Paper No. 980746

Simulation Modeling of Electronic Screening at Weigh Stations

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Number of words: 4014

ABSTRACT

Electronic screening of trucks prior to reaching points of regulatory compliance checks (typically, weigh stations) would allow for more efficient use of government resources while reducing travel time for motor carriers. This paper studies the effects of electronic screening on reducing travel time and enhancing productivity of the weigh station using a new simulation model. The model illustrates the impact of electronic screening on motor carrier travel time savings and weigh station productivity assuming various levels of transponder equipped vehicles. The obtained results show that as participation grows, enforcement agencies, participating (transponder-equipped) and non participating trucks all share in the benefits afforded by a more efficient system.

INTRODUCTION

The Federal Highway Administration's (FHWA) Intelligent Transportation Systems for Commercial Vehicle Operations (ITS/CVO) program vision statement is: "Assisted by technology, trucks and buses will move safely and freely throughout North America (1, p. 182)." Electronic screening is seen as a key ITS function in the pursuit of this vision. Electronic screening of trucks prior to reaching points of regulatory compliance checks would allow for more efficient use of states' resources. As recently checked safe, legal trucks bypass these facilities, state enforcement agencies could focus their efforts on non participating carriers (1, p. 200).

Electronic screening systems use Automatic Vehicle Identification (AVI) technology to identify a participating vehicle as it approaches a weigh-station. Typically, an AVI tag (a transponder) is read by a roadside reader. The roadside reader identifies the truck and links its identification to the truck's weight and axle spacing information that is collected by a mainline weigh-in-motion (WIM) scale. Based on the identification of the truck, the WIM measurement, and decision rules coded into the roadside computer, a determination is made as to whether the truck is to be signaled into the weigh station or allowed to bypass. The screening decision, to permit or not permit a bypass, is communicated back to the transponder (2). The in-cab transponder, in turn, signals the driver with either a green light to bypass or a red light to pull into the weigh station. Transponder-equipped trucks that are electronically cleared do not have to leave the mainline and thus benefit from fuel and time savings. By reducing the number of vehicles that have to pull into facilities that are operating at or near capacity, mainline screening also reduces frequency of full queues at weigh stations. Full queues result in either the line of trucks backing on to the mainline, a dangerous situation, or waiving trucks past the weigh station without performing compliance checks (unauthorized bypasses).

Operation of weigh stations, without electronic screening, can and often does result in three inefficiencies. First, trucks that are in compliance with regulations are forced to stop and are delayed while checks are performed. Second, enforcement officials devote the majority of their resources checking compliant trucks. Third, trucks which are neither manually or electronically screened are allowed to bypass the weigh station without being weighed or otherwise observed. Electronic screening reduces all three inefficiencies. Because truck participating in the electronic screening programs are not routinely stopped at weigh stations (they may be stopped based on exception or random inspection), they are able to minimize or entirely avoid the delay that results from manual checks. Enforcement officials do not routinely inspect compliant trucks participating in electronic screening. Because participating trucks are not waiting in the queue at the weigh station, the queue is diminished, resulting in fewer unauthorized bypasses. In fact, our analysis of electronic screening shows that even compliant trucks which are not participating in the electronic screen program (trucks that are not transponder-equipped) benefit in terms of time savings as a result of shortened queues.

As the evaluator of the Advantage I-75 Operational Test and the Oregon Green Light deployment, two initiatives employing electronic screening, we were given the task of quantifying the impact of electronic screening in terms of travel time savings for motor carriers and enhanced productivity of the weigh station. To conduct our evaluation, we developed a simulation model that provides for visual animation of traffic operations approaching, through, and after a weigh station. The simulation provides a robust medium for evaluation as it can quantify the benefits of electronic screening under a variety of operating policy alternatives and display the operation of the system under each alternative using high fidelity animation. The animation allows a broad audience to better understand the analysis and the effect of electronic screening on weigh station throughput.

This paper documents the application of our simulation model. The paper illustrates the use of the model through a case study of a prototypical weigh station located on an interstate with high truck traffic volume. Although only one weigh station is used in the case study illustration, we have used the simulation to analyze electronic screening for other designs. One of the advantages of this simulation model is its ability to simulate hypothetical scenarios. Part of the electronic screening evaluation goal is to extrapolate the obtained results into the future. Thus performance measures (i.e., delay, unauthorized bypasses, trucks checked, etc.) can be projected into the future, illustrating the implications of growth in truck traffic or transponder usage. In many cases, existing manual facilities are unable to keep pace with current truck traffic levels and allow an inordinate number of unauthorized bypasses. State enforcement agencies are, therefore, compelled to seek capacity enhancements for the weigh stations. Electronic screening is a feasible option for increasing capacity without a multi-million dollar investment in expanding the physical infrastructure of the weigh station.

COMPUTER SIMULATION MODEL

Computer simulation is a well known and powerful technique for testing the impact of changes in variables or parameters for systems where the effect of such changes cannot be determined analytically (3, p.227). It is also an appropriate tool for traffic experiments where similar field experiments are impractical. Thus, in this study, a simulation model is used to evaluate the impact.

A review of existing traffic simulation models, such as CORSIM (4) and INTEGRATION (5), indicated that they are not applicable for evaluation of electronic screening at weigh stations. These models do not allow for dynamic change in truck characteristics which would be necessary to simulate the AVI reader/transponder function. Modifying these models to simulate electronic screening of trucks at a weigh station would be very difficult and expensive. Therefore, we developed a new simulation model.

The new model consists of two modules, a weigh station and a mainline module. This paper describes the weigh station module which examines the number of trucks forced to bypass a weigh station due to a full queue (unauthorized bypasses) and determines the travel time saved by allowing compliant trucks to be screened electronically at mainline speed. The mainline module measures the reduction in fuel consumption and potentially other benefits such as improvement in traffic efficiency due to less merge and diverge activities in the vicinity of the weigh station. The mainline module and its integration with the weigh station module will be examined in a future study.

The weigh station simulation module is a microscopic, stochastic model with a powerful animation capability. The simulation module is built in Arena (6) simulation language. The "Pack and Go" feature of Arena enables the end-users to view the model's animation and outputs using Arena Viewer software. The Arena Viewer software, runs the "packed" model on any Personal Computer running Windows 95.

Weigh Station Simulation Module

The weigh station model design is based on the existing geometry and functionality of a given weigh station, yet is flexible enough to accommodate the potential modifications of the weigh station policy and procedure. Given an option to change the model's parameters, a "what-if" analysis can be done.

The weigh station module is specifically designed to simulate traffic operations in and around a weigh station facility. It simulates truck movement through a weigh station, the weighing of the trucks, and inspection. One of the most important parts of this module is the inclusion of the decision making logic that is associated with the electronic screening system's assignment of bypass or pull-in flags to the approaching trucks. The electronic screening decision making logic for this study is based on the Advantage I-75 functional requirements document (7). Figure 1 presents an overview of the electronic screening bypass and pull-in logic.

The model generates each entity (a truck), according to an exponential distribution in the simulation and attributes the entity with vehicle characteristics. For example, if the user decides to test the implication of having ten percent of the population of trucks equipped with transponders, the program randomly allocates transponders to ten percent of the entities. Other attributes are assigned following a discrete or continuous probability function. These attributes could include such vehicle characteristics as classification, axle spacing, and axle weights. When electronic screening is deployed in a network or a corridor of weigh stations, the simulation also has the ability to take into account information regarding the vehicle which was written to the transponder during prior interrogation (e.g., the transponder might contain the weight when it was weighed at a static scale upstream earlier in the day).

The decision making engine is triggered when a transponder-equipped truck passes the Advance AVI reader site located on the mainline. The transponder data (prior information written to the transponder) as well as WIM data (e.g., axle weights and spacing), which initially were assigned to each truck, are recorded by the roadside reader. If a truck successfully satisfies all the conditions stated in the logic, it is awarded a bypass flag. If not, it must enter the upcoming weigh station (pull-in). All trucks that are not assigned a transponder must also enter the weigh station.

The allowable weight criteria and the bridge formula are the two main components of the decision making processor. Given a truck's axle weights and spacing information from the WIM, these components determine the truck's compliance with weight regulations.

The logic used by the simulation have been verified and the results of the simulation have been validated by comparing the travel time collected in the field to those generated by the simulation without the availability of electronic screening. The validation procedure will be described in more detail later in the paper.

Input and Output Data

The weigh station simulation module is built based on actual truck traffic patterns and geometry data collected at weigh station sites or obtained from local agencies. The default input data, therefore, presents the existing conditions of a weigh station. The model, however, provides the users the opportunity to modify the default parameters to examine different scenarios. The following are examples of parameters that can be modified prior to a simulation run:

- Hourly traffic volume
- Percent of trucks in the traffic stream
- Percent of trucks with transponders
- Percent of truck subjected to an safety inspection which is more thorough than weighing
- Average duration of safety inspection

The static scale weighing duration is not listed among the changeable parameters. The weighing times are randomly generated according to a statistical distribution which may not be modified by the users. Field data provides no good statistical distribution for the safety inspection duration since only a small number of the weighed trucks (less than 3 percent) are being sent for the safety inspection.

The output provides the principle performance attributes. This includes the number of unauthorized bypasses and trucks' travel times (time spent being weighed and in line at the scale). Other output parameters include the queue length, the average time in the system, and total number of trucks processed per hour.

Model Validation

The model may provide results which are not identical to the observed system. The purpose of model validation is to determine if the model replicates the actual system at an acceptable level of confidence (8, p.129). The simulation results are compared to the real system to validate the weigh station simulation module.

The resemblance of the functionality of traffic movements through an unsignalized intersection and static scale at weigh stations led to the validation data collection method suggested for delay study at unsignalized intersections. In this method, total delay at unsignalized intersections is defined as "...the total elapsed time from when a vehicle joins the queue until the vehicle departs from the stopped position at the head of the queue (9, p.2-9)." Using the same concept, total delay at weigh stations' static scales is measured using a plate-reading method.

The data collection crew consists of two individuals who record arrival times and plate numbers of trucks joining the queue (point 1), another individual who records the arrival and departure times and plate numbers of trucks at the static scale (point 2), and two other individual who record the departure time and plate number of trucks leaving the weigh station (point 3). The number of unauthorized bypasses are concurrently collected by another individual positioned at point one.

Having the truck arrival times at the these points, the static scale total delay (i.e., delay from points one to two; d_{12}) and the travel time from the static scale to the exit point (i.e., points two to three; d_{23}) of each truck can be determined by matching the plate numbers in a database system. The time difference between the arrival and departure of trucks at the static scale is referred to as static scale service time.

The static scale total delay (d_{12}), unauthorized bypass percentages, and travel time (d_{23}) are determined by running the weigh station simulation model, assuming existing conditions at a weigh station (i.e., no transponder-equipped truck participation) and using the traffic volume and service time collected at peak and off-peak periods.

Table 1 compares the field data to the simulation results which are obtained from ten two-hour simulation runs. This table also includes the 95 percent confidence intervals for evaluation of the generated point estimate of means. These confidence intervals provide lower and upper limits of the true point estimate of averages. Therefore, it can be stated that with 95 percent confidence the true afternoon peak average total delay (d_{12}), for example, is within three percent of the average delay (288 seconds).

The comparison of the field data with the model's outputs establishes a level of confidence that the model is capable of simulating the existing conditions of the weigh station. The confidence in the simulation model yields a similar level of confidence in the model outputs obtained under the electronic screening strategy.

CASE STUDY

The weigh station simulation module is developed for a conventional weigh station with a static scale as shown in Figure 2. It is assumed that AVI roadside readers, located about a half of a kilometer (one quarter of a mile) upstream of the weigh stations, scan the approaching transponder-equipped trucks. In less than a second, the implemented electronic screening logic assigns bypass/pull-in flags to the trucks. The pull-in trucks must enter the weigh stations unless the queue is full. Trucks with bypass flags continue on at the mainline speed without entering the weigh station. In the simulation animated portrayal of the weigh station, green and red colors indicate truck's assignment of a bypass or a pull-in.

The system performance of electronic screening at the weigh station is evaluated by conducting a "before and after" study. In the absence of an electronic screening system all trucks must enter the weigh station. With the engagement of electronic screening logic, most of the transponder-equipped trucks are electronically cleared at the mainline. By comparing the results obtained from the simulation model run under the two described scenarios, the system performance of electronic screening at the weigh station is evaluated at different levels of transponder-equipped truck participation.

The case study involves a weigh station with a high volume of truck traffic (i.e., 440 trucks per hour). The collected field data at this site indicates that more than two thirds of trucks on the mainline are currently bypassing the weigh station due to a full queue at the weigh station (unauthorized bypasses). It also shows that under the weigh station's existing operation (i.e., disengaged electronic screening) the average static scale total delay is 290 seconds per truck.

Ten two-hour simulations were run for each of five scenarios. The input parameter, “percentage of trucks with transponders” was treated as the variable. Scenarios included 0, 10, 25, 40, and 65 percent transponder usage. All other input parameters presented in Table 2 remained constant and reflected field observations. Figures 3a and 3b show the output results in graphic form.

The figures illustrate the expected delay and percent of unauthorized bypasses. It indicates a reduction in average static scale delay (d_{12}) and unauthorized bypasses as the percentage of transponder-equipped truck increases. As a result, the weigh-station's capacity continues to be saturated even when forty percent of the truck stream is equipped with transponders, and hence the delay at the static scale does not appreciably diminish until participation is above forty percent. However, as participation surpasses forty percent, non-participating trucks begin to share in the benefits of electronic screening in the form of diminished queues and thus shorter delay times at the scales.

Relationship between participation levels and the number of authorized and unauthorized bypasses is illustrated through Figure 4a. Shown in the figure are the travel time savings components of the three possible outcomes for a truck traveling past a scale; unauthorized bypass, authorized bypass, and pull-in. As participation increases, the number of unauthorized bypasses decreases and total travel time savings for unauthorized bypassers decreases. Symmetrically, as the percentage of participants in the electronic screening increases, the aggregate travel time savings for participating trucks increases. Travel time savings for each truck that pulls into the scale also increases because congestion through the weigh station has been diminished. Total travel time savings for all trucks in the system increases markedly as the entire system has become more efficient. Enforcement also benefits because the percentage of trucks screened (see Figure 4b), by either manual or electronic means, increases as participation increases. Figure 4 provides a side by side comparison of the benefit curves for the enforcement agencies, in terms of capacity, and the motor carriers.

Reduced travel time is an incentive for all trucks to participate in electronic screening. However, as more trucks participate in electronic screening, the more efficient manual screening becomes, and relative time savings for participating trucks in comparison to non participating trucks decreases. Therefore, the marginal incentive to participate decreases as participation increases. This relationship is shown in Figure 5. Figure 5a shows the travel time savings per truck for participating trucks as the proportion of participating trucks increases. Above a forty percent participation rate, the travel time savings per truck diminishes precipitously. The total travel time saved (the number of trucks being electronically bypassed multiplied by the time each truck saves by bypassing) is illustrated in Figure 5b.

CONCLUDING REMARKS

The Federal Highway Administration's Office of Motor Carriers is currently funding the ITS/CVO Mainstreaming program. The FHWA has defined Mainstreaming as moving ITS/CVO from research, development, and testing to model deployment, then full deployment at the state and regional levels (10). Participating states are in the process of developing state and regional ITS/CVO business plans.

The Mainstreaming program demonstrates the FHWA's realization that the barriers to deployment of technologies such as electronic screening are not so much technical but, in fact, institutional. For electronic screening to compete successfully in the arena of state infrastructure investment, state decision makers must understand the nature and extent of benefits of electronic screening in weigh station productivity, vehicle safety, and reduced congestion. Furthermore, they must understand these benefits on a case by case or project by project basis. This is the level at which infrastructure investment decisions are made.

The weigh station simulation model holds great potential as an evaluation tool for decision makers. Simulation demonstrates and quantifies the effect of electronic screening for a particular weigh station factoring in its unique geometrical and functional characteristics.

The simulation results, presented in this study, indicate the effectiveness of electronic screening in reducing the travel time and number of unauthorized bypasses. Assuming a value of 16.25 dollars per hour for the travel time savings of a larger semi-truck (11), the simulation results of the case study indicate that the forty percent of transponder equipped trucks (i.e., 165 trucks) could save about 228 dollars per hour at the static scale weigh station equipped with the mainline electronic screening systems. At the same time, enforcement is made more efficient by reducing the number of unauthorized bypasses.

The application of the simulation model is not limited to the evaluation of electronic screening at weigh stations. Simulation would be as effective at evaluating the impact of design modifications or changes in service time on the productivity of a static weigh station. Simulation could be used to predict the impact of electronic screening at international border crossings. Simulation might also be used as a decision making tool when examining the benefits of introducing automation to a static toll bridge or road in terms of alleviating traffic congestion.

ACKNOWLEDGMENTS

The authors wish to thank the Federal Highway Administration, the Advantage 75 partners, and the Kentucky Transportation Center for providing the opportunity to work on the project that lead to this paper.

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LIST OF TABLES

TABLE 1. Field and Simulation Results

Parameters	Morning			Noon			Afternoon		
	Field	Model		Field	Model		Field	Model	
	Avg	Avg	C.I.[a]	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	321	320	314, 326	250	248	243, 252	290	288	284, 292
Unauth. bypasses %	61	60	58, 62	55	55	53, 56	63	63	62, 64
Travel time (d_{23}), sec.	38	37	36, 38	43	42	41, 43	57	57	56, 58

[a]95% confidence Intervals.

TABLE 2. Simulation Input Parameters

Parameters	Value
Traffic volume (vph)	2200
Truck percentage	20
Safety inspection rate (%)	5
Average safety inspection time (min)	15

LIST OF FIGURES

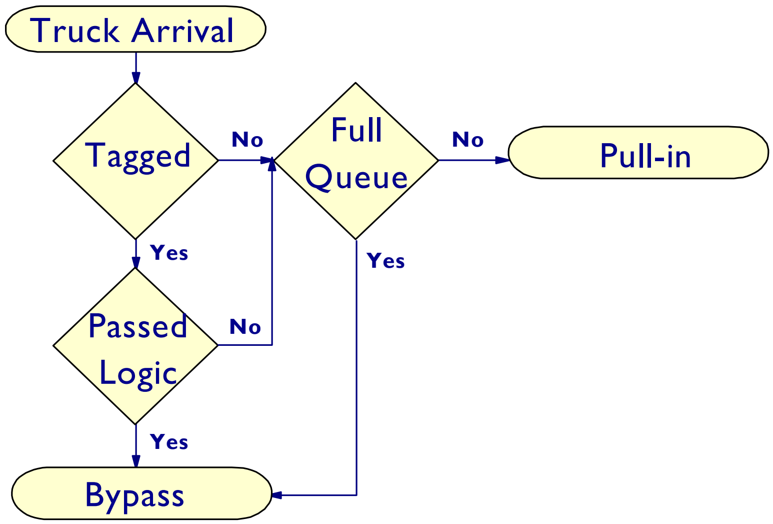

Figure 1. Electronic Screening System Bypass/Pull-in Logic

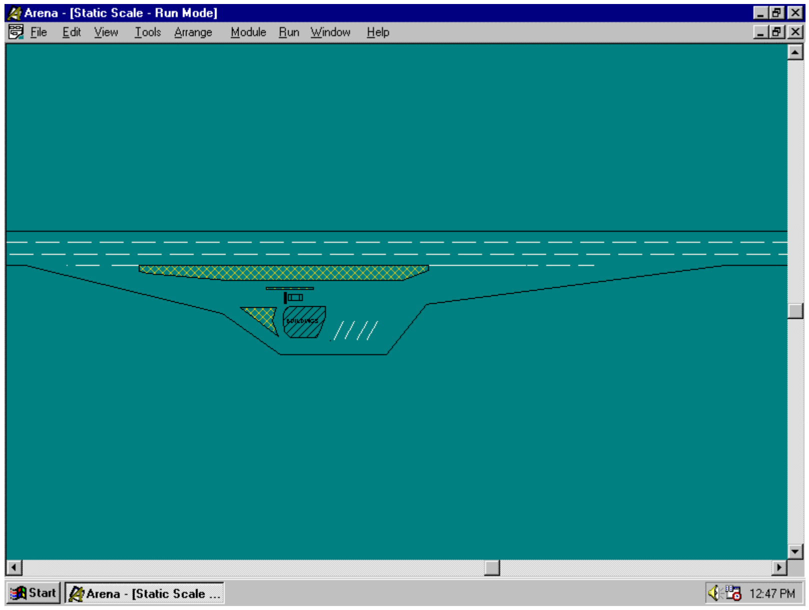

Figure 2. Static Scale Weigh Station

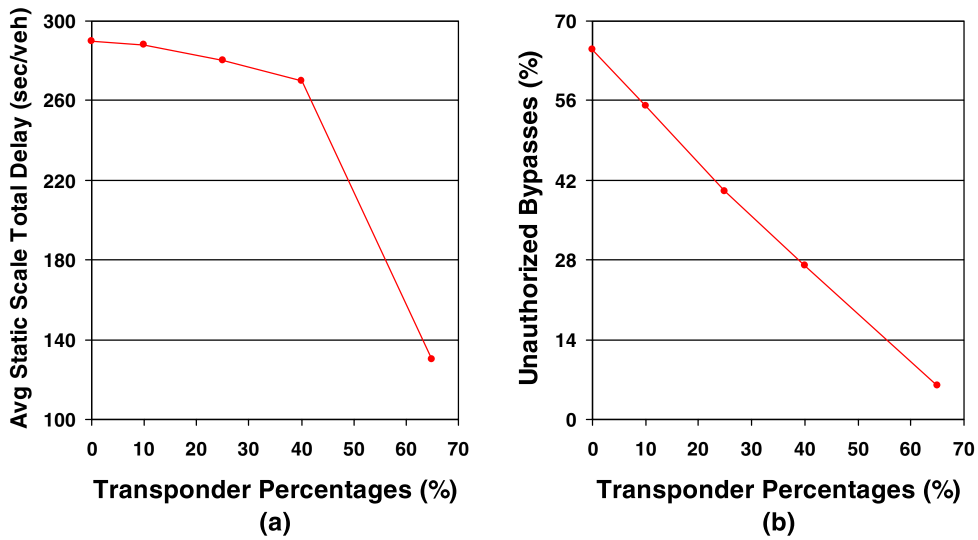

FIGURE 3. Effects of Electronic Screening on (a) Total Delay and (b) Unauthorized Bypasses

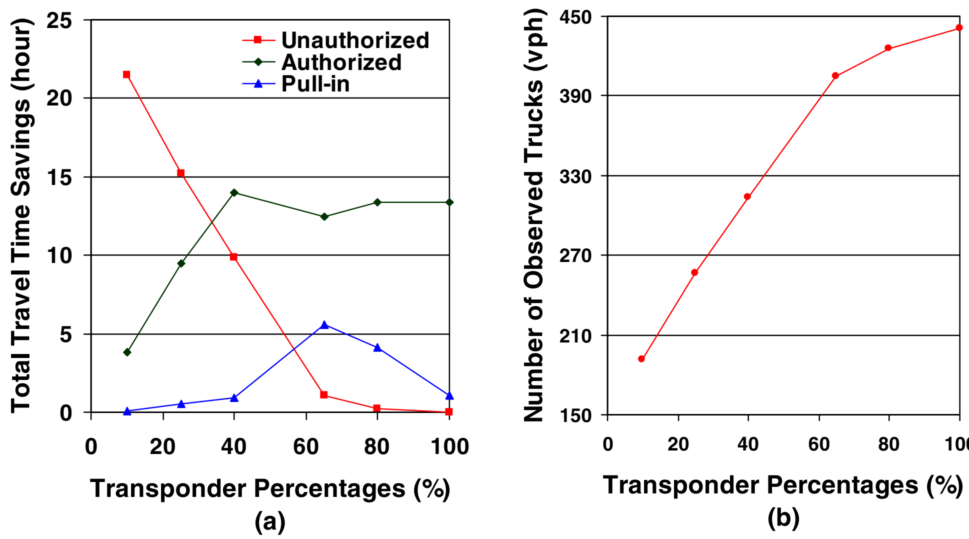

FIGURE 4. Benefits of Electronic Screening for (a) Motor Carriers and (b) Enforcement Agencies

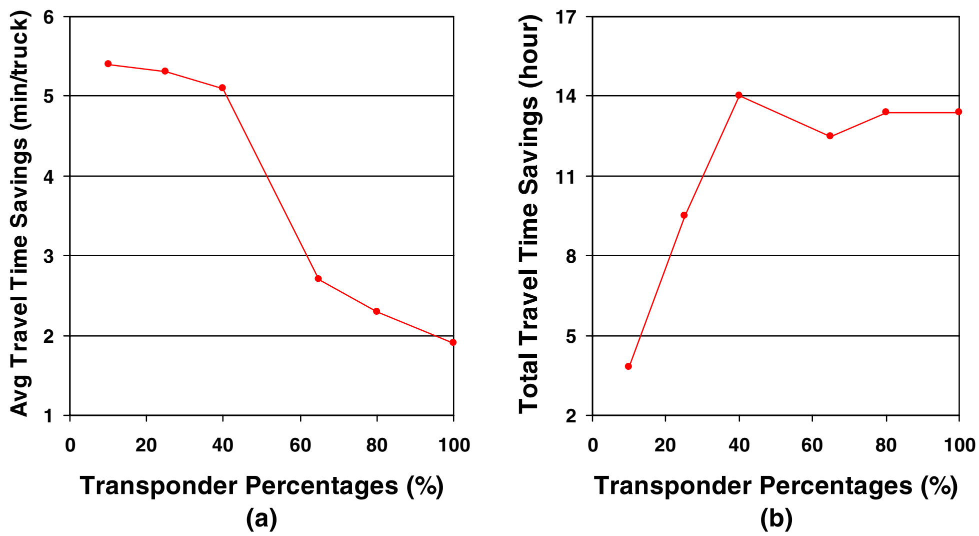

FIGURE 5. (a) Single and (b) Total Truck Travel Time Savings