

Evaluation of Weigh Station Design and Operational Strategies Using Simulation

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ABSTRACT

In the past twenty years, states have utilized Weigh-in-Motion (WIM) technology to reduce delay and increase enforcement of overweight vehicles. The authors simulated the operation of a weigh station by VISSIM, a microscopic, time step, and behavior based traffic simulation software. This study evaluated weigh station design and operational strategies using simulation under different design strategies (one static scale, two static scale, ramp WIM scale, and mainline WIM scale) and the impact of threshold, accuracy level of WIM scale, transponder percentage. The authors found that WIM technology can improve the efficiency of weigh station operation, and for a weigh station with WIM scale on the mainline, if the percentage of trucks equipped with transponders is less than 30%, it is not effective; Currently because of the low percentage of trucks equipped with transponder, the WIM scale on the ramp should be a best alternative to increase the productivity of a weigh station. The authors also concluded that the accuracy of WIM scale is very important for the operation of a WIM weigh station, and a suitable threshold is very important for WIM operation under specific truck demand.

INTRODUCTION

The issue of commercial truck safety is the number one focus of virtually every commercial vehicle enforcement agency in North America. In 1993, over 30% of all the trucks on the road had safety deficiencies such that the truck or driver could be placed out of service. In 1994 during Roadcheck '94, this level was at 25%.⁽¹⁾

With limited human resources, highway agencies have a difficult task of identifying vehicles with the most serious safety problems. A Wisconsin study found that as many as 70% of overloaded trucks also were in violation of motor carrier safety and driver regulations. This indicates that overloaded trucks are three times as likely to be in violation of safety regulations when compared with the estimated safety violation rate for general truck traffic.⁽²⁾

As documented in the past, the relationship between vehicle weight and pavement damage follows an exponential geometric relationship closely resembling a fourth power. Recent research in the area of mechanistic-empirical pavement performance predictions indicates that the exponential factor used to predict damage may be considerably higher than a fourth power relationship, especially on thinner pavement structures in adverse climatic conditions such as freeze thaw.⁽²⁾ As a result, a slight increase in truck loading may result in orders of magnitude more damage to the road structure. A federally funded study undertaken in the United States in 1990 indicated that overloaded truck axle costs between \$160 million and \$670 million per year in pavement damage.⁽³⁾

In traditional weigh station operation, all trucks are required to report to the weigh station for visual inspection and/or static weighing. Where truck volumes are low, static scales are a reasonable means to weigh trucks. However, in many instances, the existing weigh stations cannot accommodate the existing or projected truck volumes. There are currently over 5.1 million trucks on the nation's highways, with the number increasing 6-7% yearly. Weighing each one just once would require 10 million minutes, or 17 years, given the average two minute delay at a weigh station for most trucks.

In the past twenty years, states have utilized Weigh-in-Motion (WIM) technology to reduce delay and increase enforcement of overweight vehicles. A WIM sorts out arriving trucks based on a set weight threshold. It could be set up on the entrance ramp of a weigh station or on the mainline. These trucks that do not exceed the threshold weight are directed by an overhead sign to bypass. Using automated vehicle identification (VIN) systems and mainline WIM scales, bypass systems enable commercial trucks to be weighted and verified in seconds as they travel past a weigh station. The overweight trucks and those flagged for credential and/or safety problems are signaled to the weigh station for a thorough inspection. Bypass systems significantly improve the efficiency of both truck carriers and the state highway patrols that operate weigh stations by a substantial reduction in travel time and weigh station close due to overflow.

Although WIM has improved weigh station operations, there are various types of WIM scales with various levels of accuracy. As accuracy decreases, the number of vehicles that must enter the static scale increases in order to ensure that all potential overweight vehicles are weighed on the static scale. Additionally, if the WIM underestimates a vehicle's weight, violating trucks could potentially go through the system without being stopped.

There are five objectives of this paper. First, develop a simulation model of weigh station operation by VISSIM. Second, quantify the performance of weigh station operation as a function of the different design strategies. Third, quantify the performance of weigh station operation as a function of WIM accuracy. Forth, quantify the performance of WIM scale on the mainline of a weigh station operation as a function of the percentage of transponder equipped vehicles. Fifth, quantify the performance of weigh station operation as a function of WIM threshold. This process can be used to test a design strategy, to analyze the current operation, and to determine how WIM accuracy, threshold, and transponder percentage would impact the operation of a weigh station.

LITERATURE OVERVIEW

In the past, there have been some studies to evaluate the operation of a weigh station.

Benekohal *et al.*(1999) in his study on a field evaluation of the Williamsville weigh station in Springfield, Illinois attempted to measure the delay and traffic conflicts experienced by trucks at the weigh station. The goal of the study was to quantify the delay at the weigh station in order to evaluate the effectiveness of AVI in a WIM system environment as well as to examine potential benefits of Intelligent Transportation System (ITS)

technologies. In the study, delay was determined to be the difference between the ideal travel time and the observed travel time. It was found that 30 percent of the trucks were not weighed simply because queues were too long and thus were allowed to bypass the static scales in order to prevent queue spillbacks. The study also demonstrated that in many instances trucks with legal weights experienced unnecessary delays at the weigh station because they were requested to enter the static scales. Based on the conclusions of the study, the Illinois Department of Transportation considered the addition of an AVI system to the existing WIM system. The study concluded that should the weigh station integrate AVI and WIM, there would be a reduction of delays and an increase in productivity. ⁽¹⁾

Kamyas, (1998) designed two approaches that weigh stations can increase capacity: mainline electronic screening and physical expansion. In mainline electronic screening, trucks with an AVI system are able to send information to a controller that identifies the truck and the WIM weight measurement to determine whether or not the truck needs to be stopped for further screening. The second method for increasing capacity is physical expansion. With physical expansion, a ramp WIM system and bypass lane is added to allow vehicles that do not exceed the weight requirement to continue through the system without stopping. The simulations were done using a microscopic, stochastic model for a before and after scenario. Through the simulation results, it is shown that travel times will decrease as well as the number of trucks with an unauthorized bypass (not able to be weighed due to overflow). Physical expansion would solve the problems in a shorter amount of time, but electronic screening has the potential to permanently eliminate inefficiencies of WIM stations. ⁽⁴⁾

Hanscom and Goelzer (1998) evaluated the measures of effectiveness of truck weight enforcement. Although it is important to consider delay and capacity at a weigh station, it is also important to look into the most important characteristic of all, enforcement. In this study, the measures of effectiveness were ranked based on the practicality, reliability, ability to be randomly sampled, absence of bias, compatibility with existing data collection methods, sensitivity to infrastructure damage, and use of future technology. Based on the criteria for a measure of effectiveness, there were five main measures established that demonstrate enforcement efforts. First, the severity of the overweight violation must be considered. This could be taken to be the gross vehicle weight, axle weights, or bridge formula weights. Second, the proportion of overweight trucks in the sample should be calculated. Third, Equivalent Single Axle Loads (ESALs) should be determined as a direct measure of the effects that the vehicle has on pavement wear. Fourth, excess ESALs should be calculated as "the sum of the total ESALs attributable to the illegal portion of the individual single or tandem axle group." Fifth, bridge formula violations should be determined. This data serves as a more accurate way to compare enforcement measures of weigh station facilities. ⁽⁵⁾

Richard A. Glassco (1999) used the Westa (Weigh Station) simulation model to represent the current and alternate scenarios. Westa is a detailed simulation of truck, car, and other traffic around inspection stations and was coded in C++. Model development and the 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. Studies were performed for three state agencies as a pilot test of the accuracy and applicability of the Westa model. This study got three findings. First, longer ramps did not produce significant improvements in any of the measures of effectiveness studied, except for hard deceleration by trucks on the station entrance ramp. Second, greater percentages of transponder-equipped trucks yield greater benefits. However, low market penetration (5% to 10%) is not sufficient to make significant improvements in the measures of effectiveness. It takes 40% to 50% of trucks with transponders to reduce congestion to minimal levels. Third, A WIM scale is very effective in reducing the number of trucks that must be weighed at the static scale. ⁽⁶⁾

Bryan J. Katz (2001) developed a procedure using Integration simulation model to evaluate the accuracy of the WIM technology in addition to the operations of the weigh station in terms of service time, system time, and delay incurred at the static scales and provided a methodology that can be used to determine the effects of the truck demand, the WIM accuracy, the system threshold, and the WIM calibration on system performance. ⁽⁷⁾

ANALYSIS APPROACH

Similar to any transportation facility, a weigh station has characteristics such as capacity that affect how efficient the station operates. Long vehicle queues can cause excessive delay to the facility and at times to the adjoining highway that the weigh station is monitoring. Additionally, where traffic must enter and exit a roadway, accident rates can also increase. Weigh-in-Motion has the potential to increase weigh station capacity and thus can reduce queue length and system time. At the same time, the threshold of WIM affects the effectiveness of a WIM system. This paper quantifies the delay experienced by the trucks at weigh stations

under different scenarios. The goal is to quantify the effectiveness of a WIM system on mainline, a WIM system on the weigh station ramp, WIM thresholds, and WIM accuracy.

The operation of a weigh station is dependent on a number of factors that include the arrival demand, the weight distribution of trucks, the service time for violating and non-violating trucks, the geometric configuration of the weigh station, the accuracy of the WIM system, transponder percentage, and the operator defined threshold for diverting trucks to the static scales (Figure 1).

Simulation Tools Selection

The VISSIM model was chosen for the analysis because of its ability to address the many complex interrelationships in the analysis. VISSIM has the built-in VAP (Vehicle Actuated Programming) function allowing a user to route vehicles and pedestrians and make necessary decision strategies outside the simulation model.

Traffic Characteristics

In order to understand the performance of a weigh station, it is important to know the traffic going through the weigh station and its characteristics. The characteristic of trucks of interest in this study was weight and the presence or absence of a transponder.

It is also necessary to have the WIM weight of the vehicle. Because this type information was not readily available, each vehicle was assigned a WIM weight consistent with the ASTM requirements. The American Society for Testing and Materials (ASTM) establishes functional requirements for WIM system accuracy.

Service Time

The service time for the static scale was defined as the amount of time it took for static scale to weigh a truck. Most of the time a truck should stop on the static scale completely for a while. For a violating truck, it should spend more time to check carefully or be ordered into an inspection area.

Transponder Percentage

For a mainline WIM scale, the transponder on trucks and roadside devices let truck drivers get the order whether to bypass or enter a weigh station. If a truck is not equipped with a transponder, it will enter the weigh station for inspection. So the percentage of trucks equipped with transponders is very important for mainline WIM scale system. The higher percentage, the more productive a weigh station is. It is estimated that nationally only two percent of trucks are currently equipped with transponders.

Weigh Limitation

Federal and each state have their truck weigh and size limitation. ⁽⁸⁾ Current Federal law includes the following limits:

- 20,000 pounds for single axles on the Interstate System;
- 34,000 pounds for tandem axles on the Interstate System;
- Application of the Federal Bridge Formula for other axle groups up to the maximum of 80,000 pounds gross vehicle weight on the Interstate System;
- 102 inches for vehicle width on the National Network (NN) for STAA vehicles;
- 48-foot (minimum) or longer if grandfathered, for semitrailers in a semitrailer combination on the NN; and
- 28-foot (minimum) for trailers in a twin-trailer combination on the NN.

Threshold Value

If a truck weight is over the threshold, it should go to a static scale for further inspection; otherwise, it will bypass the weigh station. The less value of threshold is, the more trucks should go for further inspection, the more possible there are trucks before the static scale. If the queue length of trucks before a static scale is long enough for trucks to back up on the mainline, the weigh station must be closed, which makes more trucks

bypass the weigh station, even some of them are overweight. So there are should be a tradeoff of the threshold value.

MOE (Measurements of Effectiveness)

For a given weigh station, it is very important to choose MOEs to evaluate how effectively an enforcement strategy impacts on a weigh station. Traditionally, enforcement is merely gauged by the number of trucks weighed, the number of violators, and the amount of fines. After studying what have been done before, some adjustments are taken here to make MOEs to demonstrate enforcement efforts better.

First, the percentage of violating trucks caught. It should be the most important MOE to measure a weigh station operation. The high this percentage, the more efficient the enforcement is.

Second, the percentage of trucks bypassing the weigh station because of the weigh station close, It can be used to the risks for violating trucks bypassing the weigh station.

Third, travel times for trucks during the weigh station open. It tests how an enforcement to impact the truck flows in a weigh station.

SIMULATION SPECIFICATION

Site Description

The Knox County Weigh Station is located near the I-75/I-40 junction, in Knoxville, Tennessee, which is the second busiest weigh station in the USA. The north side of this weigh station was selected.

Weight Distribution

According to Federal and State law, weight limitation is not only on gross weight, but also on the single axle and tandem axle. For this analysis, only gross weight is used for screening vehicles. In the analysis, the truck weight was expressed as a normal distribution with mean of 60,000 lbs and standard deviation of 8,800 lbs. The specific graph is as Figure 2.

Actually in the VAP programming, you can use real weigh data or use other data.

WIM Scale Accuracy

In the simulation, WIM scale accuracy was defined as contrary to the error of truck weight by WIM scale (WIM weight) from the weight by static scale (actual weight). Here WIM weight was defined as a normal distribution with mean of actual weight and standard deviation of a specific percentage of mean. The Figure 3 shows the distribution of WIM weight with 90% WIM accuracy.

Service Time

Static scale service time of violating trucks and non-violating trucks are different. The service time of violating trucks is defined as the normal distribution and the with mean of 45 seconds and standard deviation of 20 seconds, the service time of non-violating trucks is defined as the normal distribution with mean of 20 seconds and standard deviation of 10 seconds.

Traffic Demand

In the simulation, traffic demand is 3,600 vehicles per hour with 20% trucks.

Control Algorithms

There are 4 main scenarios, whose control algorithms have a little difference.

1. A weigh station with one static scale

- When the queue length of trucks on the ramp exceeds the maximum queue length, the weigh station is closed; during weigh station closure, if the queue length of trucks on ramp is less than one specific number, the weigh station will reopen. If weigh station is open, the truck will enter the weigh station for static scale weighing; otherwise, the arrival truck will bypass the weigh station;
 - If the truck's weight by the static scale is more than weight limitation, it will be sent to the inspection area.
2. A weigh station with two static scales
 - When the queue length of trucks on the ramp exceeds the maximum queue length, the weigh station will be closed. During weigh station closure, if the queue length of trucks on ramp is less than one specific number, the weigh station will reopen. If weigh station is open, the truck will enter the weigh station for static scale to weigh; otherwise, the arrival truck will bypass the weigh station;
 - If the queue length of trucks before static scale 1 is larger than the queue length of trucks before static scale 2, the arrival truck will be sent to static scale 2 for weighing; otherwise, it will be sent to static scale 1 for weighing.
 - If the truck's weight by the static scale is more than weigh limitation, it will be sent to the inspection area.
 3. A weigh station with WIM scale on ramp
 - When the queue length of trucks on the ramp exceeds the maximum queue length, the weigh station will be closed. During weigh station closed, if the queue length of trucks on ramp is less than one specific number, the weigh station will reopen. If weigh station is open, the truck will enter the weigh station for WIM scale to weigh; otherwise, the arrival truck will bypass the weigh station;
 - If the weight of a truck by WIM scale is larger than the threshold value, it will be directed to a static scale weighing; otherwise, it will choose bypass lane.
 - If the truck's weight by the static scale is more than weigh limitation, it will be sent to the inspection area.
 4. A weigh station with WIM scale on mainline
 - When the queue length of trucks on the ramp exceeds the maximum queue length, the weigh station will be closed; during weigh station close, if the queue length of trucks on ramp is less than one specific number, the weigh station will reopen. If weigh station is open, the truck will enter the weigh station for static scale to weigh; otherwise, the arrival truck will bypass the weigh station;
 - During the weigh station open, if the weight of a truck by WIM scale is larger than the threshold value, it will be pulled into for static scale to weigh; otherwise, it will choose bypass lane.
 - If the truck's weight by the static scale is more than weigh limitation, it will be sent to the inspection area.

Simulation Scenarios

In order to analyze the sensitivity regarding different design strategies, WIM accuracy, WIM threshold value, and transponder percentage, distributions were estimated for the following scenarios:

1. Scenarios of design strategies (Shown in Table 1)
2. Scenarios of transponder percentage (Shown in Table 2)
3. Scenarios of WIM accuracy (Shown in Table 3)
4. Scenarios of WIM threshold (Shown in Table 4)

SIMULATION RESULTS

For each of scenario, the simulation model ran 7200 seconds and the data was collected from the 300 seconds to the 7000 seconds. And in the sample, the total number of violating trucks in this collecting period is 15.

Scenarios of Design Strategies

When a static scale weigh station cannot meet its demand, there are three alternatives which could be adopted, building another static scale, WIM on the ramp technologies, and WIM on the mainline technology. The results are shown as Table 5.

In the base case scenario, the weigh station almost cannot take effect. Just 27% violating trucks were caught though the average travel time was 618.6s per truck and the percentage of the bypassing truck due to the weigh station closure was 79%. In this situation, some measurements must be taken. The physical expansion strategy does improve the performance, but not too much, especially compared to the two WIM technology strategies. All violating trucks were caught and just a little percent of trucks (4%-6%) bypassed due to the weigh station being closed. The average travel time was very low too, 102.8 s for WIM on the ramp, 76.93s for WIM on the mainline. In this situation, WIM technology should be introduced into the weigh station operation, especially for the busy weigh stations. As for the WIM on the ramp and WIM on the mainline, each has its own advantages. For WIM on the ramp, because of low speed of trucks on the scale, the accuracy of WIM scale is higher. Most important, it does not need transponder. Most of the advantage of the WIM scale on the mainline is that a truck whose WIM weight is less than threshold will not enter the weigh station, which can reduce the travel time and safety issues of entrance and exiting the weigh station. But because mainline WIM requires a transponder for a truck to pass the weigh station and currently less than 2 percent for trucks are equipped with them, the benefit is minimal.

Scenarios of Transponder Percentage

For a WIM on the mainline weigh station, the more trucks are equipped with transponders, the higher the enforcement level. If the percentage is over 90%, all the three MOEs are very good. But if the percentage is less than 35% in this case, all the MOEs are very similar to the basic base which was analyzed in the design strategies, WIM scale hardly took effect. The results are shown as Table 6.

Scenarios of WIM Accuracy

In this case, there is a trend that the higher accuracy of a WIM scale, the higher weight enforcement level. At the same time, because of trucks' random arrival, sometimes there is some abnormality, such as the average travel time and percentage of trucks bypass due to the weigh station being closed. The results are shown as Table 7.

Scenarios of WIM Threshold

The average travel time and percentage of bypass trucks due to the weigh station being closed drop when the threshold value increases; but the percentage of violating trucks caught shows a different trend. When threshold is less than 68,500 lbs, the percentage of violating trucks caught increases when the threshold increases; when threshold is larger than 72,000 lbs, it decreases when the threshold increases. The results are shown as Table 8.

CONCLUSIONS

From the results, it can be concluded that:

1. WIM technology can improve the efficiency of weigh station operation. WIM technology can greatly decrease the travel time of truck and the number of trucks bypassing the weigh station due to the weigh station close, and increase the possibility of catching violating trucks;
2. The percentage of trucks equipped with a transponder is a key issue to the operation of a weigh station with WIM scale on the mainline. If the percentage is less than 30%, it is not effective;
3. Currently because of the low percentage of trucks equipped with transponder, the WIM scale on the ramp should be a best alternative to increase the productivity of a weigh station;
4. The accuracy of WIM scale is an important issue.
5. A suitable threshold is very important for WIM operation. A low threshold will cause a higher amount of delay for non-violating drivers and higher risk for violating truck drivers to bypass the weigh station due to the weigh station closure; a high threshold may cause violating truck drivers go though the weigh station without being found because of the accuracy of the WIM scale though it reduces the travel time of trucks drivers;
6. VISSIM is a good tool to simulate a weigh station.

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LIST OF TABLES

| | |
|---|----|
| TABLE 1 Scenarios of Design Strategies | 10 |
| TABLE 2 Scenarios of Transponder Percentage..... | 11 |
| TABLE 3 Scenarios of WIM Accuracy | 12 |
| TABLE 4 Scenarios of WIM Threshold | 13 |
| TABLE 5 MOEs of Scenarios of Design Strategies..... | 14 |
| TABLE 6 MOEs for Scenarios of Transponder Percentage..... | 15 |
| TABLE 7 MOEs of Scenarios of WIM Accuracy..... | 16 |
| TABLE 8 MOEs of Scenarios of WIM Threshold..... | 17 |

LIST OF FIGURES

| | |
|---|----|
| FIGURE 1 Simulation model graph..... | 18 |
| FIGURE 2 Weigh distributions..... | 19 |
| FIGURE 3 90% accuracy WIM scale weight distribution | 20 |

TABLE 1 Scenarios of Design Strategies

| No. | Name | Description |
|-----|---------------------------|--|
| 1 | Base Case | One static scale weigh station |
| 2 | Physical Expansion | Two static scale weigh station |
| 3 | WIM Scale on the Ramp | A WIM scale set up on the ramp of a weigh station to sort trucks. During weigh station open, if a truck weight by WIM scale is less than the specified threshold, the truck bypasses the static scale by a bypass lane; otherwise, the truck will be pulled into static scale for further inspection. WIM scale Accuracy = 90% |
| 4 | WIM Scale on the Mainline | A WIM scale set up on the mainline of a weigh station to sort trucks. During weigh station open, if a truck weight by WIM scale is less than the specified threshold, the truck bypasses the weigh station; otherwise, the truck will be pulled into static scale for further inspection. WIM scale Accuracy = 90% Transponder percentage = 100% |

Note: Threshold value for WIM scale: 68,500 lbs

TABLE 2 Scenarios of Transponder Percentage

| No. | Name | Description |
|-----|------|--------------------------------|
| 1 | 100% | 100% Trucks with a transponder |
| 2 | 95% | 95% Trucks with a transponder |
| 3 | 90% | 90% Trucks with a transponder |
| 4 | 85% | 85% Trucks with a transponder |
| 5 | 80% | 80% Trucks with a transponder |
| 6 | 75% | 75% Trucks with a transponder |
| 7 | 70% | 70% Trucks with a transponder |
| 8 | 65% | 65% Trucks with a transponder |
| 9 | 60% | 60% Trucks with a transponder |
| 10 | 55% | 55% Trucks with a transponder |
| 11 | 50% | 50% Trucks with a transponder |
| 12 | 45% | 45% Trucks with a transponder |
| 13 | 40% | 40% Trucks with a transponder |
| 14 | 35% | 35% Trucks with a transponder |

Notes: a. WIM scale on the mainline

b. WIM scale Accuracy = 90%

c. Threshold value for WIM scale: 68,500 lbs

TABLE 3 Scenarios of WIM Accuracy

| No. | Name | Description |
|-----|--------------|---|
| 1 | 90% accuracy | WIM scale weight 10 % deviations from the actual weight |
| 2 | 88% accuracy | WIM scale weight 12 % deviations from the actual weight |
| 3 | 85% accuracy | WIM scale weight 15 % deviations from the actual weight |
| 4 | 83% accuracy | WIM scale weight 17 % deviations from the actual weight |
| 5 | 80% accuracy | WIM scale weight 20 % deviations from the actual weight |
| 6 | 78% accuracy | WIM scale weight 22 % deviations from the actual weight |
| 7 | 75% accuracy | WIM scale weight 25 % deviations from the actual weight |

Notes: a. WIM scale on the mainline

b. Transponder percentage = 100%

c. Threshold value for WIM scale: 68,500 lbs

TABLE 4 Scenarios of WIM Threshold

| No. | Name | Description |
|-----|------------------|---------------------|
| 1 | Threshold 60,000 | Threshold 60000 lbs |
| 2 | Threshold 63,000 | Threshold 63000 lbs |
| 3 | Threshold 65,000 | Threshold 65000 lbs |
| 4 | Threshold 68,500 | Threshold 68500 lbs |
| 5 | Threshold 70,000 | Threshold 70000 lbs |
| 6 | Threshold 72,000 | Threshold 72000 lbs |
| 7 | Threshold 74,000 | Threshold 74000 lbs |
| 8 | Threshold 76,000 | Threshold 76000 lbs |
| 9 | Threshold 78,000 | Threshold 78000 lbs |

Notes: a. WIM scale on the mainline

b. Transponder percentage = 100%

c. WIM scale Accuracy = 90%

TABLE 5 MOEs of Scenarios of Design Strategies

| Case | Percentage of bypass trucks when the weigh station close | Percentage of violating trucks caught | Average Travel Time seconds (Not including bypass trucks due to weigh station closed) |
|---------------------|--|---------------------------------------|--|
| Base case | 79% | 27% | 618.60 |
| Physical Expansion | 60% | 60% | 457.10 |
| WIM on the Ramp | 6% | 100% | 102.80 |
| WIM on the Mainline | 4% | 100% | 76.93 |

Note: Threshold value for WIM scale: 68,500 lbs

TABLE 6 MOEs for Scenarios of Transponder Percentage

| Transponder Percentage | Average Travel Time s (Not including by pass truck due to weigh station close) | Percentage of bypass trucks due to the weigh station close | Percentage of violating trucks caught |
|------------------------|---|--|---------------------------------------|
| 100% | 76.93 | 4% | 100% |
| 95% | 107.21 | 16% | 100% |
| 90% | 129.86 | 27% | 100% |
| 85% | 143.15 | 32% | 100% |
| 80% | 161.15 | 40% | 100% |
| 75% | 202.71 | 49% | 87% |
| 70% | 227.14 | 54% | 87% |
| 65% | 254.95 | 58% | 73% |
| 60% | 275.34 | 61% | 67% |
| 55% | 310.10 | 65% | 60% |
| 50% | 325.97 | 66% | 53% |
| 45% | 349.26 | 68% | 40% |
| 40% | 376.73 | 70% | 33% |
| 35% | 403.97 | 73% | 27% |

- Notes: a. WIM scale on the mainline
b. WIM scale Accuracy = 90%
c. Threshold value for WIM scale: 68,500 lbs

TABLE 7 MOEs of Scenarios of WIM Accuracy

| Accuracy | Average Travel Time s (Not including by pass truck due to weigh station close) | Percentage of bypass trucks due to the weigh station close | Percentage of violating trucks caught |
|--------------|---|--|---------------------------------------|
| 90% accuracy | 76.93 | 4% | 100% |
| 88% accuracy | 81.03 | 8% | 100% |
| 85% accuracy | 119.91 | 19% | 87% |
| 83% accuracy | 114.67 | 20% | 80% |
| 80% accuracy | 130.95 | 29% | 80% |
| 78% accuracy | 129.81 | 27% | 67% |

Notes: a. WIM scale on the mainline

b. Transponder percentage = 100%

c. Threshold value for WIM scale: 68,500 lbs

TABLE 8 MOEs of Scenarios of WIM Threshold

| WIM Scale Threshold lbs | Average Travel Time seconds (Not including by pass truck due to weigh station close) | Percentage of bypass trucks due to the weigh station close | Percentage of violating trucks caught |
|----------------------------|--|--|--|
| 60000 | 253.23 | 58% | 73% |
| 63000 | 197.54 | 48% | 93% |
| 65000 | 152.07 | 35% | 93% |
| 68500 | 76.93 | 4% | 100% |
| 70000 | 25.12 | 0% | 100% |
| 72000 | 10.96 | 0% | 100% |
| 74000 | 6.99 | 0% | 93% |
| 76000 | 2.93 | 0% | 87% |
| 78000 | 2.92 | 0% | 60% |

Notes: a. WIM scale on the mainline

b. Transponder percentage = 100%

c. WIM scale Accuracy = 90%

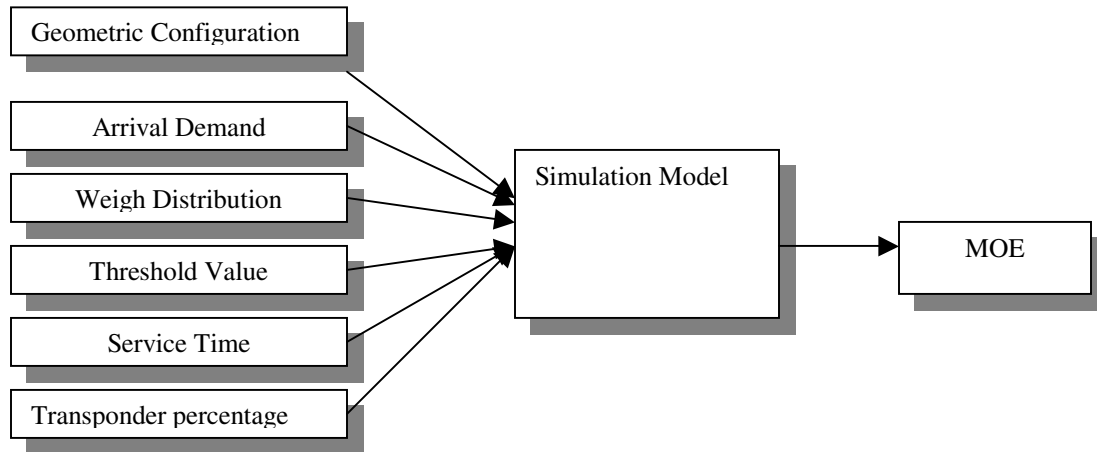


FIGURE 1 Simulation model graph

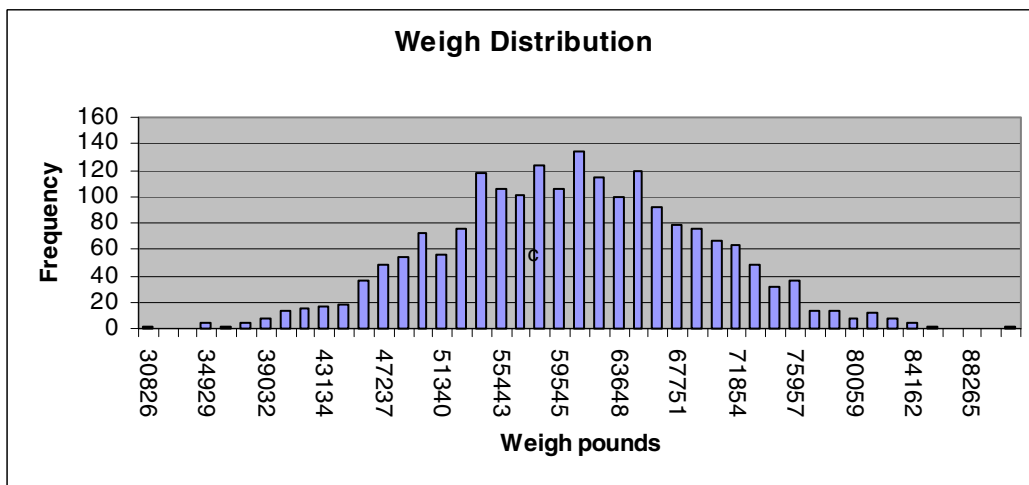


FIGURE 2 Weight distributions

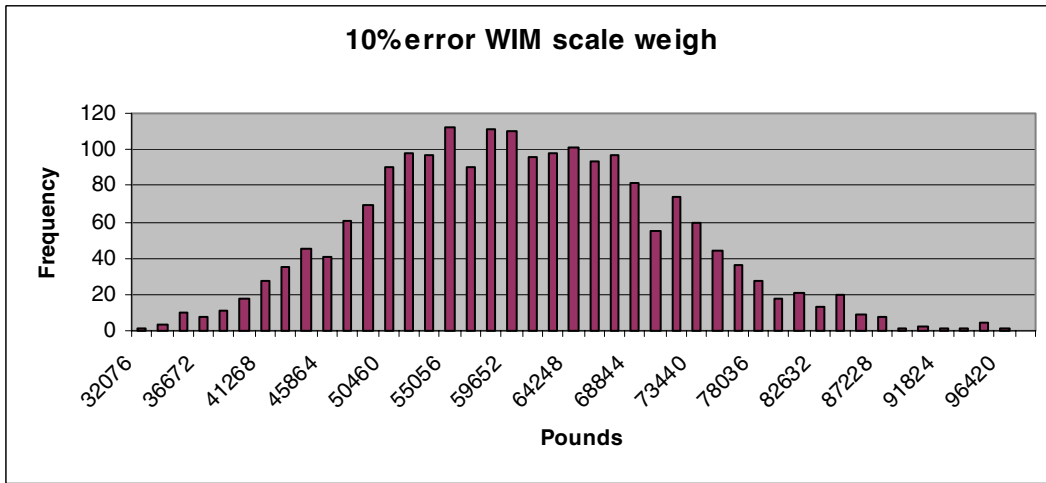


FIGURE 3 90% accuracy WIM scale weight distribution