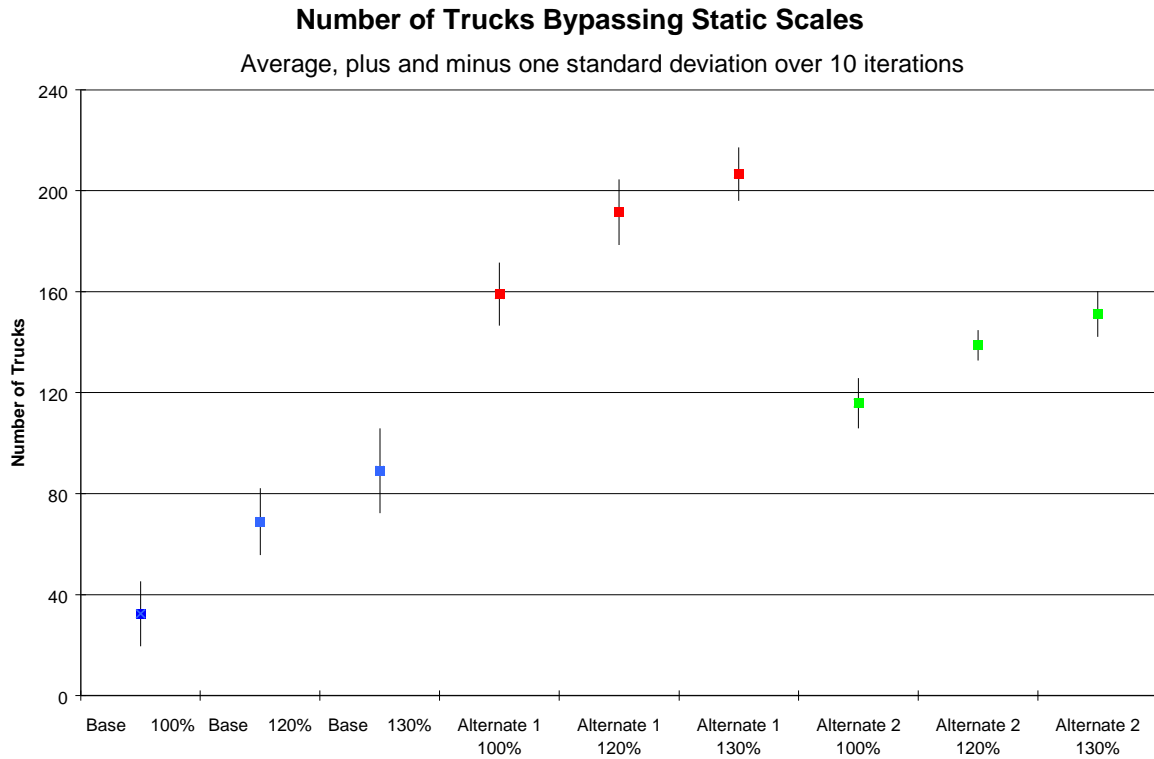


Figure 4-3. Average Number of Trucks Bypassing Static Scales

4.4 Average Number of Problem Trucks Missed

For each iteration, Mitretek counted the number of problem trucks missed as the sum of overweight trucks and trucks with safety or credential problems that were not weighed or inspected. For each scenario, Mitretek found the average percent of problem trucks missed across the ten iterations. Table 4-4 and figure 4-4 present the results.

Nbr problem trucks missed	Base 100%	Base 120%	Base 130%	Alt. 1 100%	Alt. 1 120%	Alt. 1 130%	Alt. 2 100%	Alt. 2 120%	Alt. 2 130%
Mean	2.40	4.70	5.70	2.80	3.30	3.60	0.00	0.00	0.00
Std. Deviation	1.35	2.16	1.77	1.32	1.64	1.51	0.00	0.00	0.00
Statistical Significance:									
Compared to base case same volume				87%	88%	88%	100%	100%	100%
Difference is Significant?				No	No	No	Yes	Yes	Yes
Compared to same case base volume		9%	53%		12%	6%		N/A	N/A
Difference is Significant?		No	No		No	No		N/A	N/A

Table 4-4 Statistics for Number of Problem Trucks Missed

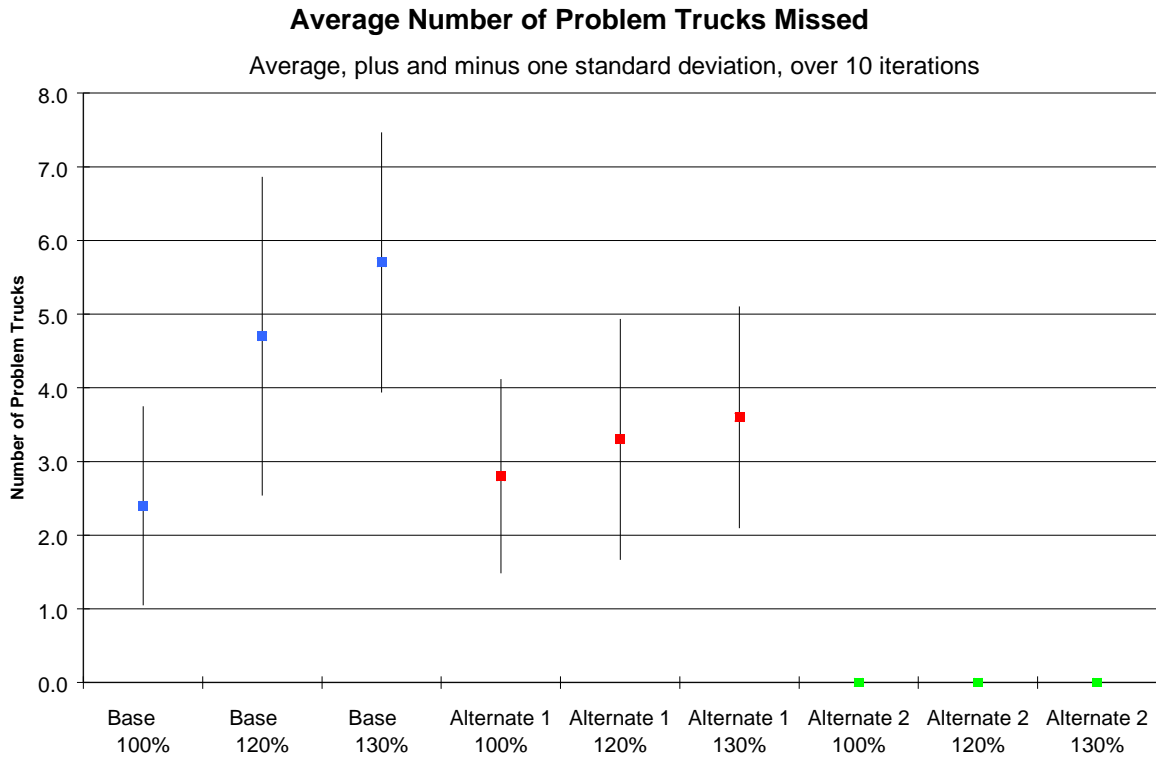


Figure 4-4. Average Number of Problem Trucks Missed

For the base case scenarios, problem trucks were missed when the scales were closed because of queue backup. When the scales were closed, no trucks were weighed, and trucks with credential or safety problems were not identified and inspected. The average number of such trucks increased with increasing volume. That stands to reason, because problem trucks were generated throughout the simulation, and the chance of a problem truck approaching the scales at a time when they were closed is proportional to the chance the scales were closed. The standard deviation is relatively large because the number of problem trucks was relatively small, and it was largely a matter of chance whether problem trucks came along at a time the scales were closed.

For the proposed WIM operation, the problem trucks missed were those overweight trucks allowed to bypass the scales because they did not exceed axle weight limitations and were not part of the random sample. Thus it was fully intentional that overweight trucks bypassed the scales and may not be regarded as a problem at all. As expected, this number increased with increasing traffic volume. The model assumes that trucks with safety or credential problems that are in the bypass lane are nevertheless spotted and directed to proceed to the inspection lot. Real-world experience indicates that it is problematic to spot these issues for trucks in a bypass lane.

In the second alternate case, all overweight trucks were weighed at the static scale, so none were missed. Likewise trucks with safety or credential problems that were in the bypass lane were spotted and directed to proceed to the inspection lot.

4.5 Average Queue Length

Table 4-5 and figure 4-5 show the average queue length over the course of the simulated two hours. This statistic included the count of all trucks on links 9, 10, and 11 up to the static scale. During the simulation the queue could be in any of the following states: (a) maximum value when trucks nearly reach the entrance to the ramp on the highway, causing the scales to close, (b) decreasing in size quickly if the scale is closed and trucks pass by without stopping, (c) decreasing in size slowly if trucks are being weighed at the scale at a rate faster than new trucks arrive, or (d) growing, if trucks are being weighed at the scale at a rate slower than new trucks arrive. Most of the time, the queue did not extend back to the highway and the scales did not close. The number of trucks that fit on each link is not constant because of the variations in truck length, but it doesn't change much.

Queue length	Base 100%	Base 120%	Base 130%	Alt. 1 100%	Alt. 1 120%	Alt. 1 130%	Alt. 2 100%	Alt. 2 120%	Alt. 2 130%
Mean	9.67	10.43	10.92	0.01	0.02	0.03	0.47	0.62	0.71
Std. Deviation	0.86	0.73	0.88	0.03	0.04	0.05	0.19	0.21	0.26
Statistical Significance:									
Compared to base case same volume				100%	100%	100%	100%	100%	100%
Difference is Significant?				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume		95%	100%		44%	71%		89%	97%
Difference is Significant?		Yes	Yes		No	No		No	Yes

Table 4-5. Statistics for Average Queue Length

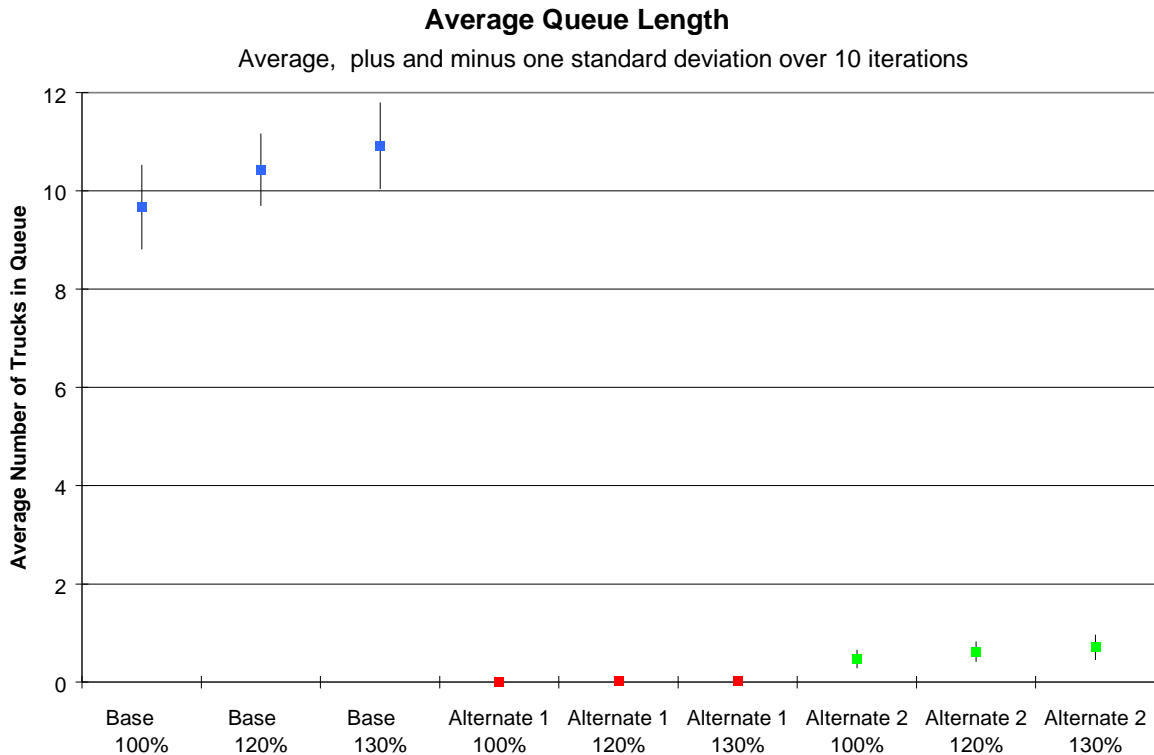


Figure 4-5. Average Queue Length

It is clear that the average queue length for the base case scenarios increased with the traffic arrival rate, and this is consistent with the average amount of time the scales were closed in section 4.1. The

queue is practically non-existent in the first alternate scenario because the number of trucks weighed during the simulation is so small. The small increase in queue size with traffic volume is not statistically significant. The queue length for the second alternate scenario is less than one, somewhat greater than for the first alternate scenario, but still significantly less than the base case.

Figure 4-6 portrays the simulated queue length as a function of time for one iteration of the base case, and the actual queue length recorded periodically by SDDOT during six hours of station operation. While nothing can be proved or disproved by such a comparison, the simulated queue length appears to exhibit the same type of behavior and stay within the same bounds as the actual queue length observations.

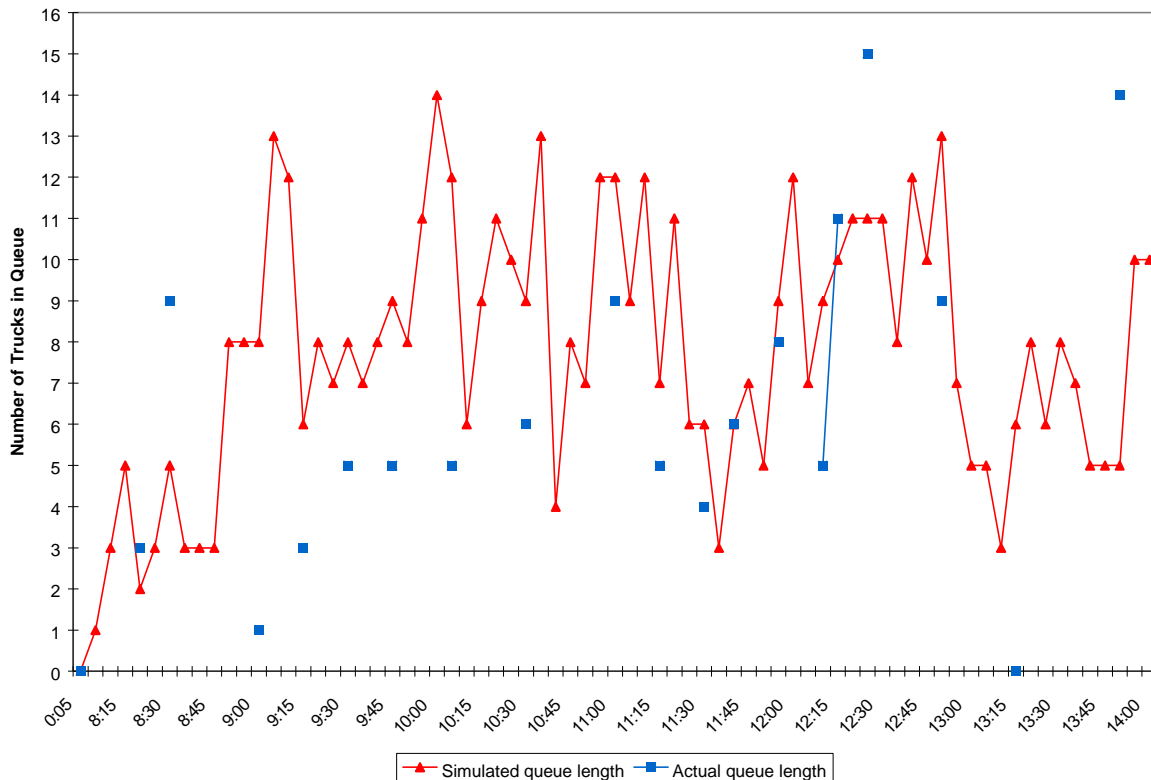


Figure 4-6. Comparison of Simulated to Actual Queue Length over Time

4.6 Average Time to Transit Station

Table 4-6 and figure 4-7 show the average time to transit the station for trucks of legal weight that entered the station. Overweight trucks or trucks that were inspected because of safety or driver credential concerns were excluded because their longer times were not caused by waiting in line. The time to transit the station for each truck is the number of minutes from when it was created on an origin link to when it left the simulation on a destination link. The average time is the sum of a constant (the travel time with no delay) and a waiting time caused by queuing.

Within the base case, the average time went down slightly as the traffic level increased because the scales were closed more often and more trucks were waved past the scale without stopping. The lower time for those trucks lowered the average time.

The average waiting time for the first alternate scenario was significantly less than for the base case scenarios, and somewhat smaller than for the second alternate scenario. These results are consistent with the average queue lengths reported in section 4.4. Most trucks took the bypass lane without stopping, and the trucks that were weighed encountered short or non-existent queues at the scale.

Station transit time (min.)	Base	Base	Base	Alt. 1	Alt. 1	Alt. 1	Alt. 2	Alt. 2	Alt. 2
	100%	120%	130%	100%	120%	130%	100%	120%	130%
Mean	8.68	7.86	7.56	1.14	1.15	1.15	1.75	1.84	1.65
Std. Deviation	0.77	0.39	0.39	0.03	0.02	0.02	0.35	0.65	0.40
Statistical Significance:									
Compared to base case same volume				100%	100%	100%	100%	100%	100%
Difference is Significant?				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume		99%	100%		45%	59%		28%	47%
Difference is Significant?		Yes	Yes		No	No		No	No

Table 4-6. Statistics for Average Time to Transit Station

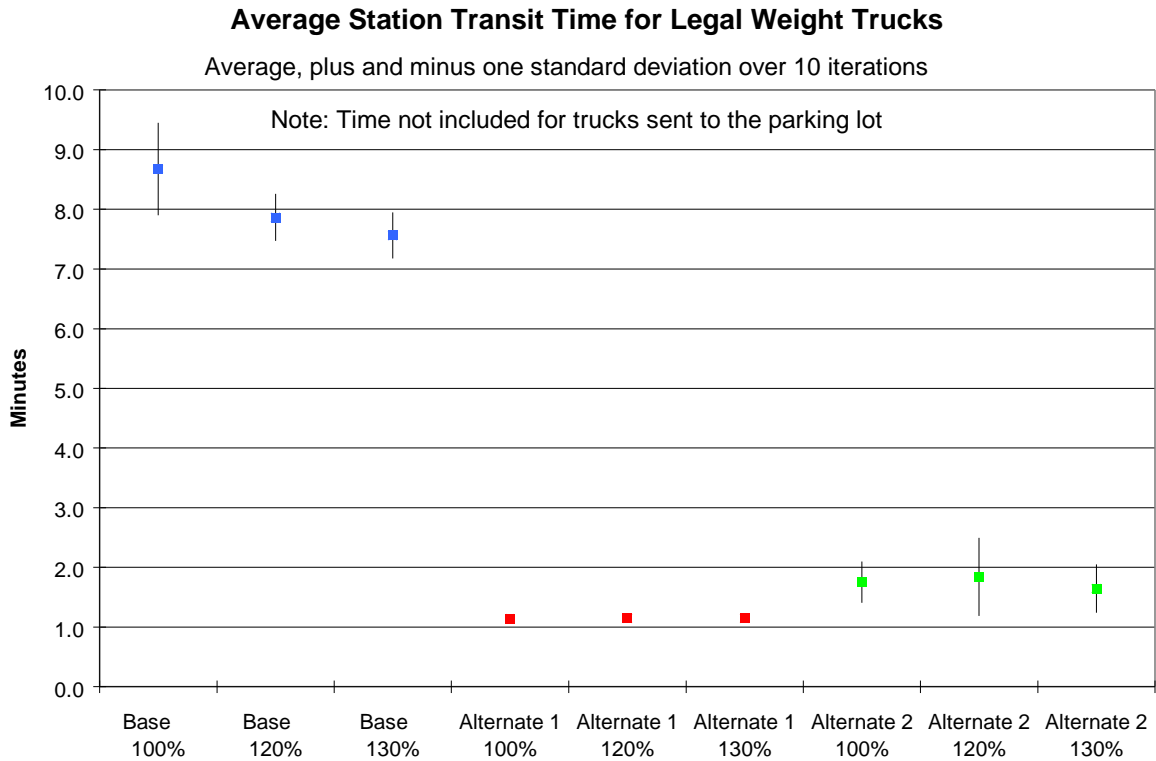


Figure 4-7. Average Time to Transit Station

4.7 Average Hard Deceleration for Cars

Table 4-7 and figure 4-8 show the average number of seconds of hard deceleration for cars. As explained in section 2, Mitretek’s threshold of hard deceleration for a car is 0.3g. In perfect driving conditions, hard deceleration would never be necessary. However, variations in driver attentiveness, reaction time, speed, and brake performance result in some cases where harder braking than average is necessary to avoid a collision. Westa does not try to predict collisions, but uses the measure of

hard deceleration as a surrogate measure of safety. Hard braking for cars is typically caused by having to brake harder than expected to avoid hitting the truck slowing to enter the station and having to brake on the right lane of the highway approaching the spot where trucks exiting the station merge onto the highway. Cars may shift to the left lane to avoid slowing down at this spot, but sometimes a lane shift is not possible.

Hard decel. for cars (sec.)	Base 100%	Base 120%	Base 130%	Alt. 1 100%	Alt. 1 120%	Alt. 1 130%	Alt. 2 100%	Alt. 2 120%	Alt. 2 130%
Mean	4.05	6.01	7.40	3.64	4.22	6.67	2.96	5.03	6.59
Std. Deviation	1.46	2.30	2.29	1.78	1.31	1.97	1.61	1.65	1.88
Statistical Significance:									
Compared to base case same volume				42%	95%	55%	87%	71%	60%
Difference is Significant?				No	Yes	No	No	No	No
Compared to same case base volume		96%	100%		58%	100%		99%	100%
Difference is Significant?		Yes	Yes		No	Yes		Yes	Yes

Table 4-7. Statistics for Seconds of Hard Deceleration for Cars

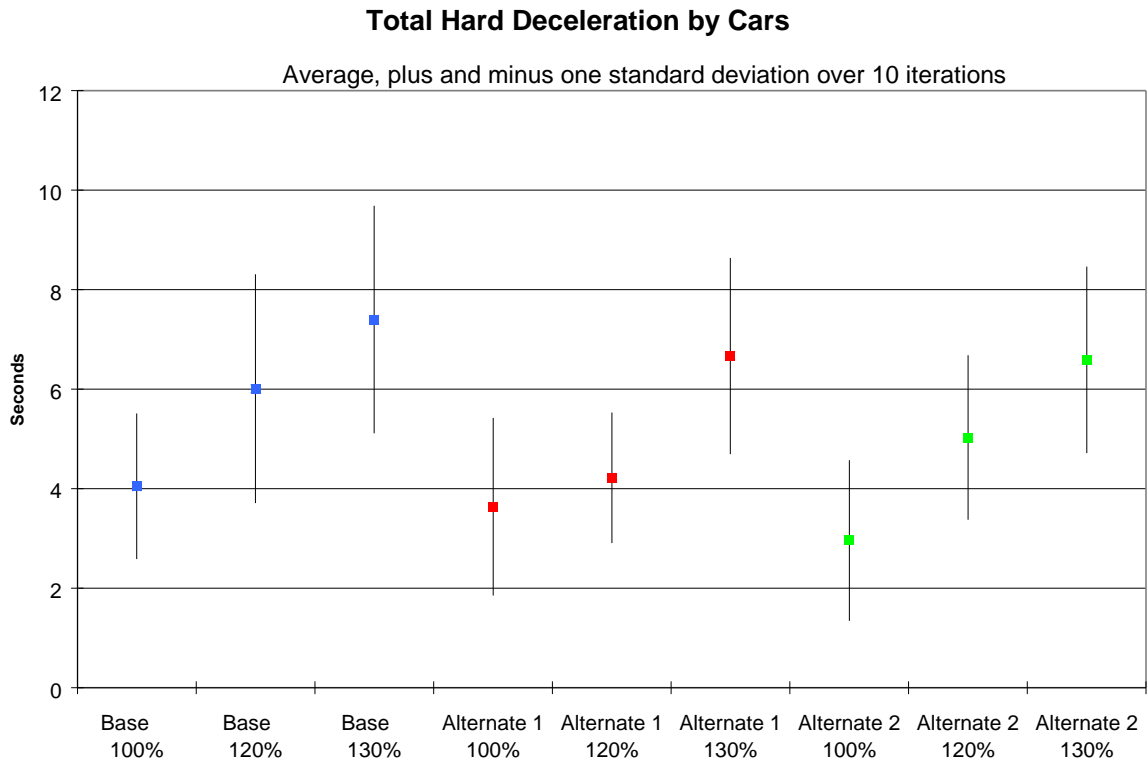


Figure 4-8. Average Number of Seconds of Hard Braking for Cars

All scenarios clearly experience greater levels of cars decelerating as the traffic level increases. As more trucks exit and reenter the highway, there is more friction with cars. However, there is no statistically significant difference among the scenarios with a given traffic level. That is to be expected since there is no difference in number of trucks exiting or reentering the highway among the three scenarios. All trucks exit the highway and then reenter the highway, whether they have been weighed or not.

4.8 Average Hard Deceleration for Trucks

Table 4-8 and figure 4-9 show the average number of seconds of hard deceleration for trucks. Most of the deceleration comes on the exit ramp and as trucks reenter the highway. Mitretek’s threshold of hard deceleration for a truck is 0.2g. For the base case scenario, the amount of hard deceleration increases with traffic volume. As the volume increases, the average truck queue length increases, and the tail end of the queue is encountered sooner by trucks entering the station.

For the first and second alternate scenarios, the queue of trucks is far shorter, and the trucks have much more time to slow gradually as they enter the station. For each of these cases, the increase caused by the increase in traffic is small but statistically significant because of the small standard deviations.

Hard decel. for trucks (sec.)	Base	Base	Base	Alt. 1	Alt. 1	Alt. 1	Alt. 2	Alt. 2	Alt. 2
	100%	120%	130%	100%	120%	130%	100%	120%	130%
Mean	286.70	371.06	409.82	23.41	35.46	42.60	33.16	48.71	56.74
Std. Deviation	29.29	37.73	42.24	8.33	11.11	9.63	12.48	15.73	13.52
Statistical Significance:									
Compared to base case same volume				100%	100%	100%	100%	100%	100%
Difference is Significant?				Yes	Yes	Yes	Yes	Yes	Yes
Compared to same case base volume		100%	100%		99%	100%		98%	100%
Difference is Significant?		Yes	Yes		Yes	Yes		Yes	Yes

Table 4-8. Statistics for Seconds of Hard Deceleration for Trucks

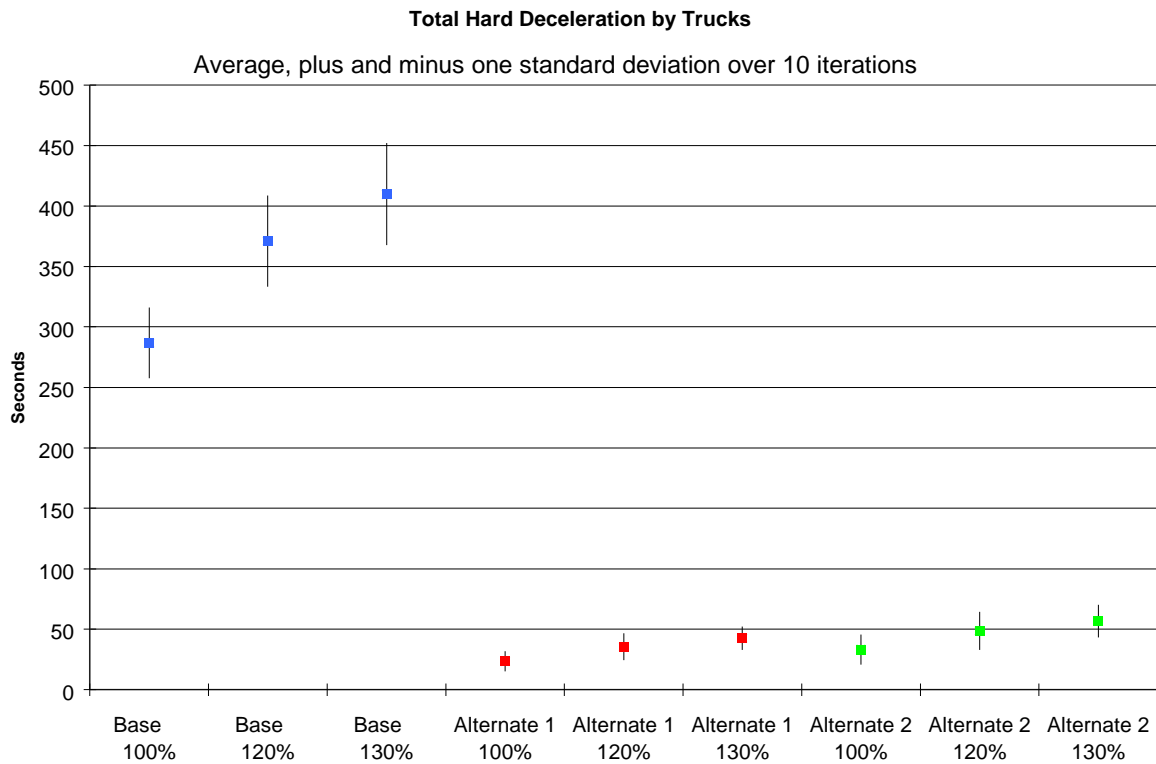


Figure 4-9. Average Number of Seconds of Hard Deceleration for Trucks

Section 5

Summary and Conclusions

5.1 Results for Base Case Scenarios

The measures of effectiveness for the base case scenario confirm the presence of congestion at the McCook weigh station during peak periods. During each simulation run of the current peak period scenario with the average truck arrival rate exceeding the average weighing rate at the scales, the queue of trucks waiting in line backed up nearly to the highway on several occasions. During those occasions, the scales were closed and all trucks, including overweight or unsafe trucks, were permitted to proceed without any enforcement. SDDOT staff and weigh station operators confirmed that the results of the base case scenario are consistent with their actual experience.

The problem of queue overflow grows significantly when an increase of 20% or 30% in the average traffic arrival rate is simulated, causing the time the scales are closed to more than double. With the expectation that truck traffic will increase by 20% to 30% on South Dakota highways over the next seven years, it is evident that the current McCook facility will often be overwhelmed.

5.2 Results for the First Alternate Scenario

The first alternate scenario represents the operation of a replacement station with a WIM scale, a bypass lane, and an operating policy of sending to the static scales a randomly-selected 10 percent of the trucks over 80,000 pounds gross weight plus all trucks exceeding maximum axle weight limitations (Mitretek assumed 10 percent of the trucks over 80,000 pounds gross weight exceeded axle weight limitations). The results of the simulations showed that the WIM scale and operating policy would be very effective in reducing the number of trucks that must be weighed at the static scale. With the distribution of truck types and truck weights supplied by SDDOT, one to two percent of the simulated trucks were overweight. When only 20 percent of those overweight trucks were sent to the scales, the queue length and the time spent waiting in line were cut nearly to zero. The number of trucks weighed was very small. The frequency of queue overflow was cut to zero. Even with a growth in traffic of 20 or 30 percent the overflow/congestion problem is completely eliminated.

5.3 Results for the Second Alternate Scenario

The second alternate scenario modeled the same replacement station configuration as the first alternate case, but the operating policy was changed to direct all trucks measured over a 70,000 pound threshold by the WIM scale to the static scales. This scenario was also sufficient to reduce congestion to very low levels. The number of trucks in the queue was significantly reduced and the time the scales were closed because of queue overflow was cut to zero, even with a growth in traffic of 20 or 30 percent. The difference in results between this scenario and the previous one (the lower and upper bound for overweight trucks sent to the static scales) was small, suggesting that the precise percentage of axle weight violations or the percentage of gross weight violations sent to the static scales does not make a significant difference.

5.4 Conclusions

The congestion level at the current McCook facility during peak period will persist and will increase as truck traffic levels increase. The safety risk to traffic from queue backups, the workload of the

station operator, and the time spent by trucks waiting in line will increase. More overweight and unsafe trucks will be missed because the scales must be closed to prevent overflow.

The construction of a replacement station with a WIM scale and an operating policy permitting most trucks to bypass the static scales would eliminate the congestion problem for current and project traffic loads. Truck queue lengths would not reach levels requiring the scales to close to prevent overflow. The state would be able to target overweight trucks for weighing and enforcement and would be able to spend more time inspecting trucks with safety or driver credential concerns. In addition, all trucks would experience a reduction in delay, since most trucks would not have to stop at all and those trucks that must be weighed would wait in line significantly less time.

One drawback to the WIM scale is that the station operator has a reduced opportunity to scan the truck and driver for safety concerns as trucks pass by farther from the station without stopping.

TABLE OF ACRONYMS

CVO	Commercial Vehicle Operations
FHWA	Federal Highway Administration
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
OMC	Office of Motor Carriers
OOS	Out-of-Service
PRT	Perception-reaction time
PT	Perception time
RT	Reaction time
SDDOT	South Dakota Department of Transportation
SDHP	South Dakota Highway Patrol
VIN	Vehicle Identification Number
VMS	Variable Message Sign
WIM	Weigh-in-Motion

References

1. *Best Practices for Commercial Vehicle Monitoring Facilities Design*, Publication No. FHWA-SA-96-001, September 1995, U.S. Department of Transportation, Federal Highway Administration, Office of Motor Carriers, Washington, DC.
2. Glassco, R.A., 1999, *Westa Version 2.3 User Guide*, Mitretek Systems, Washington, DC.
3. *States' Successful Practices Weigh-in-Motion Handbook*, Publication No. FHWA-SA-96-001, September 1995, U.S. Department of Transportation, Federal Highway Administration, Office of Motor Carriers, Washington, DC.
4. Weng, Ying, *Analysis Procedures for Queue and Delay at Weigh Facilities*, Appendix C to Reference 1. .
5. Facts About the Trucking Industry, Team 2000, Washington, DC.

Appendix A

This appendix presents a complete listing of the input file defining the McCook base scenario. Variations of this file defining the alternate scenarios are discussed in sections 3.3 through 3.5.

```
McCook 100% Base case scenario
runLength:      120      # run for two hours
randomSeed_truck: 101
randomSeed_link: 11
avgCreatTime:   10      #
maxWt:          80000    # <- maxWt for static scales
TimeStep .1

[TruckInfo]
Class 2 Cars
maxAccRange:    2.8      6.3      .009      # (mi/hr/sec)
maxDecRange:    17.3     20.7     .30      # (mi/hr/s)
weightRange:    0        6000     # (lbs)
weightDistrib:  0.0 0.0 4.1 9.9 31.4 27.3 14.9 6.6 4.1 1.7 (%)
lengthRange:    10 20      # (ft)
lengthDistrib:  0.0 0.0 1.7 7.4 19.0 28.9 27.3 10.7 5.0 0.0 # %

Class 3 2-axle 4-tire (Pickup trucks)
maxDecRange:    16.8     18.6     .30
lengthDistrib:  0.0 0.0 96.2 0.0 0.2 1.5 1.9 0.3 0.0

Class 4 Buses
maxDecRange:    16.8     18.6     .30
lengthRange:    30 40
lengthDistrib:  0.0 0.0 96.2 0.0 0.2 1.5 1.9 0.3 0.0

Class 5 2-axle 6-tire single units
weightRange:    0        100000    # (lbs)
weightDistrib:  0.7 23.1 28.6 20.4 14.3 12.2 0.0 0.0 0.7 0.0 # (%)
lengthRange:    0        50      # (ft)
lengthDistrib:  0.0 0.0 2.4 64.1 23.6 9.9 0.0 0.0 0.0 0.0

Class 6 3-axle single units
maxAccRange:    1.3      2.6      .009      # (mi/hr/sec)
maxDecRange:    12.8     16.0     .30      # (mi/hr/sec)
weightDistrib:  0.0 0.0 0.0 84.6 15.4 0.0 0.0 0.0 0.0 0.0 # (%)
lengthDistrib:  0.0 0.0 0.8 18.7 72.3 8.2 0.0 0.0 0.0 0.0

Class 7 4 or more axles, single unit
weightDistrib:  0.0 0.0 9.6 38.6 43.4 8.4 0.0 0.0 0.0 0.0 # (%)
lengthDistrib:  0.0 0.0 0.0 11.5 50.0 34.6 3.8 0.0 0.0 0.0

Class 8 4 or fewer axles, single trailer
weightDistrib:  0.0 20.6 14.7 8.8 2.9 17.6 32.4 0.0 0.0 # (%)
lengthRange:    20 70      # (ft)
lengthDistrib:  0.0 6.8 22.4 35.1 16.4 7.4 6.5 4.2 1.1 0.0

Class 9 5-axle, single trailer
weightDistrib:  0.0 0.0 0.1 3.9 13.3 15.7 15.7 48.5 2.7 0.1 # (%)
lengthRange:    35 85
lengthDistrib:  0.2 0.6 2.1 10.0 37.1 46.0 3.9 0.2 0.0 0.0

Class 10 or more axles, single trailer
weightRange:    10000 110000
weightDistrib:  0.0 0.0 0.0 1.9 11.3 17.0 24.5 24.5 13.2 7.6 # (%)
lengthDistrib:  0.0 0.0 0.9 8.8 31.0 27.9 27.4 3.5 0.4 0.0

Class 11 5 or fewer axles, multi-trailer
weightRange:    20000 120000
```

```
weightDistrib: 0.0 1.9 10.1 33.5 42.4 8.2 1.9 1.3 0.0 0.6 # (%)
lengthDistrib: 0.0 0.0 0.0 0.0 0.0 33.4 33.3 11.1 22.2 0.0
```

Class 12 6 axles, multi-trailer

weightRange: 20000 120000

```
weightDistrib: 0.0 1.9 10.1 33.5 42.4 8.2 1.9 1.3 0.0 0.6 # (%)
lengthDistrib: 0.0 0.0 0.0 0.0 0.0 0.0 26.4 36.8 36.8 0.0
```

Class 13 7 or more axles, multi-trailer

weightRange: 70000 170000

```
weightDistrib: 0.0 0.0 0.0 0.0 11.1 22.2 11.1 11.1 22.2 22.3 # (%)
lengthRange: 55 105
lengthDistrib: 10.7 9.0 6.3 1.7 4.2 3.6 10.7 25.2 27.0 1.7
```

ClassDistribution 2 origins

```
Link c1 c2 c3 c4 c5 c6 c7 c8 c9 c10 c11 c12 c13
0 0.0 44.6 27.4 0.3 3.5 1.0 0.0 17.0 3.1 0.1 2.3 0.4 0.3
1 0.0 74.0 21.2 0.0 0.8 1.6 0.0 0.8 1.6 0.0 0.0 0.0 0.0
```

[GraphInfo]

```
Stat "Total number of trucks" Count 2
Stat "Overweight trucks" Count 3
Stat "Waved through" Count 15
Stat "Violators missed" Count 16
Stat "Average time" Time 12
Stat "Trucks in queue" Queuelen
```

```
View 1 1817 2857 -237 545
View 2 1160 2701 -237 545
View 3 784 1317 57 457
View 4 48 881 -96 529
View 5 888 1107 135 298
View 6 4160 4501 -36 221
```

GraphicsMode d

[Attributes]

#	name	cab color	trailer color	%	expr	%	expr
1	"car"	yellow	yellow	100	{ c2 }		
2	"truck"	default	default	100	{ (not c3) and (not c2)		
3	"overweight"	default	lightred		owt { }		
4	"safety check"	default	black	2	{ 2 }		
5	"credential check"	lightred	default	4	{ 2 }		
6	"fixable"	default	default	100	{ 3 }	100	{ 5 }
7	"inspected"	lightblue	lightblue	0	{ }		
8	"OOS"	black	black	0	{ }		
10	"held at scales"	default	default	50	{ 3 }		
12	"legal"	default	default	100	{ 2 and (not 3) and (not 4		
) and (not 5) }						
15	"waved through"	default	lightgray	0	{ }		
16	"bad misses"	default	brown	0	{ }		

[Tests]

```
# ----
1 "trucks right" A { 2 } { }
2 "to parking lot" A { 3 or 4 or 5 } { }
3 "safety check" A { not 6 } { 8 }
4 "fix some" A { 6 } { 7 }
6 "missed truck" A { 2 } { 15 }
7 "bad miss" A { 15 and ( 3 or 4 or 5 ) and ( not 7 ) } { 16 }
```

[ServiceTimes]

#	name	expression	random type	parms
1	"weighing time"	{ 10 }	Erlang	90 { } Erlang 41
2	"inspection time"	{ 5 }	Erlang	900 { 4 } Erlang 3000 { 3 } Erlang 1200

```

[LinkInfo]
#  type      ahead  spd      dimensions      typespecific
#  ----      - - - -      - - - - -
0  Orig      2   -   55      4400  100 3900  100      A .8 LL 1
1  Orig      3   -   55      4400   80 3900   80      A .2 RL 0
2  Trans     6   -   55      3900  100 2700  100      LL 3
3  Trans     4   -   55      3900   80 3200   80      RL 2
4  Branch   23   5   55      3200   80 2800   80      T 1
5  Trans     6   -   55      2800   80 2700  100      Y
6  Branch    7   9   55      2700  100 2200  100      T 1 LL 24
7  Trans     8   -   55      2200  100  100  100      LL 25
8  Dest      -   -   55       100  100   0  100
9  Trans    10   -   35      2200  100 1300  217      Q
10 Trans    11   -   15      1300  217 1200  230      Q AS 22
11 Branch   16  12  10      1200  230  920  230      T 1 Q
12 Branch   17  20   5       920  230  860  230      ST 1 T 2 CL 9 C .5 O .2 SC
13 Trans    14   -   10      1200  230 1170  220
14 Trans    15   -   10      1170  220  880  220
15 Trans    17   -   25       880  220  860  230      Y
16 Branch   17  17  10       920  231  860  231      T 6
17 Branch   18  18  35       860  230  730  230      T 7
18 Trans     8   -   55       730  230  100  100      Y
20 Trans    21   -   10       860  230  870  370      CC 882 297
21 Park     22  22   5       870  370 1160  350      ST 2 T 3 OC 970 440 PS 10
22 Branch   13  13  10      1160  350 1200  230      T 4 CC 1170 287
23 Trans    24   -   55      2800   80 2700   80
24 Trans    25   -   55      2700   80 2200   80
25 Dest     -   -   55      2200   80   0   80
40 Bldg     -   -   0       910  250 1000  280      "Office"
41 Bldg     -   -   0       920  224  932  234      "Scale"

```

[End]