

**Submitted to
U.S. Customs and Border Protection (CBP)
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**Modeling VACIS Security Operations
at NY/NJ Marine Terminals**

FINAL REPORT

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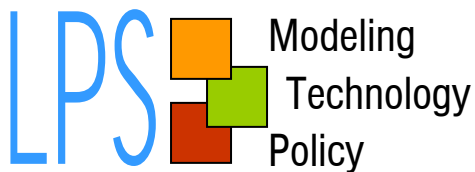
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Bridgewater, New Jersey

**DIMACS – CAIT
Laboratory for Port Security at Rutgers University**

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The **Laboratory for Port Security (LPS)** at Rutgers, The State University of New Jersey is a joint effort of DIMACS (Center for Discrete Mathematics and Theoretical Computer Science) and CAIT (Center for Advanced Infrastructure and Transportation).



Executive Summary

The goal of the project was to study the VACIS operation at the APM terminal in Port Elizabeth, New Jersey, using the simulation modeling and analysis capabilities at the Laboratory for Port Security (LPS) at Rutgers University, with the purpose of improving VACIS operational efficiency and throughput.

The project started in August 2005 on the premises of *APM Terminals* (*APM*, for short). Relevant terminal operations data and inspection process data were collected, and a detailed simulation model, called *CIPS* (*Container Inspection Process Simulator*), was developed for the container inspection operation. The model captures vessel arrivals, container storage at the yard, presentation of containers to CBP officers, and the actual inspection process.

Numerous discussions were conducted with CBP officers and APM personnel. These collaborating individuals have been instrumental in providing information and data for the model to be developed. Based on the information received, a simulation model was constructed, verified and validated, and then run for a number of scenarios to understand the capabilities of the inspection process under various surge conditions.

This report briefly describes project details, including the simulation model, run results, analysis discussions, and the next stage of the study. We present results from *CIPS* runs, based on experiments with the *CIPS* model to understand the impact of parameter changes on key performance metrics. For instance, increasing inspection percentage without changing the available resources has been shown to increase the number of inspected containers up to a certain level, beyond which the containers accumulate in the segregation area and consequently the inspected number of containers drops. Furthermore, as the batch size increases, the time a container spends in the system increases, since waiting to accumulate a container batch and inspect give rise to longer delays. Finally, the report outlines the proposed next phase of the project, where CBP operations over the entire NY/NJ port complex will be modeled.

1. Introduction

The *U.S. Customs and Border Protection (CBP)* agency of the *Department of Homeland Security (DHS)* is charged with the responsibility of securing incoming and outgoing cargo to/from the U.S., among other things. In particular, CBP performs a number of security procedures on incoming and outgoing container cargo as part of the *Container Security Initiative (CSI)*. This is a substantial operation in view of the fact that container traffic into the U.S. amounts to some 25,000 containers per day. As such, CBP operations are both security-critical and costly, and they further engender major economic consequences on the national economy as well as the global supply chain.

The Newark office of CBP has jurisdiction over terminals and port facilities in the Newark/Elizabeth and NYC area of which the *APM terminal* is the focal point in this study. This terminal sprawls over 266 acres, and has 11 cranes, 4500+ feet of wharf, including several deep water berths, a near-dock rail yard and a near-dock Customs Exam Site. It handles thousands of containers on a daily basis.

The container inspection process involves imaging anomaly analysis (*VACIS*), radiation isotope identification (*RIID*), radiation monitoring (*RPM*), as well as manual examination. The main objective of this project is to study the container inspection operations at the APM Terminal in Port Elizabeth, New Jersey, and to quantify key performance metrics associated with the following operational aspects:

- Inventory of CBP-specified containers
- Delivery processes of container from the APM terminal to CBP
- CBP container inspection operations
- Inspection resources (both CBP and APM), their capacity planning, and their utilization
- Batch-size triggering the inspection process at the APM terminal

To achieve the aforementioned objectives, Rutgers University's LPS team developed a detailed computer simulation model, called *CIPS (Container Inspection Process Simulator)*, for modeling VACIS operations in detail and accurately capturing vessel arrival processes, the current CBP-specified container delivery process, and CBP inspection procedures at the APM terminal. More specifically, the *CIPS* model incorporates

- The incoming workload (vessel arrivals and the corresponding container volume (in TEUs))
- Unloading operations by cranes and transporting them to storage areas
- Transfer of CBP-specified containers to the inspection area
- Scheduling and performing inspection operations

2. The *CIPS* Model

The *CIPS* model is a discrete-event simulation model capturing port operations relevant to container inspection operations at the APM terminal in Port Elizabeth, New Jersey. The model generates vessel arrivals using the data provided by the terminal. Arriving vessels are unloaded by cranes, and containers identified as suspicious are sent to a segregation area. This process complies with a prescribed inspection percentage (e.g., 4%). As shown in Figure 1, segregated containers are taken to the inspection area by trucks, allocated to this process by the APM terminal.

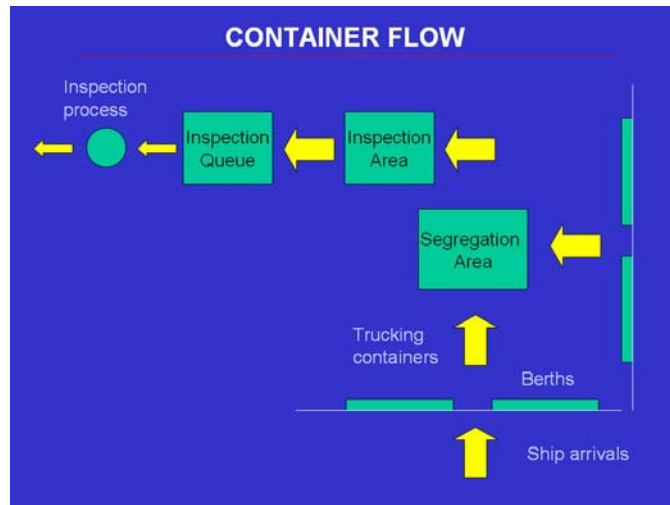


Figure 1. Container flow for inspection at the APM terminal in Port Elizabeth, New Jersey

CBP has been using two approaches in inspecting containers in the ports of New York and New Jersey: *Stationary Scan* and *Moving Scan*. In a Stationary Scan scenario, containers are brought in to the inspection queue by trucks (usually, 4 trucks are allocated to the inspection area) and each truck carries a container past the VACIS truck to be scanned and inspected. After the inspection is over, each truck takes its container back to the storage yard. In a Moving Scan scenario, a batch of containers, each placed on a chassis, is lined up so as to enable a mobile VACIS truck to move over them and inspect containers one after the other. Thus, the VACIS system is stationary and the containers are mobile in the former, while the opposite holds in the latter.

Rutgers' LPS and CBP teams developed a workflow chart for the container inspection process, depicted in Figure 2, showing task times and branching probabilities obtained using expert opinion.

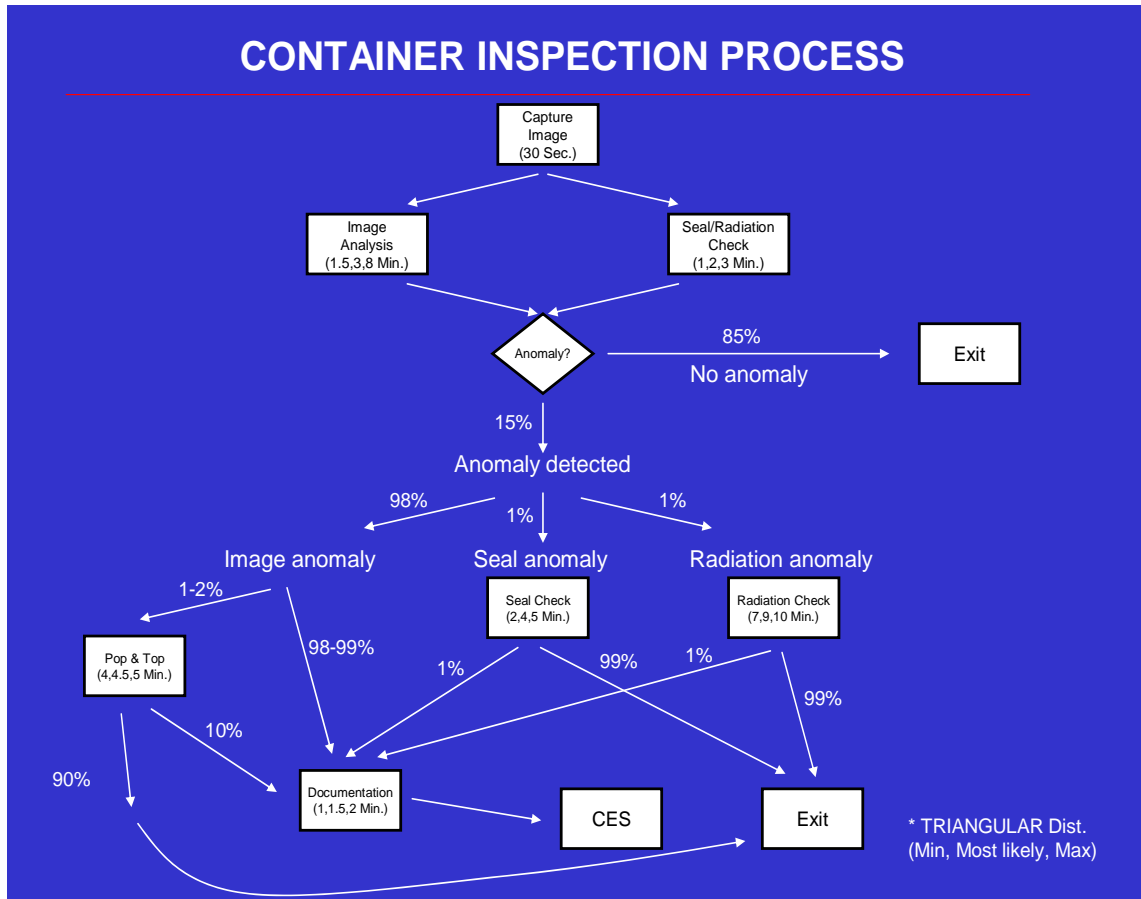


Figure 2. Workflow of the container inspection operations at NY/NJ port terminals

The workflow of the inspection process details the types of inspections and the operations (and their durations) undergone by each segregated container. In particular, the decision tree shows the processes a container may go through, once an anomaly is found (with 15% probability). The anomaly can be of image, seal or radiation type. Figure 2 details all the possibilities with the attendant processing times, which follow **TRIANGULAR** distributions with three time parameters: **Min** (minimum possible), **Most Likely** and **Max** (maximum possible).

The data was acquired from CBP officers and the decision tree was developed based on their experience and expertise.

2.1 Model Considerations

The *CIPS* simulation model of the container inspection process at the APM terminal incorporates the following operational components:

- **Vessel arrival process.** Vessel arrival patterns have a significant impact on the number of containers that accumulate in the segregation area. The vessel arrival process was modeled using the lay period/elapsed time approach and the data provided by APM. The simulation model implements a vessel arrival model which lets each vessel arrive in a particular window and captures the behavior of the vessel arrival process as manifested by the associated statistics.
- **Segregation of CBP-identified containers.** CBP identifies suspicious containers using the *Automated Targeting System* of the Department of Homeland Security. This is mapped to the *CIPS* model as a specific percentage of containers to be inspected. During the unloading process, containers are selected accordingly and taken to a staging area to be transported to the inspection area by trucks.
- **Inspection operation – minimal batch size.** The model is constructed for the VACIS operation and its associated inspection operations. The VACIS operation is initiated when a *minimal batch size* of CBP- specified containers accumulates in the inspection area. The model accommodates both Mobile Scan and Stationary Scan inspection modes.

CIPS is written using a computer simulation tool called *Arena*¹ -- a widely distributed simulation tool used worldwide by both industry and academia². It is also part of the graduate and undergraduate curricula in the Rutgers' Department of Industrial and Systems Engineering and the Rutgers Business School. The *Arena* software tool was selected due to its versatility and wide range of capabilities for modeling complex scenarios.

¹ *Arena* is a trademark of the Rockwell Software Corporation.

² Altiook, T. and B. Melamed (2001), *Simulation Modeling and Analysis with Arena*, CRIETSI, Warren, NJ.

Arena uses the so-called *Monte Carlo discrete-event* simulation paradigm, under which it can be programmed to perform the following actions:

1. Generation of transactions representing vessels at scheduled arrival points in time.
2. Scheduling of events representing vessel berthing and deberthing, breakdowns and repairs, truck arrivals, trucks (trains) loading and unloading, and truck departures.
3. Using real data as well as fitted random processes to mimic the operation being modeled.
4. Collection of statistical information (observations) in the course of simulation runs, in order to estimate performance metrics of interest.
5. Running various scenarios of interest allows the analyst to compare their performance by using the collected observations to estimate their relevant performance metrics.

2.2 Data Requirements

CIPS uses the following operational field data provided by CBP and APM:

1. **Vessel data:** vessel arrival times, berth selection, docking times.
2. **Cargo data:** number of containers per ship arrival.
3. **Cargo handling data:** equipment and personnel resources allocated by the APM terminal to handle a load, and container loading and unloading times.
4. **VACIS operational data:** equipment and personnel resources allocated by CBP to inspect a load, container inspection times, branching probabilities and the inspection procedure type.
5. **Operation disruptions data:** operation stoppages and equipment failures.

2.3 Model Verification and Validation

CIPS was **verified** to ensure that it is working as designed. This was accomplished using the verification methods described in Altiok and Melamed (2001)³.

CIPS was also **validated** to ensure that the model adequately captures the inspection process at the APM terminal. More specifically, validation by compares performance measures generated by the model with counterparts observed in the actual system. In our case, operational field data (e.g., throughput of the inspection process) is compared with the counterparts produced by the model. The comparison results will be presented in Section 5.

To facilitate making simulation runs under various scenarios of interest, we have added to the model a user interface to simplify the entry of input parameter values. In addition, model animation can be turned on to provide a dynamic pictorial view of the ATM terminal and CBP operations unfolding in time, including the inspection process details, so users and observers may enhance their understanding of the system under study (see Section 3).

2.4 Model Output and Analysis

Following validation, *CIPS* was run to produce estimates for various system performance metrics under current and various future operational scenarios. For a given minimal batch size (to initiate inspection), the following performance measures were obtained:

1. Container delivery times (for inspection)
2. VACIS system utilization, downtime and throughput
3. Total container inspection times
4. Truck delays experienced in the VACIS inspection process
5. Container inventory levels (for inspection)
6. Container transport-equipment utilization, downtimes and delivery throughput

³ Altiok, T. and B. Melamed (2001) Simulation Modeling and Analysis with Arena, Rutgers University.

The analysis of model outputs is based on multiple runs (replications) of each scenario of interest to achieve acceptable statistical reliability. In particular, a number of “what-if” scenarios were run and analyzed to consolidate ideas and reach conclusions pertaining to key operational issues germane to the VACIS inspection activity.

3. CIPS Model Components

In this section, we present various components of the *CIPS* model. The screen view of the APM port terminal area, as modeled in *CIPS*, is shown in Figure 3.

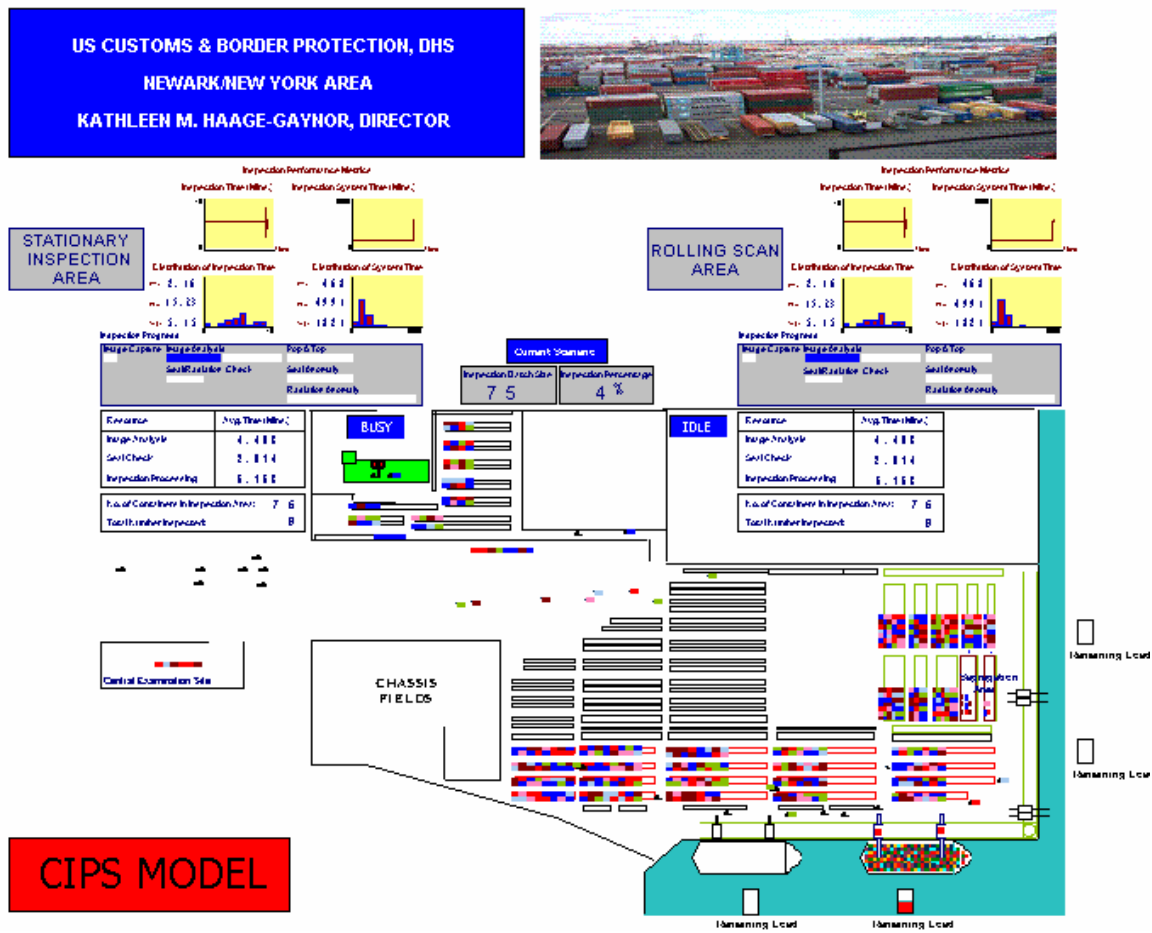


Figure 3. The *CIPS* screen view of the APM port terminal

Shown above is the layout of the APM berths, staging areas, storage yards, inspection areas, and the current configuration of container stocks on ships and in storage yards. When a simulation run is in progress, the user can also see animation and a number of statistical windows consisting of the following elements

- Ship arrivals and departures
- Loading and unloading of containers by cranes
- Shuttling of containers across the yards
- Container inspection processes

3.1 The *CIPS* User Interface

CIPS has a user interface through which the user can input values for various system parameters and select the requisite scan type (stationary or mobile). It is also used to initiate simulation runs. The user interface component is important for easy data entry – a process that can be error-prone. A sample of user-interface dialog boxes is shown in Figure 4.

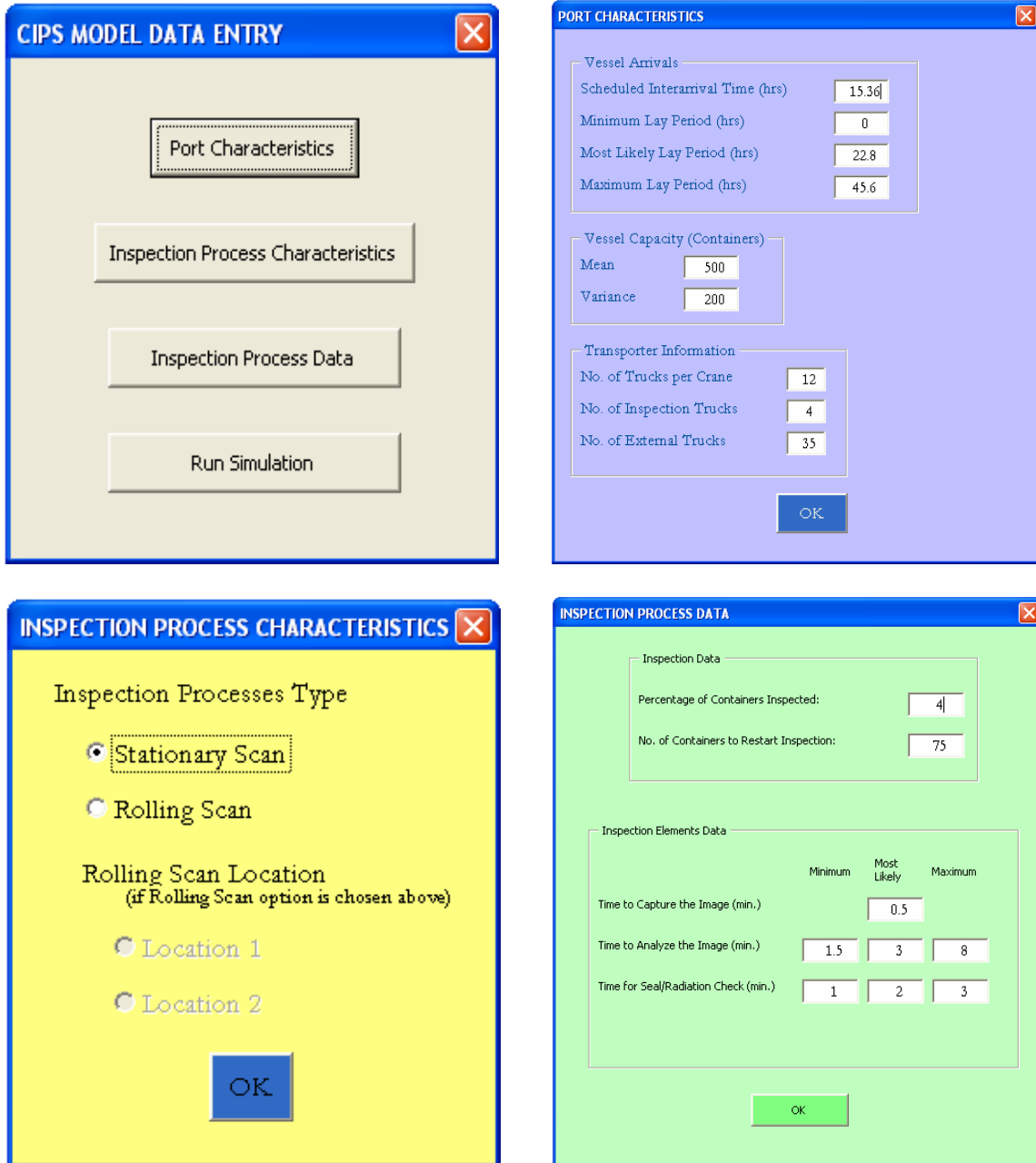


Figure 4. CIPS dialog boxes for entering port and inspection parameters

Through the user interface, users can choose a particular inspection scheme and input its corresponding data to the system. The requisite percentage of inspected containers and the inspection batch size can be easily modified, depending on the changing situations.

Vessel arrival information requires an analysis of vessel arrival data. In our case, APM provided a year's worth of data (2005) to analyze and estimate arrival process parameters as inputs to *CIPS*. Vessel inter-arrival times were found to be negatively correlated. To model such data in the simulation, each vessel is given a time window to arrive. The length of the window (called, *lay period*) and the distribution of the arrival time offset from the beginning of the window (referred to as the *elapsed time*) are obtained through an analysis of the inter-arrival time data. In the present case, the APM data revealed that the mean inter-arrival time is 15.36 hours, and the mean length of the lay period is 45.6 hours. The distribution of the elapsed time in a window turned out to be *TRIANGULAR*(0, 22.8, 45.6), that is, vessels arrive within the lay period according to a triangular distribution with minimal offset time of 0 hours, most likely offset time of 22.8 hours, and maximal offset time of 45.6 hours. When the lay period/elapsed time mechanism is used for each vessel, the mean vessel inter-arrival time is 15.36 hours and the variance of inter-arrival times matches the variance of the data. Modeled correlations are quite close to the ones observed in the data.

Vessel capacity and transporter information are self-explanatory. These data were provided by the APM terminal.

Inspection process characteristics and *inspection process data* are self explanatory. Modeling both inspection modes allows the user to compare their relative advantages and disadvantages.

3.2 Stationary Scan Scenario

The Stationary Scan process is modeled in *CIPS* in such a way that as soon as a prescribed number of containers accumulate in the inspection area, a CBP team starts the inspection process of this batch (e.g., the current APM batch size is 75 containers). Containers are delivered to the inspection area by trucks (the number of which is

specified via the user interface), which keep feeding the scanning process (APM data indicates a 4% inspection rate). The *CIPS* Model provides a large number of inspection-process statistics panels, which are dynamically updated as part of the animation, and these are shown in Figure 5.

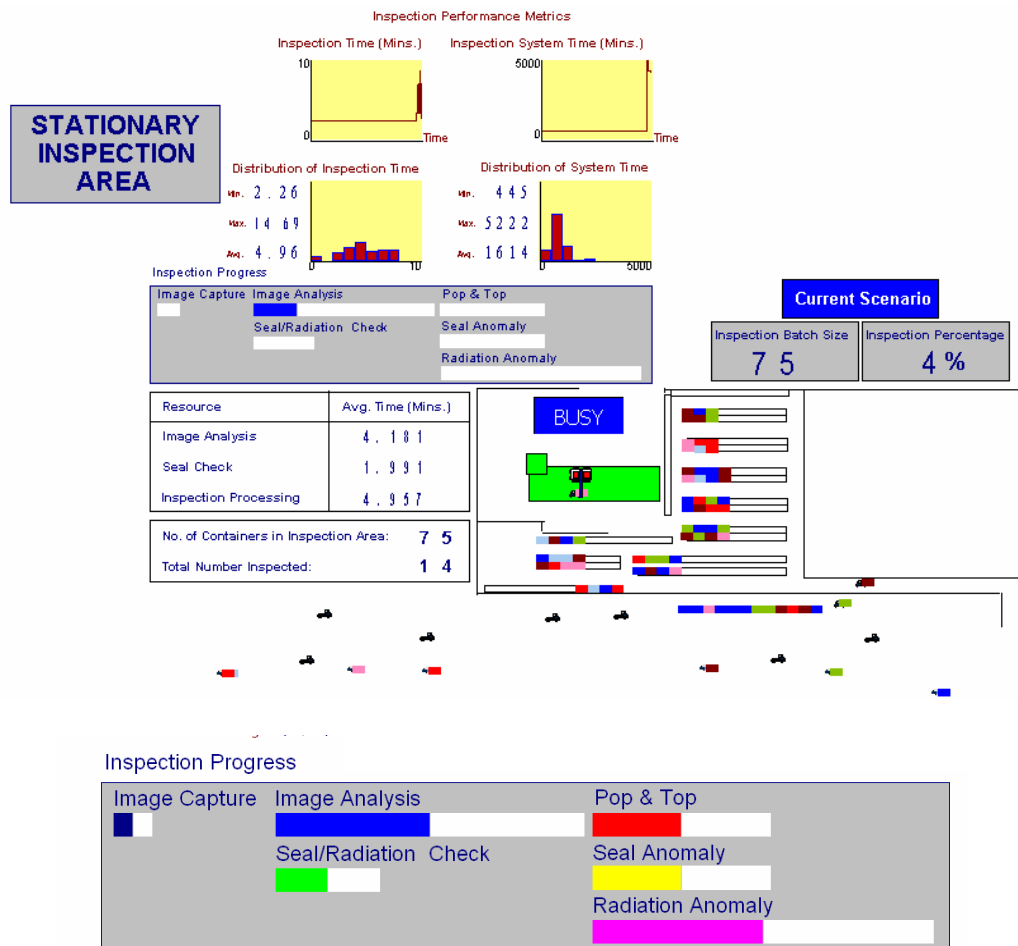


Figure 5. A snapshot of *CIPS* screen view of the Stationary Scan

CIPS provides a number of detailed images with icons representing queued containers, the state of the inspection process, inspection times and distributions of container inspection times and container system time.

3.3 Moving Scan Scenario

CIPS also models the Moving Scan mode of inspection with its complement of statistics. A sample *CIPS* screen is shown in Figure 6.

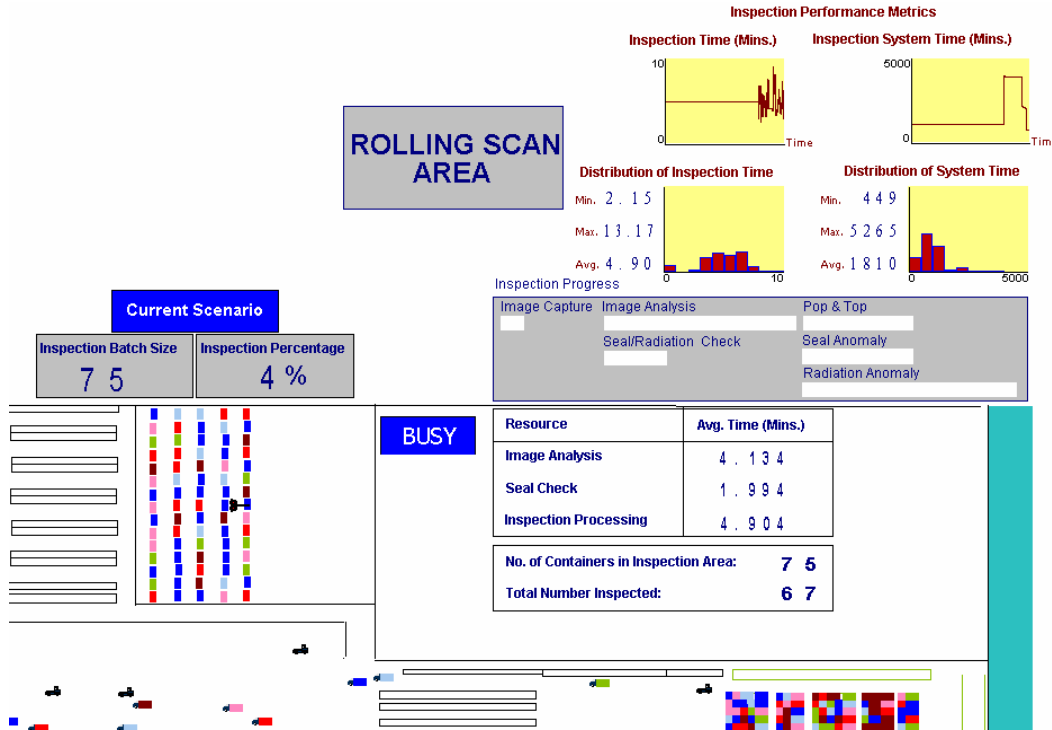


Figure 6. *CIPS* screen view of a moving scan

Here, the animation component of *CIPS* shows an inspection operation in progress of a lined up bath of containers, and displays their total durations with their distribution. It also displays system time statistics per container, which includes the inspection time and waiting time in the inspection area as constituents.

3.4 *CIPS* Model Assumptions

The *CIPS* model assumptions are summarized below in some detail:

Vessel arrival process:

- Average vessel inter-arrival time: 15.36 hours

- Lay Period: 46 hours
- Elapsed time distribution: **TRIANGULAR** (0,22.8,45.6) hours

Cargo data:

- Distribution of number of containers per ship arrival: **NORMAL** (500,200)

Inspection operation:

- Batch size: 75
- Number of containers arrived in November 2004: 24,519
- Number of containers inspected in November 2004: 940
- Inspection percentage: $940/24,519 = 3.83\% \sim 4\%$ (APM indicated that 940 containers were inspected out of 24,519 containers arrived during the year of 2005.)
- Once the number of containers in the inspection area reaches the inspection threshold (that is, the minimal batch size), the inspection process is started
- Inspection process can only start between 8:00 AM and 15:00 PM.
- During the inspection process, no other containers are allowed to enter the inspection area (they are kept in the segregation area)

4. CIPS Outputs

At the end of each replication, **CIPS** produces a number of statistical results for the inspection performance metrics as well as the port performance metrics. Figure 7 illustrates these output statistics for a replication length of one year.

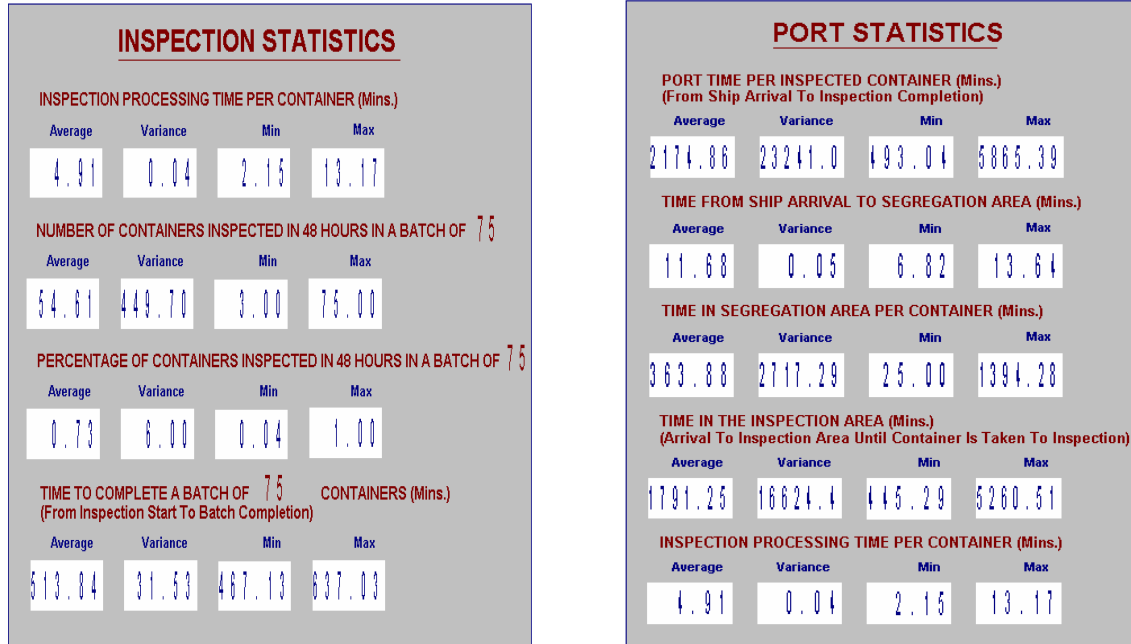


Figure 7. CIPS output statistics: inspection and port statistics

CIPS output statistics are divided into two categories: inspection statistics and port Statistics. Inspection statistics consists of the following performance metrics:

- Inspection processing time per container
- Number of containers inspected in 48 hours in the designated batch
- Percentage of containers inspected in 48 hours in the designated batch
- Time to complete a batch of designated quantity

Port statistics include the following performance metrics:

- Port time per inspected container (from vessel arrival to inspection completion)
- Time elapsed from vessel arrival to segregation area
- Time spent in segregation area
- Delay in inspection area
- Inspection time

Each metric display the simulated means, variance, minimum and maximum values. Some key statistics are also rendered graphically (e.g., probability distributions).

5. Validation of Simulation Results

In this section, we compare simulation results with the empirical results (actually observed field results) obtained from historical CBP's inspection operations at the APM terminal for both scan modes.

Input delay characteristics of various operational steps, based on such CBP historical records, are displayed below by inspection scan mode.

	<u>Stationary scan</u>	<u>Moving Scan</u>
t_1 : Warm up time	15 min.	15 min.
t_2 : Terminal delay	<i>UNIFORM</i> (40, 90) minutes with a probability of 2/11 in a given day (Stationary Scan only)	
t_3 : Natural delay	<i>EXPONENTIAL</i> (30) days up with 2 hours down (both inspection modes)	
t_4 : Lunch Break	1 hour	1 hour
t_5 : CBP associated delays	<i>EXPONENTIAL</i> (20) hours up with <i>EXPONENTIAL</i> (1) hour down (both inspection modes)	
t_6 : Shut down time	15 min.	15 min.

The following output statistics are computed and displayed by *CIPS*.

T : Terminal residence time (total time the CBP team stays at the terminal)

\bar{o} : **Throughput** (Number of containers inspected per hour) is calculated using the CBP formula

$$\bar{o} = \frac{N}{T - t_1 - t_6},$$

The throughput formula above assumes only warm up and shut down times as unproductive times and excludes them from the terminal residence time of the CBP officers.

Using the field data provided by **CBP**, we have obtained the monthly throughputs under Moving Scan, shown in Table 1.

Table 1. Mobile VACIS monthly throughputs at the APM terminal

CBP DATA (APM TERMINALS)			
Moving (Rolling) Scan Results			
	Containers Scanned	Operation Hours	Throughput (Containers/hour)
Apr-05	895	77.25	11.59
Jul-05	1070	117.75	9.09
Aug-05	1124	112.75	9.97
Sep-05	866	85.25	10.16
Oct-05	804	85.25	9.43
Nov-05	940	109	8.62
Dec-05	756	91.75	8.24
Jan-06	1152	118.8	9.70
Feb-06	544	64.75	8.40
Total	8151	862.55	9.47

Using the *TRIANGULAR*(1.5, 3, 8) distribution (in minutes) for the image analysis time, we ran a ten-year *CIPS* simulation, and obtained the following results:

Table 2. CIPS results for the field data presented in Table 1

Image analysis time <i>TRIANGULAR</i>(1.5 ,3, 8)	<i>CIPS</i> Model Results	
	Stationary Scan	Moving Scan
Throughput ($\bar{\sigma}$) (containers/hour)	8.9487	9.3264

Clearly, the results of the *CIPS* model in Table 2 accurately capture the field data in Table 1. These results validate the *CIPS* model.

Note that the *CIPS* simulation model was run for a batch of 75 containers, which is the total number of containers inspected by a CBP team in a visit to ATM terminal. Each inspection starts as soon as 75 containers are lined up at the yard and stops when all are inspected. Under this scenario, Table 2 shows that the Moving Scan inspection mode is **more efficient** (has higher throughput) than the Stationary Scan mode. However, if space is limited to a batch size of 15 containers, then, moving scan becomes **less efficient** than Stationary Scan, due to the extra overhead incurred in removing inspected containers and bringing new ones under the smaller batch size scenario.

6. Experimentation with the *CIPS* Model

Following validation, we experimented with *CIPS* to produce estimates for various system performance metrics under current and future operational scenarios. In particular, a number of “what-if” scenarios were run and analyzed. For example, for a prescribed inspection percentage, it is important to know what percentage of containers is inspected within 48 hours of their arrival. Moreover, it is also important to see how this metric changes as the inspection percentage increases. The results are depicted in Figure 8.

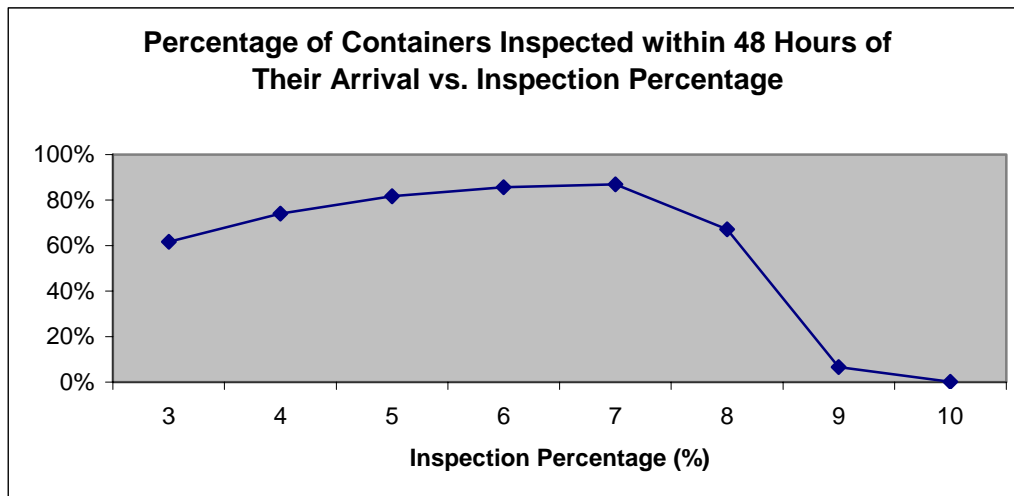


Figure 8. *CIPS* output statistics of the number of containers inspected within 48 hours as function of the inspection percentage

Notice that as the inspection percentage increases, the number of containers inspected increases up to a maximum of 7% inspection rate. That is, the CBP team's capacity is able to handle the incoming rate of containers up to this point. However, as the inspection percentage increases further, a container backlog builds up in the segregation area and the percentage of inspected containers drops sharply. In this situation, the only solution is **to increase the CBP team's capacity**, that is, to add personnel and equipment so as to keep up with the increased load.

In a similar vein, we investigated the behavior of the total container system time as function of the inspection percentage. The results are shown in Figure 9.

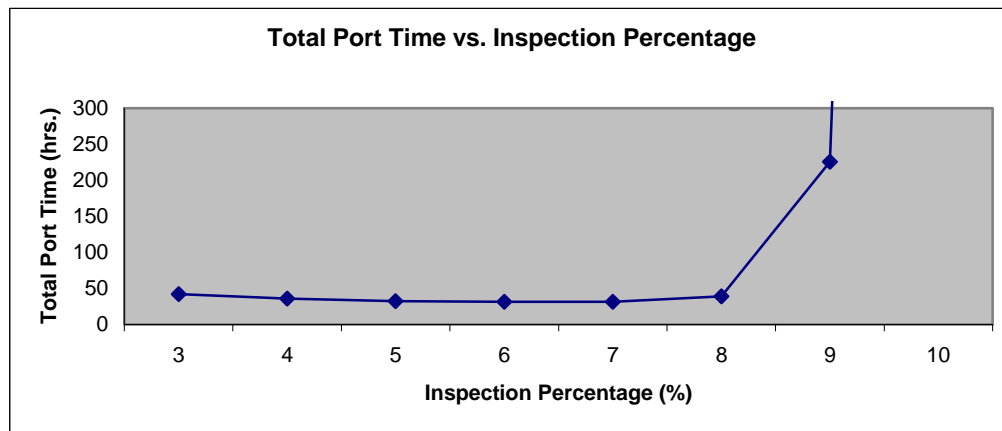


Figure 9. CIPS output statistics of port times as function of inspection percentage

Notice that here the expected port time per container does not change significantly until the inspection percentage hits 8%. Beyond that, it shoots up significantly due to major container build up in the segregation area. In this situation, the only solution is **to increase the capacity of the CBP team**, that is, to add personnel and equipment so as to keep up with the increased load.

We next experimented with the inspection batch size and investigated its impact on the percentage of containers inspected within 48 hours. The results are shown in Figure 10.

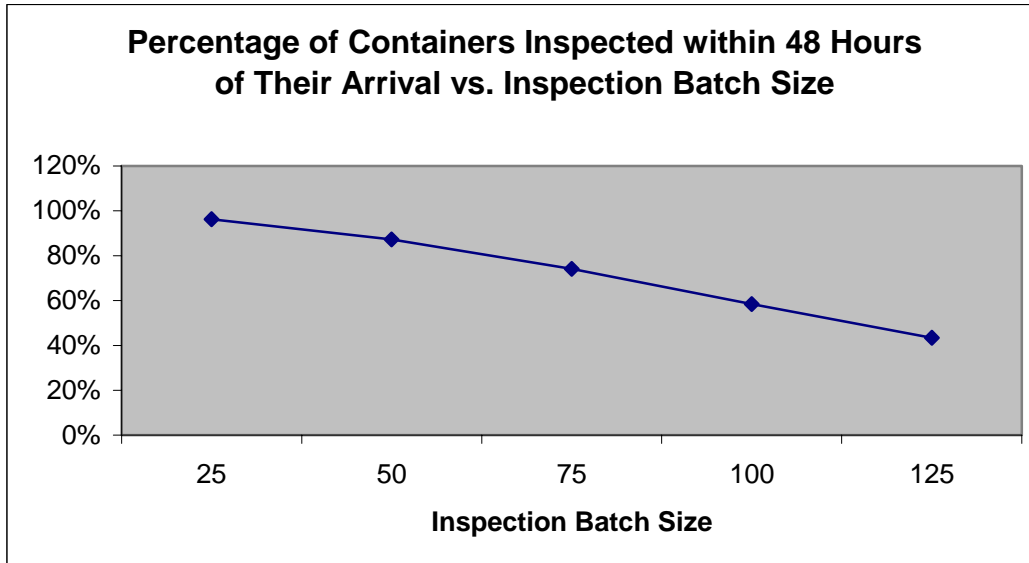


Figure 10. CIPS output statistics of the percentage of containers inspected within 48 hours as function of the inspection batch size

Clearly, as the inspection batch size increases, it takes more time to accumulate a batch since container availability for inspection depends on vessel arrivals. Thus, the percentage of containers inspected within 48 hours of arrival drops since more containers get to be inspected in periods longer than 48 hours.

Finally, we investigated the effect of the inspection batch size on container port times (the total time a segregated container spends at the terminal until its inspection is completed). Again, the time to accumulate a batch increases as the batch size increases. Consequently, port times increase concomitantly as shown in Figure 11.

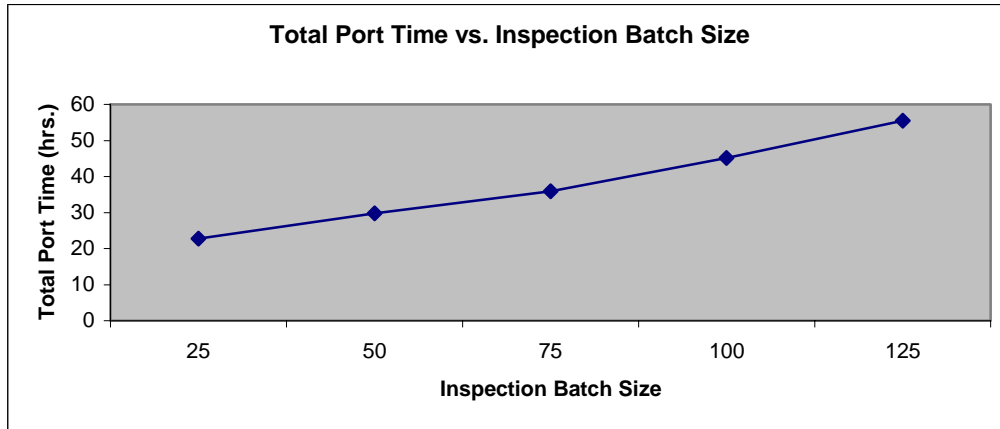


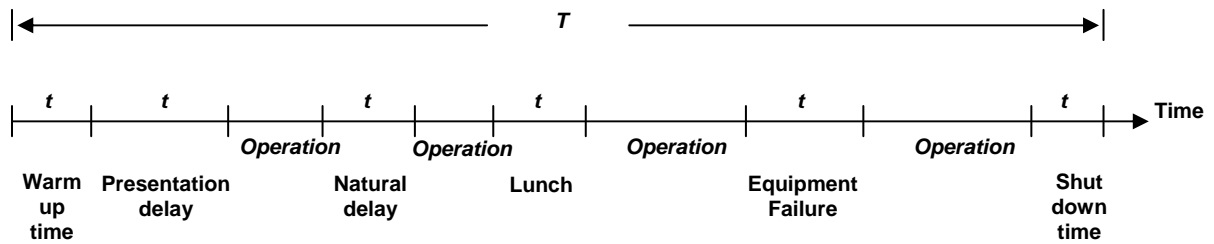
Figure 11. *CIPS* output statistics of port times of containers as function of the inspection batch size

Other analyses of “what-if” scenarios can be easily carried out via experimentation with the *CIPS* model.

7. Proposed Throughput Calculations

In this section, we propose a revision in the way the hourly throughput is calculated in CBP's inspection operations. The revised calculation method will better reflect CBP operational metrics.

Consider the scenario given in the following graph:



Define the following time periods:

T : Terminal residence time (total time the CBP team is at the terminal)

N : Number of containers inspected during time T (say, batch size)

t_1 : Warm up time

t_2 : Terminal delay (i.e., presentation delay, unavailable targets)

t_3 : Natural delay (i.e., due to natural causes such as high winds)

t_4 : Lunch break

t_5 : CBP associated delays (i.e., equipment failure)

t_6 : Shut down time

Below, we define the two performance metrics of interest to CBP operations, namely, the *overall throughput* and the *effective throughput*.

- **Overall throughput per hour:** Hourly throughput based on the total time spent at the terminal.
- **Effective throughput per hour:** Hourly throughput based on the actual hours worked.

Both of these metrics do not consider warm-up time, shut down time and breaks, such as lunch time, as productive hours, since these “non-productive” periods are not under CBP control.

Accordingly, we propose the **Overall throughput** (\bar{o}_0) metric, given by

$$\bar{o}_0 = \frac{N}{T - t_1 - t_4 - t_6}.$$

Alternatively, if the terminal delay (if any) is excluded, the overall throughput without the terminal delay (\bar{o}_1) would become

$$\bar{o}_1 = \frac{N}{T - t_1 - t_2 - t_4 - t_6}.$$

Clearly, \bar{o}_1 is larger than \bar{o}_0 , and the difference between these two measures would be the hourly throughput gained if the terminal does not impose delays on the inspection operation.

Finally, the **Effective throughput** (\bar{o}_2) is calculated as

$$\bar{o}_2 = \frac{N}{T - t_1 - t_2 - t_3 - t_4 - t_5 - t_6}.$$

Thus, the effective throughput is based only on the actual hours worked, and consequently, represents a throughput metric which is entirely under the control of CBP. Even though the effective throughput reflects most faithfully the inspection performance of CBP, each of the other throughput metrics can be used for various purposes.

8. Proposed Utilization Calculations

Using arguments similar to the ones supporting the alternative throughput metrics above, we further propose alternative utilization metrics as follows:

The **Overall utilization** (\bar{u}_0) is calculated as

$$\bar{u}_0 = \frac{T - t_1 - t_4 - t_6}{T},$$

which excludes warm up time, lunch break and the shut down time.

The **Effective utilization** (\bar{u}_1) is calculated as

$$\bar{u}_1 = \frac{T - t_1 - t_2 - t_3 - t_4 - t_5 - t_6}{T}$$

which only includes the hours actually worked.

If the terminal delay is insignificant, then the overall utilization (\bar{u}_2) is given by

$$\bar{u}_2 = \frac{(T - t_2) - t_1 - t_4 - t_6}{T - t_2},$$

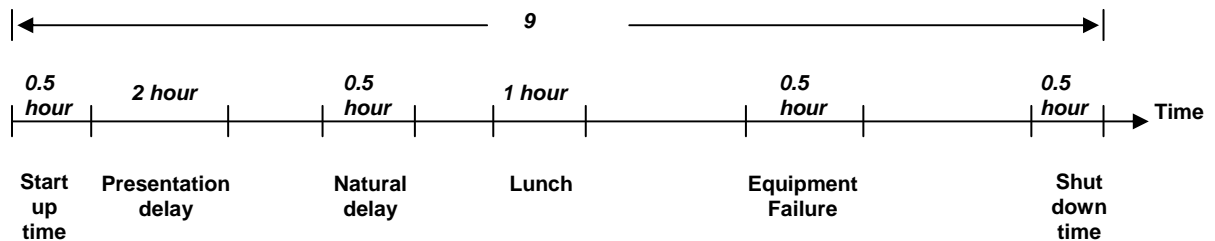
and the effective utilization (\bar{u}_3) will be

$$\bar{u}_3 = \frac{(T - t_2) - t_1 - t_3 - t_4 - t_5 - t_6}{T - t_2}.$$

Note that the terminal delay is excluded in both numerator and denominator.

Example:

Consider the following scenario for Terminal A:



Number of containers inspected: $N = 75$.

The various variants of throughput metrics under this scenario are given by

	Throughput/hour
Overall throughput (\bar{o}_0)	10.7
Overall throughput with no terminal delay (\bar{o}_1)	15
Effective throughput (\bar{o}_2)	18.8

and the corresponding utilizations are given by

	Utilization (%)
Overall utilization (\bar{u}_0)	77.8
Effective utilization (\bar{u}_1)	44.4
Overall utilization with no terminal delay (\bar{u}_2)	71.4
Effective utilization with no terminal delay (\bar{u}_3)	57.1

Notice that the impact of terminal delay on the throughput is significant in this example. Thus, we argue that the choice of an appropriate throughput metric makes a major difference.

9. **CIPS Results for the Proposed Throughput Calculations**

This section presents the proposed performance metrics obtained from CIPS simulation runs.

Input delay characteristics of various operational steps, based on such CBP historical records, are displayed below by inspection scan mode.

	<u>Stationary scan</u>	<u>Moving Scan</u>
t_1 : Warm up time	15 min.	15 min.
t_2 : Terminal delay	<i>UNIFORM</i> (40, 90) minutes with a probability of 2/11 in a given day (Stationary Scan only)	
t_3 : Natural delay	<i>EXPONENTIAL</i> (30) days up with 2 hours down (both inspection modes)	
t_4 : Lunch Break	1 hour	1 hour
t_5 : CBP associated delays	<i>EXPONENTIAL</i> (20) hours up with <i>EXPONENTIAL</i> (1) hours down	
t_6 : Shut down time	15 min.	15 min.

The following output statistics were computed and displayed by *CIPS*.

T: Terminal residence time (total time the CBP team stays at the terminal)

Throughput (Number of containers inspected in one hour, containers/hour): Using *TRIANGULAR*(1.5, 3, 8) minutes as the image analysis time, resulted in the following variants of throughput metrics

	Stationary Scan	Moving Scan
Overall throughput (\bar{o}_0)	10.5659	11.0370
Overall throughput with no terminal delay (\bar{o}_1)	10.8582	11.3547
Effective throughput (\bar{o}_2)	11.2833	11.7974

and in the following variants of utilization metrics

	Stationary Scan	Moving Scan
Overall utilization (\bar{u}_0)	79.48%	79.55%
Effective utilization (\bar{u}_1)	79.93%	79.09%
Overall utilization with no terminal delay (\bar{u}_2)	74.84%	76.12%
Effective utilization with no terminal delay (\bar{u}_3)	76.49%	74.43%

Terminal delays may not be significant at the APM terminal resulting in insignificant changes in the throughput figures. However, in those terminals where the CBP team experiences significant terminal delays, throughputs excluding terminal delay will be significantly improved.

10. Proposed Next Project Phase

The *CIPS* model presented earlier included the APM terminal only and assumed that CBP resources are always available when needed. In reality, CBP resources are shared among multiple terminals, so when a terminal invites the CBP team for inspection, the team may in fact be busy at another terminal. Thus, a more comprehensive analysis must include *lead time* (the time the CBP team takes to arrive at a terminal for the next inspection). Accordingly, the next phase in this effort involves the extension of the model from a single terminal (in our case, the APM terminal) to multiple terminals (in our case, all terminals in the port complex of NY/NJ). Since, the CBP team polls different terminals as containers accumulate for inspection, the only way to make globally-optimized decisions as to where to go next and how to allocate resources is to look at the overall picture consisting of all terminals and to make decisions based on their segregated container stocks.

10.1 Proposed Extended *CIPS* Model

The proposed schematic view of the extended *CIPS* model is depicted in Figure 12.

Modeling the Entire NY/NJ Port Complex

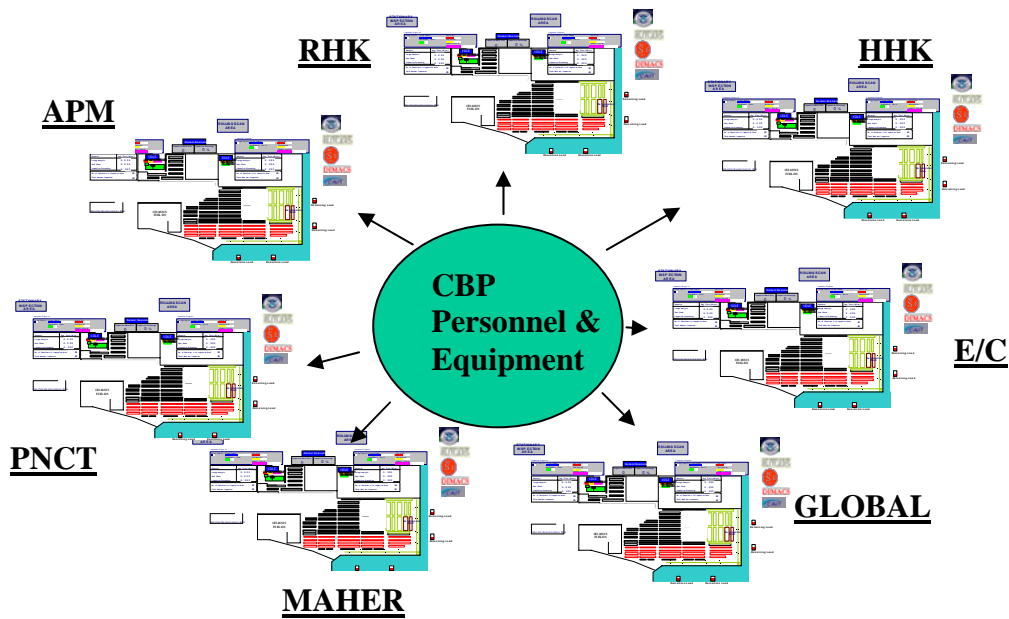


Figure 12. Schematic view of the CIPS model extension to the entire port complex of NY and NJ

The polling problem underlying the CBP's operation can be described as follows:

Each terminal k will be assigned a batch size, Q_k , of the number of containers to be inspected per visit. That is, terminal k will initiate a request when Q_k containers accumulate in its inspection area. The CBP team will place the request into the queue of inspection requests and will serve them according to some optimal scheduling rule.

The ultimate goal of this study is to optimize terminal batch sizes, such that the expected total port time over all segregated containers is minimized. The problem can be mathematically expressed as follows:

Key input parameters:

q : Percentage of containers to be inspected

Res(CBP): CBP resources such as personnel and equipment

Decision variables:

Q_k : Batch size for terminal k

Objective function:

$$\min_{Q_k} f(Q_{APM}, Q_{MAHER}, \dots, Q_{PNCT}) = \sum_{\text{every NY/NJ terminal, } k} \text{Total Port Time}(q, Q_k, \text{Res}(\text{CBP}))$$

Optimizing this function will yield optimal values of the terminal batch size decision variables, $Q_{APM}^*, Q_{MAHER}^*, \dots, Q_{PNCT}^*$.

10.2 Discussion

Given adequate CBP resources, as Q_k^* increases for a given terminal, k , the expected port time per container decreases concomitantly, because smaller batches accumulate faster. Consequently, the inspection will likely start earlier than in the case of a larger batch size. Also, smaller Q_k^* imply more frequent visits to terminals. However, frequent CBP visits will result in increased transportation time among terminals causing, thereby reducing the availability of CBP resources for inspection.

Thus, the problem boils down to identifying optimal terminal batch sizes that balance the demand for inspection with the resources available for inspection.

10.2 Completion Time for the Next Phase

Leveraging prior experience with modeling the APM terminal, we anticipate that modeling the inspection operations in the extended model (including data collection) will take 3-4 months per terminal. The entire project will be completed in 2 year.

Appendix: Project Information

Drs. Altiok and Melamed are the joint principal investigators (PI) of the proposed project, with **Dr. Altiok serving as the contact person and coordinator to CBP**. The PIs will lead and supervise the project for its duration, even though each will receive just one-month summer support from the project.

Rutgers University information is given below:

Correspondence can be made with Keith Osterhage, Director of ORSP.

More info can be found at <http://orsp.rutgers.edu/proposal.asp> **PROPOSAL COVERSHEET INFORMATION**

University Fiscal Year is July 1st to June 30th.

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