Advantage I-75 Mainline Automated Clearance System

Final Report
Part 4 of 5: Simulation Modeling Individual Evaluation Report
Prepared for
The Advantage I-75 Evaluation Task Force

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The following is the fourth of five evaluation reports for the Advantage I-75 MACS electronic screening project. The vision of the Advantage I-75 program is to incorporate existing technologies into an ITS operational setting that will provide an initial step in the process of adapting the nation's highway systems to accommodate the increased demands placed on it. A field operational test entitled *Mainline Automated Clearance Systems* (MACS) was designed and implemented for the then-termed Advantage I-75 MACS program. The objective of the Advantage I-75 MACS operational test was to allow transponder-equipped trucks to travel any segment of the entire length of I-75 and Highway 401 at mainline speeds with no more than a single stop at a weigh station.

PURPOSE OF THE EVALUATION

The purpose of this portion of the evaluation was to develop a reliable computer simulation model to assess the effect that the Advantage I-75 Mainline Clearance Operational Test (MACS) has on weigh station queue length and the number of unauthorized (queue-based) bypasses resulting from weigh station overcrowding.

INTRODUCTION

As the evaluator of the Advantage I-75 MACS Operational Test, 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.

The simulation model consists of two modules, a weigh station and a mainline module. The weigh station module 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 fewer merges and diverge activities in the vicinity of the weigh station. The mainline module and its integration with the weigh station module is not examined in this project.

The weigh station simulation module is a microscopic, stochastic model with a powerful animation capability. The simulation module is built in Arena simulation language (1). 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.

This report documents the application of the weigh station simulation model. The report illustrates the use of the model through a case study of the Knoxville, Tennessee northbound weigh station. This is 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 the average static scale total delay is 290 seconds per truck.

Although only one weigh station is used in the case study illustration, we have used the simulation to analyze electronic screening for the other selected weigh stations along the I-75 corridor. Table 1 includes the locations and types of the simulated weigh stations. Each state is provided with the Arena Viewer software, the “packed” model of the state’s selected weigh station, and a user manual.

Table 1. Selected Weigh Stations Along I-75 Corridor

Weigh Station	Design Type
Knoxville, TN (northbound)	Static scale
Hancock, OH (southbound)	Static scale
Halton, ON (eastbound)	Ramp WIM
Monroe, MI (northbound)	Ramp WIM
Kenton, KY (southbound)	Ramp WIM
Lowndes, GA (southbound)	Ramp WIM
Charlotte, FL (southbound)	High-speed ramp WIM

WEIGH STATION SIMULATION MODEL

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 (2). Figure 1 presents an overview of the electronic screening bypass and pull-in logic.

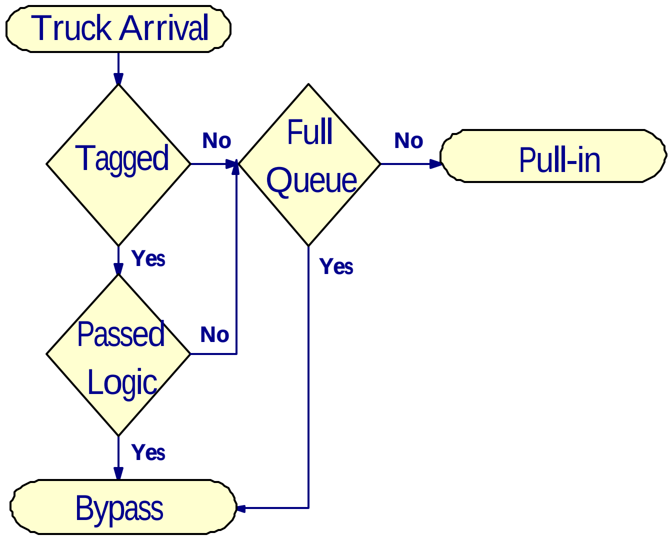

Figure 1. Electronic Screening System Bypass/Pull-in Logic

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 report.

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. Table 2 shows the default input data that reflects the field observations at the Knoxville weigh station. The model, however, provides the users the opportunity to modify the default parameters to examine different scenarios. Figure 2 presents an example of parameters that can be modified prior to a simulation run at the Knoxville static scale weigh station. Appendix I includes the input data for the other simulated weigh stations.

Table 2. Knoxville Simulation Input Parameters

Parameters	Morning	Noon	Afternoon
Traffic volume (vph)	1866	1559	2134
Truck percentage	16	25	20
Safety inspection rate (%)	1	1	1
Average safety inspection time (min)	15	15	15

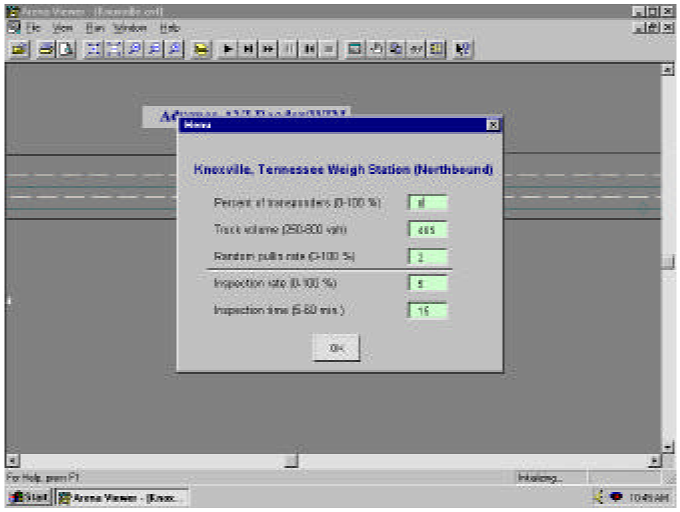

Figure 2. Knoxville Simulation Model Menu

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. Figure 3 shows a summary of the results during a simulation run of the Knoxville weigh station.

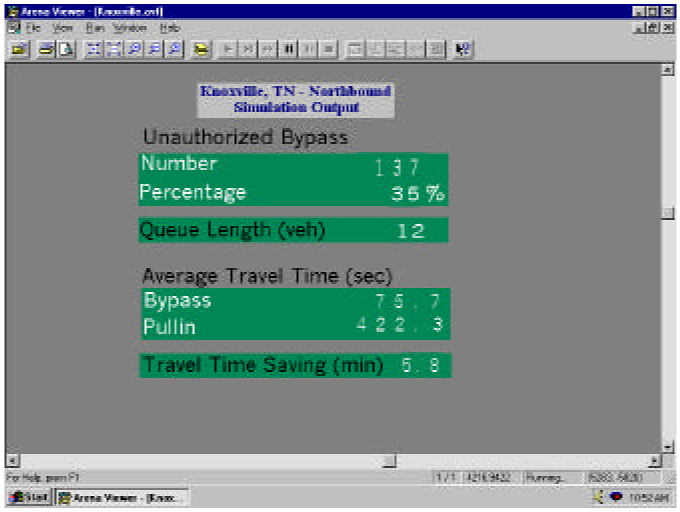

Figure 3. Knoxville Simulation Sample Output

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 (3). 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 (4)." 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 is 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 original data collection plan called for recording of only the departure times at the static scale. In developing the model, it became apparent that the service time, or the duration, for which a truck was stopped on the scale, varied significantly and effected the static scale total delay (d_{12}). Service times are dependent upon the behavior of the weigh station operator in response to the truck traffic situation within the weigh station and the condition of the truck on the static scale.

It was determined that the service times should be recorded independent of the total delay time (d_{12}). During the first data collection trip, a small sample of service times was collected. Unfortunately, the sample was too small to construct a reliable statistical distribution. A larger sample would have to be collected. A second trip to the weigh station would be necessary.

The data collection procedure was revised to include the recording of arrival times in addition of departure times and plate numbers of trucks at the static scales. The Knoxville weigh station was revisited on November 12, 1996. A new set of data was collected at the station throughout the day according to the new procedure and replaced the old data. Using the Arena Input Analyzer, the best fitted statistical distribution was estimated for the new sample of static scale service times and incorporated into the simulation model.

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.

The simulation results are naturally subject to the random fluctuations within the model. To account for this variation, interval estimates (also called confidence intervals) for evaluation of the generated point estimate of means are provided. Table 3 compares the field data to the simulation results that 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 two percent of the average delay (288 seconds). Appendix II includes the simulation results for the other weigh stations.

Table 3. Knoxville Field and Simulation Results - Northbound

Parameters	Morning			Noon			Afternoon		
	Field	Model		Field	Model		Field	Model	
	Avg	Avg	C.I.	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

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.

CONCLUSIONS

The weigh station simulation model is capable of assessing the impact of electronic screening at weigh stations. One of the advantages of this 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.

Each of the participating states and province in the Advantage I-75 MACS project has received a copy of the simulation model for its particular weigh station providing the participants with a powerful tool for understanding the benefits of electronic screening. The model demonstrates the effectiveness in electronic screening of commercial vehicles by illustrating the reduction in travel time for vehicles and showing the increased productivity of weigh stations. As participation in the process grows, enforcement agencies and motor carriers alike share in the benefits of the system.

Appendix I. Simulation Input Parameters

Table I.1. Hancock, Ohio – Southbound

Parameters	Morning	Afternoon
Truck volume (vph)	214	224
Safety inspection rate (%)	1	1
Average safety inspection time (min)	5	6

Table I.2. Halton, Ontario - Eastbound

Parameters	Day one	Day two
Truck volume (vph)	503	493
Ramp bypass rate (%)	35	67
Safety inspection rate (%)	15	8
Average safety inspection time (min)	8	7

Table I.3. Monroe, Michigan - Northbound

Parameters	Day one	Day two
Truck volume (vph)	333	331
Ramp bypass rate (%)	99	99
Safety inspection rate (%)	90	90
Average safety inspection time (min)	3	5

Table I.4. Kenton, Kentucky - Southbound

Parameters	Day one	Day two
Truck volume (vph)	200	211
Ramp bypass rate (%)	96	97
Safety inspection rate (%)	10	10
Average safety inspection time (min)	5	5

Table I.5. Lowndes, Georgia – Southbound

Parameters	Morning	Noon	Afternoon
Traffic volume (vph)	672	755	884
Truck percentage	17	19	19
Ramp bypass rate (%)	94	91	89
Safety inspection rate (%)	29	20	16
Average safety inspection time (min)	11	16	18

Table I.6. Charlotte, Florida - Southbound

Parameters	Morning	Noon	Afternoon
Traffic volume (vph)	874	838	932
Truck percentage	17	18	22
Ramp bypass rate (%)	82	80	80
Safety inspection rate (%)	3	11	11
Average safety inspection time (min)	5	10	6

Appendix II. Field and Weigh Station Simulation Results

Table II.1. Hancock, Ohio - Southbound

Parameters	Morning			Afternoon		
	Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	71	72	70, 74	83	87	83, 91
Unauth. bypasses %	18	1	0, 2	23	3	1, 4
Travel time (d_{23}), sec.	52	52	51, 53	50	50	49, 51

The Hancock weigh station's mainline open/closed sign is changed to "closed" as soon as a full static scale queue is observed. This allows the approaching trucks to bypass the weigh station. The sign will be changed back to "open" shortly after the queue dissipation starts. The observed travel time from points one to two (d_{12}) is relatively short (average of 75 seconds per truck) for the weigh station to produce about 20 percent of unauthorized bypasses if the open/close sign operates properly. The observed number of unauthorized bypasses could be due to having the weigh station closed even after the queue has completely dissipated. The simulation model assumes the ideal open/close sign operation. The model would be capable of matching the observed unauthorized bypasses by keeping the weigh station closed more often.

Table II.2. Halton, Ontario - Eastbound

Parameters	Day one			Day two		
	Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	194	196	192, 200	182	175	170, 180
Unauth. bypasses %	89	86	85, 87	73	78	77, 79
Travel time (d_{23}), sec.	61	70	67, 73	65	66	62, 70
Travel time-ramp bypass lane (d_{13}), sec.	120	124	123, 125	102	109	108, 110

Table II.3. Monroe, Michigan - Northbound

Parameters	Day one			Day two		
	Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	143	150	143, 157	119	127	123, 131
Unauth. bypasses %	0	0	0, 0	1	0	0, 0
Travel time (d_{23}), sec.	223	229	213, 245	293	296	269, 323
Travel time-ramp bypass lane (d_{13}), sec.	77	77	77, 77	77	77	77, 77

Table II.4. Kenton, Kentucky - Southbound

Parameters	Day one			Day two		
	Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	97	101	98, 104	96	101	97, 105
Unauth. bypasses %	2	0	0, 0	3	0	0, 0
Travel time (d_{23}), sec.	124	131	124, 138	130	127	116, 138
Travel time-ramp bypass lane (d_{13}), sec.	149	144	144, 144	150	144	144, 144

Table II.5. Lowndes, Georgia - Southbound

Parameters	Morning			Noon			**Afternoon**		
	Field	Model		Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	131	130	123, 137	136	137	127, 146	105	113	115, 121
Unauth. bypasses %	0	0	0, 0	0	0	0, 0	0	0	0, 0
Travel time (d_{23}), sec.	229	224	200, 248	188	175	159, 191	259	240	220, 260
Travel time-ramp bypass lane (d_{13}), sec.	71	75	75, 75	72	75	75, 75	73	75	75, 75

Table II.6. Charlotte, Florida - Southbound

Parameters	Morning			Noon			Afternoon		
	Field	Model		Field	Model		Field	Model	
	Avg	Avg	C.I.	Avg	Avg	C.I.	Avg	Avg	C.I.
Total delay (d_{12}), sec.	120	119	118, 120	207	201	200, 201	102	107	106, 108
Unauth. bypasses %	1	0	0, 0	0	0	0, 0	0	0	0, 0
Travel time (d_{23}), sec.	50	53	49, 57	104	111	100, 122	78	80	75, 85
Travel time-ramp bypass lane (d_{13}), sec.	74	78	78, 78	183	177	177, 177	74	83	82, 84

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