Weigh Station Model

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ABSTRACT

Preventing the smuggling of radiological and nuclear material into the United States has become a major effort of the DHS-DNDO since the tragic events of September 11, 2001. The implementation of the DNDO's GNDA consists of several layers of opportunity to detect RN material overseas, at the borders, and within the US. One of the most abundant resource DNDO can use is the presence of weigh stations on the borders and throughout the US interior. Installing detection equipment into a system that is already in place will not only save money, but increase security and reduce the threat of RN material. By modeling a weigh station and implementing proposed solutions it is found that the detection equipment has little impact on the current system, yet greatly increases the probability of catching potential threats.

INTRODUCTION

The US Department of Homeland Security (DHS) Domestic Nuclear Detection Office (DNDO) is attempting to prevent the smuggling of Radiological and Nuclear (RN) materials into the United States by implementing what it calls the Global Nuclear Detection Architecture (GNDA)[1]. This architecture consists of several layers for detecting and interdicting the potential smuggling of RN material. Having a series of overlapping layers "provides multiple detection and interdiction opportunities overseas, at our borders, and within the United States to effectively increase the overall probability of system success."

Our project will model an arbitrary Point of Entry (POE) weigh station that is commonly encountered on the United States borders. We have determined critical point(s) in the system where an added "layer" of radiation detection equipment can be used within the current weigh station operations. We want to provide a decision tool that allows weigh station operators to know what RN scanners to use each day, given the DHS Daily Threat level rating, that will have the least impact on the flow of traffic through the station, but will increase the probability of catching potential threats.

MODEL

From our research, it was found that many weigh stations have similar characteristics. The first being a transponder system known as PrePass[2]. The PrePass system allows trucks to be pre-cleared to pass through a station and continue with no delay through a "Fast Lane". Secondly, many use a Weigh-In-Motion (WIM)[3] technology that allows trucks to be weighed without having to come to a complete stop. Both the PrePass and WIM technologies have proven to decrease the stress on weigh stations. Lastly, all weight stations employ a Static Scale. At a static scale the trucks must come to a complete stop to be weighed. During the weighing, the officer on duty will usually check shipping manifest documents and perform other formal procedures.

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1 Testimony of Acting Director Charles R. Gallaway, Domestic Nuclear Detection Office, before the House Appropriations Committee, Subcommittee on Homeland Security, "Container Security". Modified April 1, 2009. Accessed December 1, 2009. http://www.dhs.gov/ynews/testimony/testimony_1238610092655.shtm

2 PrePass. Accessed December 1, 2009. http://www.prepass.com/Pages/Home.aspx

3 ORNL Review: Better Ways to Weigh Trucks. Oak Ridge National Laboratory ReView Volume 33. Accessed December 1, 2009. http://www.ornl.gov/info/ornlreview/v33_3_00/weigh.htm

We did not have access to information regarding any specific weigh stations operations. We have designed an arbitrary weigh stations based on our research and observations from public mapping utilities that will use all three of the main characteristics previously described.. The diagram below is a flow diagram depicting our arbitrary weight station operations.

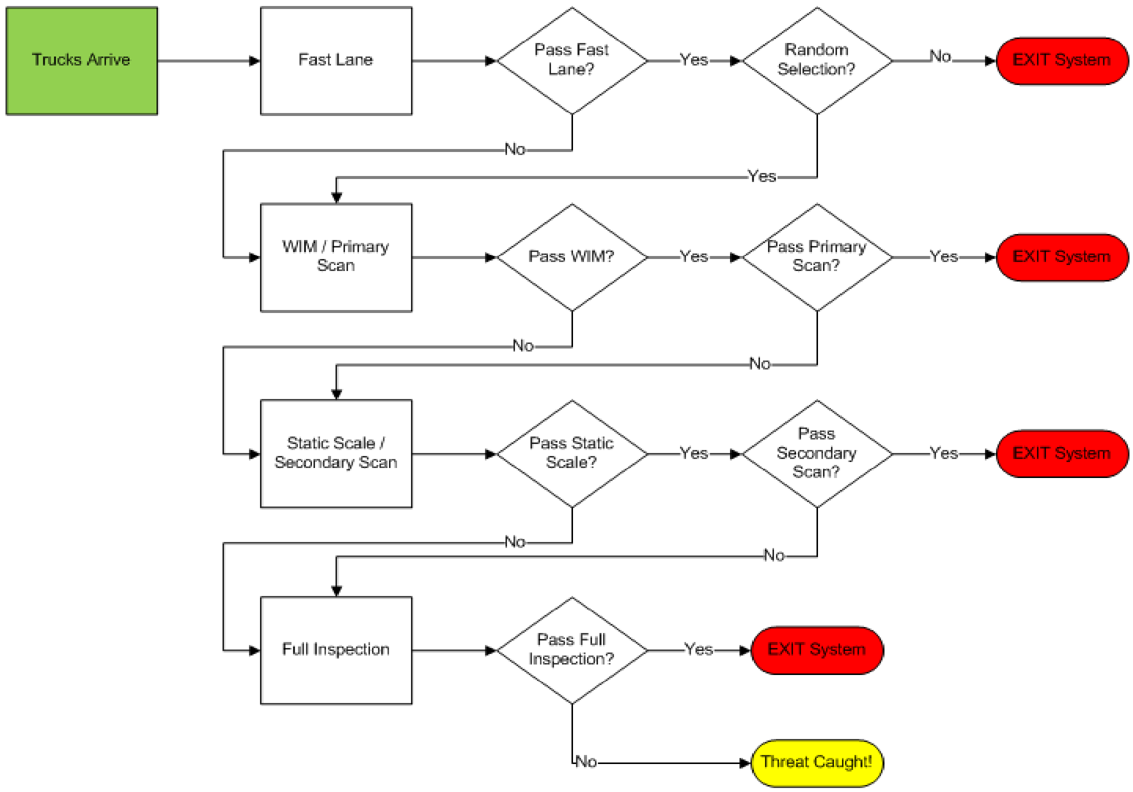


Fig. 1: Weigh Station Model Flow

Upon arriving to the system, trucks pass under the PrePass transponder. If the truck is pre-cleared, it is allowed to pass through the stations fast lane without delay. If it is not pre-cleared or if the truck just happens to be randomly selected for further processsing, it is signaled to enter the station. Upon entering the station, the trucks will slow and pass over a WIM sensor. This WIM sensor has been identified as a location for the Primary RN scanning equipement to be installed since it is a point in the system that all trucks will have to traverse. If the truck passes both the WIM and the Primary scan, it is allowed to exit the station. If the truck fails either the WIM or the Primary RN scan, it will be signaled to pull into the static scale. The truck will then stop on the static scale and be weighed. The static scale has been identified as a second location for RN detection equipment to be installed. If the truck passes both the static scale and the Secondary RN scan, it is allowed to exit the station. If it fails either the static scale or the Secondary RN scan, it is signaled to pull over for a full inspection. If a truck is subject to a full inspection, any potential threats will be found.

Our arbitrary station, as with all weigh stations, has its limitations. Our weigh station does not have infinite capacity. The station can only hold so many trucks, therefore if the station becomes overwelmed, waiting can occur for PrePass, WIM, Static Scale, and Full Inspections. Our system will be highly sensitive to the Scan Failure rates of the Primary and Secondary RN scans. The higher the rates, the faster the system will reach its capacity, and the longer amount of time trucks will spend in the system.

INPUT DATA

We built our weigh station as a discrete event model using Rockwell Softwares' ARENA[4]. The model required various inputs. Some careful research and data mining of our sources was performed to derive the necessary inputs. Below is a list of the required model inputs:

	Input
1	System Capacity
2	Truck arrival rate
3	PrePass Processing Time
4	% trucks with PrePass
5	% trucks randomly selected for inspection
6	WIM processing time
7	Primary scan processing time
8	% Trucks that pass/fail WIM
9	Primary Scan False Alarm Rates
10	Static Scale processing time
11	Secondary Scan processing time
12	% trucks that pass/fail static scale
13	Secondary Scan False Alarm Rates
14	Full Inspection processing time
15	Probability of threat being present.

1. *System Capacity:*
   Using public mapping utilities, it is estimated that approximately 30 trucks could be in the system at one time. We will use this as our weigh station system capacity.

2. *Truck Arrival Rate:*
   For truck arrival rates, we used the arrival distribution for trucks at the Pacific Highway POE station in Washington State as found in the 2009 Cascade Gateway Almanac[5]. Using the 2006 Pacific Highway Southbound (Canada to US) Hour-of-day Distribution of Trucks data and the 2006 Pacific Highway Southbound Monthly Cross-border Truck Volume data, we were able to reverse engineer estimated mean truck inter-arrival rates per hour of day. The data does not tell us what distribution

4 Arena Portal: Home. Accessed December 1, 2009. http://www.arenasimulation.com/Arena_Home.aspx
5 International Mobility & Trade Corridor Project. Cascade Gateway Almanac 2009. Accessed December 1, 2009. http://resources.wcog.org/data/border_data.pdf

the inter-arrival rates follow. It is commonly assumed in Queuing Theory[6] that inter-arrival rates follow an exponential distribution, and this is what will be assumed in this model as well.

2006 Pacific Highway SOUTHBOUND POE Station

Month	# Days	Trucks per Month
Jan	31	28978
Feb	28	27013
Mar	31	30184
Apr	30	29458
May	31	31189
Jun	30	30646
Jul	31	29534
Aug	31	31202
Sep	30	28592
Oct	31	34325
Nov	30	33079
Dec	31	31759
Average	30.42	30496.58

Avg. Trucks per Day	1002.63

6 Gross, Donald, Shortle, John F., Thompson, James M., Harris, Carl M. Fundamentals of Queueing Theory Fourth Edition. John Wiley & Sons, Inc. 2008. Page 16.

2006 Pacific Highway SOUTHBOUND POE Station

Hour	Percent	# Trucks per Hour	# Trucks per Minute	Mean inter-arrival time (min)
0	4	40.11	0.67	1.5
1	3.9	39.1	0.65	1.53
2	2.8	28.07	0.47	2.14
3	1.8	18.05	0.3	3.32
4	1.8	18.05	0.3	3.32
5	2.4	24.06	0.4	2.49
6	2.5	25.07	0.42	2.39
7	2.6	26.07	0.43	2.3
8	3.2	32.08	0.53	1.87
9	4.7	47.12	0.79	1.27
10	4.9	49.13	0.82	1.22
11	5.9	59.16	0.99	1.01
12	4.7	47.12	0.79	1.27
13	5.1	51.13	0.85	1.17
14	5	50.13	0.84	1.2
15	5.5	55.14	0.92	1.09
16	5.3	53.14	0.89	1.13
17	5.2	52.14	0.87	1.15
18	4.9	49.13	0.82	1.22
19	4.6	46.12	0.77	1.3
20	4.8	48.13	0.8	1.25
21	5	50.13	0.84	1.2
22	5.1	51.13	0.85	1.17
23	4.3	43.11	0.72	1.39
Sum	100	1002.63		

3. *PrePass Processing time:*
   The station will only have 1 PrePass transponder. Trucks can pass under a PrePass transponder at highway speeds. Given a range of common highway speeds of 45-75 MPH, it is estimate that it takes a 70ft. 18 wheeler between 0.6365sec (75 MPH) and 1.0602sec (45 MPH) to pass under a PrePass transponder. This will give us a range to use a Uniform distribution to represent processing time for PrePass.

4. *% Trucks with PrePass:*
   Data could not be found on the number of trucks that use PrePass. Arbitrarily chosen to be set at 10%.

5. *% Trucks Randomly Selected:*
   Data could not be found on the number of trucks that are randomly selected to enter the station. Arbitrarily chosen to be set at 10%.

6. *WIM Processing Time:*
   The station will only have 1 WIM sensor for trucks to pass over. Trucks are weighed on a WIM sensor at highway speeds and will follow the same Uniform distribution as the PrePass processing time.

7. *Primary Scan Processing time:*
   The Primary Scan will not have any processing times associated with it. Its processing will occur during the WIM processing.

8. *% Trucks that Pass WIM:*
   No data was found on the percentage of trucks that pass WIM. Arbitrarily set at 90%.

9. *% Tucks Pass Primary Scan:*
   This is one of the parameters that will be varied in our model to determine which set up is optimal. There are three possible alarm rates to use depending on the DHS daily assigned threat level. The percentage of trucks passing the scan will be 100%*(1-P(alarm)):

Primary Scan Alarm rate for Threat level	
Blue	0.08
Yellow	0.12
Orange	0.25

10. *Static Scale Processing time:*
    There is only 1 static scale. It was found that on average in the US, a truck spends 5 minutes getting weighed and having its documents looked over. A Triangular distribution from 3 to 7 minutes with a mean of 5 minutes will be used as the static scale processing time.

11. *Secondary Scan Processing time:*
    The Secondary Scan will not have any processing times associated with it. Its processing will occur during the Static Scale processing.

12. *% Trucks that pass Static Scale:*
    No data could be found on the percentage of trucks that pass the Static Scale. Arbitrarily set to 90%.

13. *% Trucks Pass Secondary Scan:*
    This is one of the parameters that will be varied in our model to determine which set up is optimal. There are three possible alarm rates to use depending on the DHS daily assigned threat level. The percentage of trucks passing the scan will be 100%*(1-P(alarm)):

Secondary Scan Alarm Rate for Threat level	
Blue	0.05
Yellow	0.12
Orange	0.4

14. *Full Inspection Processing time:*
    Only 1 resource will be available for full inspections. No data could be found on how long a full inspection takes. Arbitrarily set to a Triangular distribution with range of 30 to 60 minutes and mean of 45 minutes.

15. *Probability of threat being present:*
    If the truck contains a threat it will be found. There is no known probability of a threat attempting to be smuggled into the US via commercial vehicles. The GNDA is a set of layers that attempts to find that "what if" attempt. This value is arbitrarily set to 1%, so the percentage of trucks that pass Full Inspection is 99%.

Based on these inputs, output data has been identified and will be used as system performance measures to compare model scenario runs:

1. Average Total Time in the System
2. Average Number of Threats caught
3. Queue Wait times for:
    - PrePass
    - WIM / Primary Scan
    - Static Scale / Secondary Scan
    - Full Inspection

ANALYSIS

The base time units for the model is Minutes. The weigh station is never closed, so the model cannot start recording data immediately after initialization. A warm up period of 1 day was selected to initialize the system and a length of 1 day to record data giving a total run length of 2 days. In all, 10 scenarios were developed to test the operations of the weigh station.

1. Baseline – No Primary or Secondary Scan

2. Primary Scan Only at DHS Threat Levels:
    a) Blue
    b) Yellow
    c) Orange

3. Secondary Scan Only at DHS Threat Levels:
    a) Blue
    b) Yellow
    c) Orange

4. Both Primary and Secondary Scans at DHS Threat Levels
   a) Blue
   b) Yellow
   c) Orange

The baseline scenario was originally run at 50 replications. To test if 50 replications would be sufficient, we looked at the ratio of the 95% confidence interval half width to the mean for the Average Total Time in the system.

Average: 1.0854 min
Half Width: .06 min
Ratio: .06 / 1.0854 = 0.05527 ~ 5.53%

Our ideal criteria for this ratio would be to have the half width less than or equal to 5% of the mean. Working backwards using the standard normal distribution, the minimum number of replications that would satisfy this 5% rule is theoretically found to be n = 62 replications:

$$let\ x = new\ half\ width$$
$$\frac{x}{1.0854} = 0.05 \rightarrow x = 0.05 * 1.0854$$
$$x = 0.05427\ half\ width$$

$$100(1-\alpha) = 95 \rightarrow \alpha = 5$$
$$Z_{1-\frac{\alpha}{2}} = Z_{.975} = 1.96$$

$$half\ width = Z_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{(n)}}$$
$$0.06 = 1.96 \frac{s}{\sqrt{(50)}}$$
$$s = \frac{0.06 * \sqrt{(50)}}{1.96} \rightarrow s = 0.2165$$

$$n = (Z_{1-\frac{\alpha}{2}} \frac{s}{half\ width})^2$$
$$n = (\frac{1.96 * 0.2165}{0.05427})^2$$
$$n = 61.14 \approx 62\ replications$$

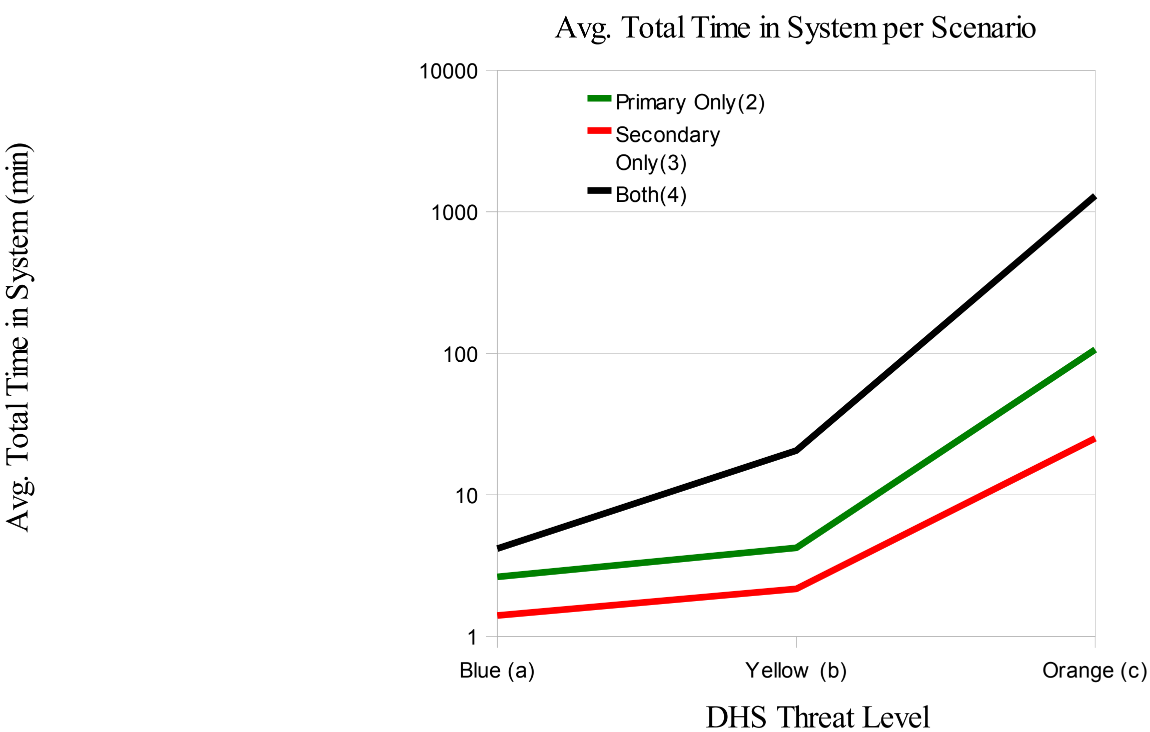
It is important to note that this is only an estimation for a new number of replications to run. There is an inherent error in this calculation and it is with s, our sample standard deviation. The sample standard deviation depends on n, the number of replications, thus using it to find a new number of replications is not correct. It does however give us starting point in our search.

Since 62 is the approximate minimum number of replications required, we have decided to round up and use 100 replications for all scenarios. In doing so, we indeed satisfy our criteria for our baseline model at 100 replications:

Average: 1.0965 min
Half Width: 0.05 min
Ratio: 0.05 / 1.0965 = 0.04559 ~ 4.56%

This data was gathered from the model output produced by ARENA. Data tables for all scenarios can be found in the appendix.

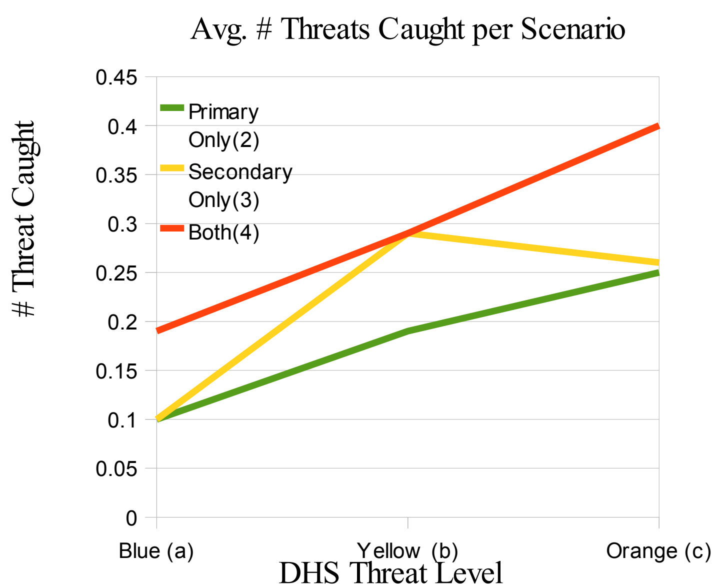
All 10 scenarios were run setting n = 100 replications. As can be seen in the plot below, the Average Total Time in the System increases as the alarm rates increase with the DHS Threat Levels.



This observation is expected. As the alarm rates increase, more trucks will be pushed to other processes in the system, and waiting will occur.

From inspecting the data tables for all of the scenarios (these data tables can be found in the appendix), it is found this does not occur for all variables collected. Lets look at the static scale wait time for scenarios 3a, 3b, and 3c. As the alarm rate increases from threat levels Blue to Yellow, the wait time increases. Oddly, the wait time decreases from Yellow to Orange. How can this be? Take a look at the PrePass wait time. The value changes from no wait in Yellow to a wait of 6.265 minutes in Orange. This tells us that there are moments when the system is at full capacity and no trucks are able to enter the station. Since no trucks can enter the station, no trucks or very few trucks will be waiting in queue at the static scale once room becomes available. This, in turn, decreases the wait time in queue for the static scale. This same effect occurs for scenarios 4a, 4b, and 4c.

Another observation is the increase in the number of threats caught as the alarm rates increase. This is expected, however, one should look at the two plots Avg. Total Time in System and Avg. Number of Threats caught together. Sure, as you increase the alarm rate you catch more potential threats, but there is no free lunch. In doing so, the system will become overloaded and wait times will grow. A decision make should use these two plots together to determine the best scenario set up to use to maximize the detection of potential threats, while keeping the wait time down to a bearable length.



CONCLUSION

The intended use of our model is for the user to pick a threat level and compare the effectiveness and efficiency across several weigh station setups. The model produces several metrics to provide different perspectives on determining the "best" setup. Our project was designed to show that our model can run various policies and inputs and compare the results.

One hindrance in the development of our model was that several of the inputs and policies in this model have no expert basis. Some of the assumptions used in our model were marked as sensitive data where others required more data collection. For example, the probability of a threat being present and the sensitivity of the false alarm rates given the threat level are marked as sensitive information. Elicitation of data from subject matter experts could also be used to gather the necessary data. Further analysis should be done on all input data and policies to refine our suggested values.

Using our set of inputs and policies, we ran ten scenarios through our model. We computed a baseline run and three different system setups for three different threat levels. Given the outputs from each run, we made a decision for each threat level on which system would be best. Based on these simulation results, for the DHS daily threat level we would recommend the weigh station to operate the scanners as follows:

Threat Level	Scanner (Scenario)
Green	No scanner (baseline)
Blue	Secondary Only (3a)
Yellow	Secondary Only (3b)
Orange	Secondary Only (3c)
Red	Primary and Secondary (4c)

APPENDIX A

The charts below are the results from all scenarios:

Scenario 1 – Baseline (50 replications)

Measure	Average	Half Width
Total Time	1.0854 min	0.06 min
# Threats Caught	0.10	0.10
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	1.4948 min	0.17 min
Full Inspection Wait Time	9.1262 min	2.06 min

Scenario 1 – Baseline (100 replications)

Measure	Average	Half Width
Total Time	1.0965 min	0.05 min
# Threats Caught	0.13	0.07
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	1.4619 min	0.13 min
Full Inspection Wait Time	8.4122 min	1.48 min

Scenario 2a – Primary Only (Blue)

Measure	Average	Half Width
Total Time	2.6404 min	0.13 min
# Threats Caught	0.10	0.06
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	4.3526 min	0.34 min
Full Inspection Wait Time	23.12 min	3.45 min

Scenario 2b – Primary Only (Yellow)

Measure	Average	Half Width
Total Time	4.2185 min	0.27 min
# Threats Caught	0.19	0.09
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	8.1101 min	0.87 min
Full Inspection Wait Time	37.3342 min	5.24 min

Scenario 2c – Primary Only (Orange)

Measure	Average	Half Width
Total Time	106.32 min	12.57 min
# Threats Caught	0.25	0.10
PrePass Queue Wait Time	70.2226 min	16.69min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	107.37 min	4.64 min
Full Inspection Wait Time	106.10 min	16.69 min

Scenario 3a – Secondary Only (Blue)

Measure	Average	Half Width
Total Time	1.4059 min	0.08 min
# Threats Caught	0.10	0.06
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	1.3802 min	0.12 min
Full Inspection Wait Time	15.7005 min	3.00 min

Scenario 3b – Secondary Only (Yellow)

Measure	Average	Half Width
Total Time	2.1622 min	0.16 min
# Threats Caught	0.29	0.11
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	1.4078 min	0.12 min
Full Inspection Wait Time	34.2186 min	5.24 min

Scenario 3c – Secondary Only (Orange)

Measure	Average	Half Width
Total Time	25.1269 min	4.72 min
# Threats Caught	0.26	0.10
PrePass Queue Wait Time	6.2650 min	3.81 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	1.3205 min	0.10 min
Full Inspection Wait Time	507.62 min	38.63 min

Scenario 4a – Primary and Secondary (Blue)

Measure	Average	Half Width
Total Time	4.1679 min	0.31 min
# Threats Caught	0.19	0.08
PrePass Queue Wait Time	~0 min	0 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	4.0423 min	0.33 min
Full Inspection Wait Time	64.2909 min	8.54 min

Scenario 4b – Primary and Secondary (Yellow)

Measure	Average	Half Width
Total Time	20.5314 min	2.72 min
# Threats Caught	0.29	0.11
PrePass Queue Wait Time	2.6018 min	1.86 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	7.3938 min	0.67 min
Full Inspection Wait Time	442.36 min	37.84 min

Scenario 4c – Primary and Secondary (Orange)

Measure	Average	Half Width
Total Time	1299.46 min	21.01 min
# Threats Caught	0.40	0.15
PrePass Queue Wait Time	1263.71 min	21.40 min
WIM / Primary Queue Wait Time	~0 min	0 min
Static Scale / Secondary Wait Time	0.4590470 min	0.02 min
Full Inspection Wait Time	1224.92 min	7.24 min

APPENDIX B

Listed below is a series of websites we found useful in determination of data and policies for our model.

1. BTS | National Transportation Statistics.Accessed December 1, 2009. http://www.bts.gov/publications/national_transportation_statistics/#chapter_1
2. Clay III, Edwin S., Bangs, Patricia. Weigh Stations in Virginia. Posted November 12, 2007. Accessed December 1, 2009. http://www.baconsrebellion.com/Issues07/11-12/Curious.php
3. FHWA – 2006 Conditions and Performance: Chapter 14: Freight Transportation. Modified March 14, 2007. Accessed December 1, 2009. http://www.fhwa.dot.gov/policy/2006cpr/chap14.htm
4. PrePass. Accessed December 1, 2009. http://www.prepass.com/Pages/Home.aspx
5. Testimony of Acting Director Charles R. Gallaway, Domestic Nuclear Detection Office, before the House Appropriations Committee, Subcommittee on Homeland Security, "Container Security". Modified April 1, 2009. Accessed December 1, 2009. http://www.dhs.gov/ynews/testimony/testimony_1238610092655.shtm
6. Hagan, William K. The Science of Security: Lessons Learned in Developing, Testing, and Operating Advanced Radiation Monitors. http://gop.science.house.gov/Media/hearings/oversight09/june25/hagan.pdf
7. ORNL Review: Better Ways to Weigh Trucks. Oak Ridge National Laboratory ReView Volume 33. Accessed December 1, 2009. http://www.ornl.gov/info/ornlreview/v33_3_00/weigh.htm
8. Arena Portal: Home. Accessed December 1, 2009. http://www.arenasimulation.com/Arena_Home.aspx
9. International Mobility & Trade Corridor Project. Cascade Gateway Almanac 2009. Accessed December 1, 2009. http://resources.wcog.org/data/border_data.pdf
10. Fazzalaro, James J. Truck Weight Inspection Stations. Posted December 22, 2006. Accessed December 1, 2009. http://www.cga.ct.gov/2006/rpt/2006-R-0776.htm
11. Gross, Donald, Shortle, John F., Thompson, James M., Harris, Carl M. Fundamentals of Queueing Theory Fourth Edition. John Wiley & Sons, Inc. 2008. Page 16.