

Maximizing Port and Transportation System Productivity by Exploring Alternative Port Operation Strategies

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Report 09-03
June 7, 2010

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Research sponsored by the Georgia Transportation Institute

Georgia Institute of Technology
Atlanta, Georgia
June 2010

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No

4. Title and Subtitle
Maximizing Port and Transportation System Productivity by Exploring Alternative Port Operation Strategies

5. Report Date
June 07, 2010

6. Performing Organization Code
GTI/UTC

7. Author(s)
James Tsai

8. Performing Organization Report No.

9. Performing Organization Name and Address
Georgia Transportation Institute/UTC
Georgia Institute of Technology
790 Atlantic Drive,
Atlanta, GA 30332-0355

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Georgia Transportation Institute/UTC
Georgia Institute of Technology
790 Atlantic Drive
Atlanta, GA 30332-0355

13. Type of Report and Period Covered
Research Report, 2009-2010

14. Sponsoring Agency Code

15. Supplementary Notes
n/a

16. Abstract

Truck delays at terminal gates decrease productivity of ports and truck fleets (e.g. trucker idle time) and increase truck emissions. U.S. ports have explored solutions, such as gate appointment systems, to improve gate operations and reduce truck delays. It is important to quantitatively evaluate these solutions and to understand their impact on the underlying behavior (e.g. truck arrival pattern) using actual, measured gate performance data. However, researchers have difficulty obtaining measured, detailed gate performance data (e.g. for each truck) by visually reviewing images because the process is labor-intensive, time-consuming, and costly. Thus, gate performance data collection is often limited to a short period of time (only a few hours), which limits the understanding of the performance of the actual gate system. Therefore, an effective means to collect detailed gate performance data over a longer time periods (e.g. one week) using images widely available is needed.

A vision-based sensing system is proposed to automatically extract port gate performance data. The development of the sensing system is divided into two phases. In Phase 1, an image processing algorithm, integrating a frame-change motion detection model that takes into account color distortion to address the unique characteristics of the port gate environment, was developed to extract the service time using images widely available from surveillance cameras at the gates to demonstrate the feasibility of the proposed sensing system The actual images acquired from surveillance camera systems at the port gate will be used to evaluate the performance of the developed algorithm in the next phase. The developed algorithm has a great potential to be used at other ports for the service time data collection since the surveillance camera systems are widely available.

In Phase 2, a vision-based sensing system, including an enhanced image processing algorithm and a multi-camera system, will be developed to collect truck arrival time, wait time, and service time at the gate. In addition, the research team is in discussions with the Georgia Ports Authority to conduct an experimental test at the Port of Savannah to test the vision-based system. The detailed gate operation at Savannah Port was reviewed in Phase 1 to support the multi-camera design, and a multi-camera system was designed to collect the images for capturing the truck movement at various critical locations (portal, pedestal and inspection canopy) at the gate in support of the development and validation of the enhanced image processing algorithm.

17. Key Words
Gate Operation, Gate System, Vision-Based Sensing System

18. Distribution Statement
No restrictions.

19. Security Classif (of this report) Unclassified	20. Security Classif (of this page) Unclassified	21. No. of Pages 35	22. Price

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LIST OF ABBREVIATIONS

ATAMS	Automated terminal asset management system
EIR	Equipment Interchange Receipt
EXPRESS	Application used to capture transport information including Pre-Advise
FY	Fiscal Year
GPA	Georgia Ports Authority
ID	Identification
ILA	International Longshoremen Association
OCR	Optical Character Recognition
PIN	Personal Identification Number
Reefer	Refrigerated container
RDT	Radio data terminal
RFID	Radio-frequency identification
RTG	Rubber tired gantry
TEU	Twenty-foot equivalent unit
WebAccess	Express Web-based application through which transport companies enter information, such as Pre-Advice
ac.	Acre
ft.	Foot
lb.	Pound
lt.	Long ton

SUMMARY

Truck delays at terminal gates decrease productivity of ports and truck fleets (e.g. trucker idle time) and increase truck emissions. U.S. ports have explored solutions, such as gate appointment systems, to improve gate operations and reduce truck delays. It is important to quantitatively evaluate these solutions and to understand their impact on the underlying behavior (e.g. truck arrival pattern) using actual, measured gate performance data. However, researchers have difficulty obtaining measured, detailed gate performance data (e.g. for each truck) by visually reviewing images because the process is labor-intensive, time-consuming, and costly. Thus, gate performance data collection is often limited to a short period of time (only a few hours), which limits the understanding of the performance of the actual gate system. Therefore, an effective means to collect detailed gate performance data over a longer time periods (e.g. one week) using images widely available is needed.

A vision-based sensing system is proposed to automatically extract port gate performance data. The development of the sensing system is divided into two phases. In Phase 1, an image processing algorithm, integrating a frame-change motion detection model that takes into account color distortion to address the unique characteristics of the port gate environment, was developed to extract the service time using images widely available from surveillance cameras at the gates to demonstrate the feasibility of the proposed sensing system The actual images acquired from surveillance camera systems at the port gate will be used to evaluate the performance of the developed algorithm in the next phase. The developed algorithm has a great potential to be used at other ports for the service time data collection since the surveillance camera systems are widely available.

In Phase 2, a vision-based sensing system, including an enhanced image processing algorithm and a multi-camera system, will be developed to collect truck arrival time, wait time, and service time at the gate. In addition, the research team is in discussions with the Georgia Ports Authority to conduct an experimental test at the Port of Savannah to test the vision-based system. The detailed gate operation at Savannah Port was reviewed in Phase 1 to support the multi-camera design, and a multi-camera system was designed to collect the images for capturing the truck movement at various critical locations (portal, pedestal and inspection canopy) at the gate in support of the development and validation of the enhanced image processing algorithm.

CHAPTER 1:
INTRODUCTION

Truck delays at port gates decrease the productivity of the port and the truck fleet by increasing trucker idle time, and, also, increases truck emissions. “Time in line to gate” was a concern in a national survey of truck drivers (ATA Intermodal Conference, 1996). The survey confirmed drivers spend a significant portion of their work day waiting at the ports (Monaco and Grobar, 2004). The truck waiting costs were estimated more than two million dollars annually at the Maersk terminal at the Port of New York and New Jersey (Yahalom, 2001), and the truck wait time was estimated more than 3.7 million hours annually at the Los Angeles and Long Beach ports (Barber and Grobar, 2001).

To reduce truck delays at the gates, ports have explored various solutions, such as appointment systems and extended gate hours, to improve gate operation. In California, an appointment system was implemented in response to California Assembly Bill (AB) 2650, which aimed at reducing vehicle emissions at the ports (Guiliano et al., 2006). It is important to quantitatively evaluate the gate performance (e.g. truck wait time and service time) of alternative solutions and to understand their impact on the underlying gate behavior (e.g. truck arrival pattern) using actual, measured gate performance data. Researchers have conducted field observation and manual image reviews to collect detailed gate performance data (Giuliano et al., 2008; Lam et al., 2008; Guan and Liu, 2009). However, these data collection methods are labor-intensive, time-consuming, and costly.

To date, data collected has often been limited to short periods of time (e.g. hours), which limits the understanding of different solutions' impacts on gate behavior (e.g. daily pattern). Therefore, there is a need to develop an effective means to collect detailed gate performance data over longer time periods, such as weeks or months.

The objective of this project is to develop a vision-based sensing system along with an image processing algorithm to automatically extract gate performance data at a detailed level. . The development of the sensing system is divided into two phases. In Phase 1, an image processing algorithm was developed to extract the service time at the transaction level from the images taken by surveillance cameras at the gates to demonstrate the feasibility of the proposed image processing algorithm to automatically collect service time data. The proposed image processing algorithm integrates (1) a frame-difference motion detection model that takes into account color distortion and (2) a set of decision rules that determine the type of the truck movement using a port's unique gate environment and operation characteristics (e.g. lighting, shadow, weather, occlusion, stop-and-go, etc.). Actual images taken from surveillance cameras at the port gate and acquired from the web will be used to evaluate the performance of the proposed algorithm in the next phase. The proposed image processing algorithm has a great potential to be used at other ports for automatic service time data collection since surveillance camera systems are widely available.

In Phase 2, a vision-based sensing system, including an enhanced image processing algorithm and a multi-camera system, will be developed to collect truck arrival time, wait time, and service time at the gate. The research team is working with the Georgia Ports Authority to conduct experimental test at the Port of Savannah to validate the vision-based sensing system. A review of the gate operations at the Port of Savannah was conducted to provide a better understanding of the process, the layout, and the truck traffic flow at the gate. This information assists the design of the multi-camera system and the development of the image processing algorithm. A multi-camera system, including camera position, resolution, angle, and focal length, etc., was designed to collect images of truck movement at various critical locations (portal, pedestal, and inspection canopy). The images to be collected at the Port of Savannah will support the development and validation of the enhanced image processing algorithm in the next phase.

This report is divided into four chapters as follows. Chapter 2 reviews the relevant literature and identifies the need of developing an effective means to collect the data necessary to better measure port gate performance and understand freight behavior at the gate. Chapter 3 presents the proposed image process algorithm for automatic service time extraction from the images taken from the surveillance cameras at the gates. Chapter 4 presents the proposed design of a multi-camera system to collect images. The research team is in discussion with the Georgia Port Authority conducting an experimental test at the Port of Savannah to collect data for the development and validation of the vision-based sensing system.

CHAPTER 2:
LITERERTAURE REVIEW

This chapter presents the literature review relevant to the terminal gate operation. The objective of the review is to identify the need for developing an effective means to collect the port gate performance data, including truck wait time and service time, to provide a better measurement and understanding of the gate system and port-freight interaction. It was identified that the actual, measured gate data at the detailed level is necessary. They can be used to quantitatively evaluate the gate performance with different port gate operations and to better understand the impact of these operations on the underlying freight behavior (e.g. truck arrival pattern). Existing data collection methods, including field observation and manual image inspection, are labor-intensive, time-consuming, and costly. There is a need to develop an effective means to collect actual, measured gate data (e.g. truck arrival times, wait time, and service times). The following summarize the port gate operation modeling studies and selected studies are summarized by the methodologies used (analytical model vs. simulation model).

2.1 Review of Gate Related Studies

Truck delays at the terminal gates decrease productivity of port and truck fleets and increase truck emissions. The studies related to truck delays at the gate and its impacts on the port, freight industry, and environment**,** are summarized in this section.

Truck delay at the gate

Several studies have shown concerns about truck delays at the gate. "Time in line to gate" was indicated as a general concern in a national survey of truck drivers (ATA Intermodal Conference, 1996). A survey (A. Strauss-Wieder, 2002) of ports shows that 40% of the top 15 ports in the U.S. reported gate access as unacceptable; half of them saw a need for paperless gates. Yahalom (2001) studied intermodal productivity at the Port of New York and New Jersey using only a half-day average wait time and service time observed in the field. It was estimated more than two million dollars of annual truck waiting costs at the Maersk terminal alone. Barber and Grobar (2001) estimated more than 3.7 million hours of truck wait time (including within the port) annually at the Los Angeles and Long Beach ports based on the data collected from three trucking companies. About 40% of all transactions had reported wait times of over two hours. Monaca and Grobar (2004) reported, based on a survey of 60 drayage firms and drivers, drivers spend a significant wait times at the ports of Los Angles and Long Beach.

Though the studies provide some information on truck delay at the port, there is a need to collect data over a long period of time to better evaluate the performance of the gate system and to support the study of freight behavior patterns at gates.

Impacts on the port

Recognizing the problem of truck delays at the gates, port agencies have employed different strategies, including gate appointment systems and extended hours, to reduce the delay. An appointment system was implemented at the Los Angeles and Long Beach ports under California AB 2650, which aimed at reducing vehicle emissions and highway congestion by reducing gate queue and balancing truck arrivals (Giuliano et al., 2006). Giuliano et al. (2006) and Giuliano et al. (2008a) evaluated the impacts of an appointment system on the performance (e.g. wait time and turn time) using the data collect in the field. The study found different perceptions of the appointment system's effectiveness within the freight industry, and no empirical evidence shows that the appointment system has affected queuing at marine terminal gates. Giuliano et al. (2008b) evaluated the impacts of extended gate hours on the highway system, at the Los Angeles and Long Beach ports. A simulation model was developed to evaluate the impacts using heavy truck data on the highway network. The study found "the program resulted in a significant temporal shift of cargo moves at the ports." Morais and Lord (2006) confirmed that appointment systems can be effective in reducing truck idling/queuing at west coast terminals. However, they pointed out that the impacts varied depending on the factors that were producing congestion. Guan and Liu (2009) developed a multiserver queuing model to analyze gate congestion and quantify the truck waiting cost. Field observations were used to obtain the distribution functions of the interarrival time and the service time. Liu et al. (2002) evaluated the performance of four different automated container terminal concepts using a simulation model. The authors (Liu et al., 2002) decided to adopt the data from several studies to establish truck arrival rates and service times because of lack of empirical data. Results indicate the concept based on automated guidance vehicles is the most effective in terms of performance and cost. The authors (Liu et al., 2002) pointed out that small deviations from the assumed arrival and departure rates may cause saturation at the gates that leads to congestion on both sides of the gates. Namboothiri and Erera (2008) studied the impact of the appointment systems from a drayage firm's perspective of fleet efficiency. Holguín-Veras et al. (2000) and Holguín-Veras et al. (2005), from the policy-making and financial perspectives, proposed off-peak freight deliveries and analyzed the process from a decision-making and an invest-return point of view based mainly on terminal data from the Port of New York and New Jersey and survey data. Holguín-Veras et al. (2007) analyzed the off-peak pricing program implemented at the Port of New York and New Jersey. They concluded 19.3% of truck trips changed behavior because of the pricing initiative.

Gate data (e.g. wait time, service time, and truck arrival) are essential for quantitatively evaluating the performance of different improvement strategies. However, they are difficult to measure because current data collection methods are limited to field observations and image inspections, which are labor-intensive, time-consuming, and costly.

Impacts on the environment

Several studies have examined the impacts of truck delays at the gates on the environment (e.g. emission). Giuliano and O'Brien (2007) evaluated the outcomes of California AB 2650 at the Ports of Los Angles and Long Beach. The study shows no evidence of reduced queuing, and the authors concluded that AB2650 did not reduce truck emissions. Goodchild and Mohan (2008) evaluated the impacts of the Clean Air Program on terminal operations using a queuing and regression model. Wantanabe (1991) investigated the environmental impact of trucks waiting at the port entrance gate. The amount of noxious emissions of trucks in the Port of Yokohama in Yokohama, Japan was measured experimentally.

Having truck wait time data is essential for studying environmental impacts (e.g. emission). There is a need to collect actual, measured truck wait time data to quantitatively evaluate the impacts of truck delay on the environment.

Use of truck arrival information

Using truck arrival information has been proposed in the following studies to improve port operations. Using a simulation-optimization methodology, Zhao and Goodchild (2010) assessed how truck arrival time information with different levels of accuracy (e.g. truck group and complete truck sequence) can affect container handling efficiency. Huynh and Walton (2008) studied the effect of limiting truck arrivals on truck turn time and crane utilization. The results show the appointment system can be effective if the cap (maximum trucks allowed for each time window) is set properly.

Truck trip generation

Other studies have focused on truck trip generation and the infrastructure system assessment for the truck trips. Guan and Liu (2008) analyzed the behavioral patterns of the gate transactions and truck trip generations to provide a better understanding of the complexity of truck activities. Al-Deek et al. (1998) established the truck pattern in and out of the Florida Port in a report for the Florida Port planning. Al-Deek et al. (2000) and Al-Deek (2001) also developed trip-generation models for both production and attraction using data from container terminals in Florida. Hartmann (2004) introduced an approach for generating realistic container terminal scenarios that can be used as input data for simulation models.

The previous studies focus on evaluating the effect of implemented strategies, predicting the truck trips generated from the ports, and assessing the impacts of the freight traffic on the infrastructure. However, as indicated in the studies, there is no effective means to collect actual gate data (e.g. wait time). The existing data collection methods are labor-intensive, time-consuming, and costly. Due to limited resources, the data was collected over short periods of time (e.g. hours), which has limited a comprehensive evaluation of the performance improvements and true gate system behavior (e.g. day of week pattern). Therefore, there is a need to develop an effective means to collect comprehensive gate data (e.g. truck arrival times and service times) to quantify performance improvements over a long period of time, such as weeks and month.

2.2 Review of Selected Studies

In this section, selected studies on the gate operation modeling are summarized.

Queuing Theory

Several studies have modeled the gate system using a queuing theory. Queuing theory permits the derivation and calculation of several performance measures, such as the average wait time, so the queuing behavior can be analyzed mathematically. The accuracy of the queuing model relies on the essential inputs, such as truck arrival and service times. When empirical data is not available, assumptions are made based on the type of distribution assumed. The proposed vision-based sensing system can effectively collect data for studying the characteristics of truck arrivals and service times. Collecting this data is crucial to validate and refine different distributions used in the simulation models and to improve the reliability of modeling results. Relevant studies are summarized below.

Guan and Liu (2009) pointed out that, according to the characteristics of gate operation and the findings of numerous studies (Taniguchi et al., 1999; Kozan, 2000; Yamade et al., 2003; Dragovi´c et al., 2006), gate operations can be modeled as two types of multi-server models based on the distribution of truck interarrival times and service times. If both truck interarrival times and service times follow an exponential distribution, the $M(\lambda)/M(\mu)/s$ model is applicable. If truck interarrival times and service times follow an exponential distribution and an Erlang distribution, respectively, the $M/E_k/s$ can be applied.

Taniguchi et al. (1999) proposed the use of a queuing theory to model truck arrivals and wait times in their study of determining optimal size and location of public logistics terminals. A multi-server queuing model ($M/E_k/s$) with Cosmetatos approximation was used to model truck arrivals and wait times, and nonlinear programming techniques were used to determine the best solution.

Liu et al (2002) developed a microscopic simulation model to analyze and evaluate the performance of four different automated container terminal concepts. In their study, gate operation was modeled as using a queuing theory. The gate operation was modeled as a multi-server queuing system, $M(\lambda)/M(\mu)/s$, where λ, μ, and s denoted the mean truck arrival rate, the mean service rate, and the number of lanes at the gate, respectively. Due to lack of actual, measured gate data (e.g. truck arrivals and service time), the authors (Liu et al., 2002) decided to adopt the data from the Port of Rotterdam and use the findings from several studies to establish truck arrival rate and service time. The arrival rate was computed from the assumed daily arrivals and 24-hour operation. The service time was assumed to be two minutes. The minimum number of lanes could then be determined by the arrival rate and service rate. It was pointed out that small deviations from the assumed arrival and departure rates may cause saturation at the gates, leading to congestion on both sides of the gates. Thus, it will substantially impact the model reliability because the assumed distribution may not reflect the true behavior in the port. It is important to validate the assumed distribution using actual, measured data.

Guan and Liu (2009) applied a multi-server queuing model to analyze gate congestion and to quantify the truck waiting cost. In their study, a $M/E_k/s$ with Cosmetatos' approximation was used to model the gate operation because the Cosmetatos' approximation method has less than 2 percent error for most practical purposes. The data collected through field observation and observations of gate images was compiled and processed. A total of 966 trucks were observed. On a typical workday, the hourly truck arrivals indicate two peak periods, one at about 8:00 a.m. and another at about noon,. There were 334 observations of gate service time; the shortest processing time was 33 s and the longest one was 390 s. On average, it took about 2.44 min to process an inbound truck. The goodness-of-fit tests indicated the interarrival time follows an exponential distribution and the service time follows an Erlang distribution. The data used to validate the distribution was limited, though, and the time to visually process these images is time-consuming and labor-intensive.

Simulation Model

Simulation is commonly used for any non-trivial, complex, real-world system. Many researchers (Longo, 2010; Yun and Choi, 1999) have recommended simulation methodology for analyzing container terminal behavior, conducting what-if analysis and assessing management polices. Selected simulation models that include the gate as a component in the model are summarized below.

Longo (2010) proposed a simulation model for understanding the impact of the container inspection process on the container terminal efficiency. A simulation model capable of recreating the high complexity of a real container terminal in terms of ship arrivals, unloading/loading operations, port equipment, and container inspection activities was developed. Yun and Choi

(1999) proposed a simulation model consisting of gate, container yard, and berth for analyzing the performance of a real container terminal in Korea. The simulation model was used to consider whether the existing container terminal could efficiently handle the large container streams or whether a system using transfer cranes and gantry cranes would be more efficient. Kia et al. (2002) developed a simulation model for evaluating the performance of a container terminal in relation to its handling techniques and their impact on the capacity of the terminal. The actual port gate performance data to be collected can be used to support the validation and refinement of underlying distribution assumptions for improving the reliability of simulation results.

CHAPTER 3:
PROPOSED IMAGE PROCESSING ALGORITHM FOR AUTOMATICA SERVICE TIMES DETECTION

Gate service/transaction time at maritime terminals is the key performance measurement of port gate performance. The detailed level (transaction level) of service time data is essential for analyzing problematic transactions/operations and for supporting the development of port gate operation models. An image processing algorithm was developed to automatically collect service time at the detailed level using the web-available images taken by the surveillance cameras at the port gates to demonstrate the feasibility of the proposed image processing algorithm. The proposed image processing algorithm integrates a frame-change motion detection model that takes into account color distortion and a state transition model using designed regions of interest (ROIs) along with a state transition model based on a set of decision rules specifically designed for the stop-and-go behavior at the gate to reliably extract the service time. This design addresses the unique port characteristics (e.g. lighting, shadow, weather, occlusion, stop-and-go, etc.). The proposed image processing algorithm has great potential for use in other ports for service time data collection since surveillance cameras are widely available. This chapter presents (1) how to measure the service time using the images and (2) the development of the image processing algorithm for automatically extracting the service time data at the detailed level.

3.1 Service Time

This section presents the measurement of the service time, which is the time a truck being processed/served at the gate. The images taken by the surveillance cameras can be used to detect a truck approaching the station, as shown in Figure 3.1. The image was taken with a view facing the waiting area and covering multiple lanes. A truck joins a lane and gradually moves toward to the waiting line. The truck will stop at the waiting line and move toward to the station until the station is ready to serve the truck. Therefore, the service time can be measured as the difference in time between two consecutive truck departures at the waiting line in the same lane, given that the travel time between the waiting line and the station is short. A truck departure is defined as the earliest movement that a truck leaving from the waiting line and moving toward the station. A truck stops at the waiting line or continues moving toward the station after leaving the waiting line is not considered as a truck departure. Note that with this measurement method, the service time includes the idle time (i.e. no truck at the waiting line) when there is no queue in the lane.

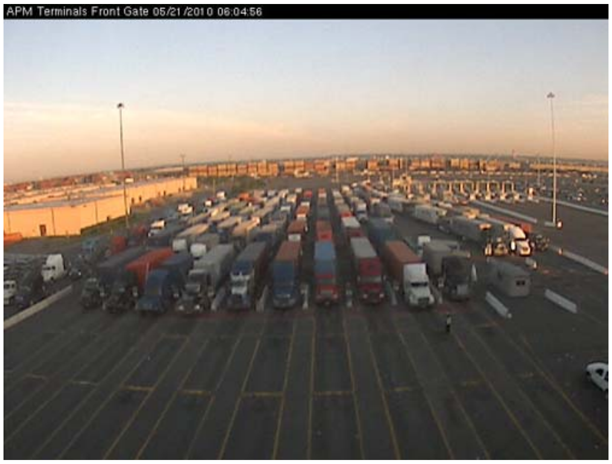


Figure 3.1 An image from surveillance camera system

3.2 Algorithm Development

An image processing algorithm was developed to automatically extract the service time at the detailed level by detecting the truck departure at the waiting line by lane using the images taken from the surveillance camera. The proposed algorithm integrates a frame-change motion detection model considering the color distortion, and a state transition model using the designed ROIs along with a set of decision rules specifically designed for the stop-and-go behavior at the gate to reliably detect a truck departure at the waiting line by lane. This design addresses the unique characteristics of the port gate environment and operation (e.g. lighting, shadow, weather, occlusion, stop-and-go, etc.). In this section, an overview of the algorithm and the design of each component in the algorithm are presented.

3.2.1 Algorithm Overview

In this section, an overview of the proposed image processing algorithm is presented. The proposed algorithm was designed to detect a truck departure at the waiting line in each lane by 1) detecting if a truck presents in the lane, and 2) determining the types of the truck movements (e.g. stop, truck departure, or continue moving). The presence of a truck in a lane is detected by a motion detection model, which detects the changes between two consecutive images. A background model is often used in motion detection by comparing an image with a background scene to detect the changes. A smooth illumination change is essential for updating the background scene from image to image. Images taken by the surveillance camera at the port gate were captured at a low frame rate (a 5-second interval), which cannot provide a smooth illumination change for background update. Therefore, a frame-change based motion detection model, which does not require the background update process, is proposed for detecting a truck in a lane. The proposed algorithm also integrates a state transition mode that uses designed RIOs and a set of decision rules specifically designed for the stop-and-go behavior to reliably detect a truck departure at the waiting line by lane.

Figure 3.2 presents the algorithm flow. First, two ROIs were carefully determined in each lane for detecting a truck in the lane because the geometry of the lanes is known. A frame-difference based motion detection model incorporating color distortion is used to detect a truck in each lane using two consecutive images. F_t and F_{t-1} are the current frame and the previous frame, respectively and are used to compute a color frame difference and the brightness distortion for each pixel in the ROIs. The brightness distortion is given as an input to compute the chromaticity distortion. Several statistics (mean, min, max) are derived from these three images (frame difference, brightness distortion, chromaticity distortion) for each of the ROIs. A set of conditions based the statistical values were developed to describe the truck texture in the ROIs and to detect the presence of a truck in each ROI. Finally, a state transition model is used to determining the types of a truck movement by tracking the truck detection results in each ROI in several frames based on the decision rules that consider the stop-and-go behavior. The three components, including the ROI design, the motion detection model, and the state transition model, are presented in the subsequent section.

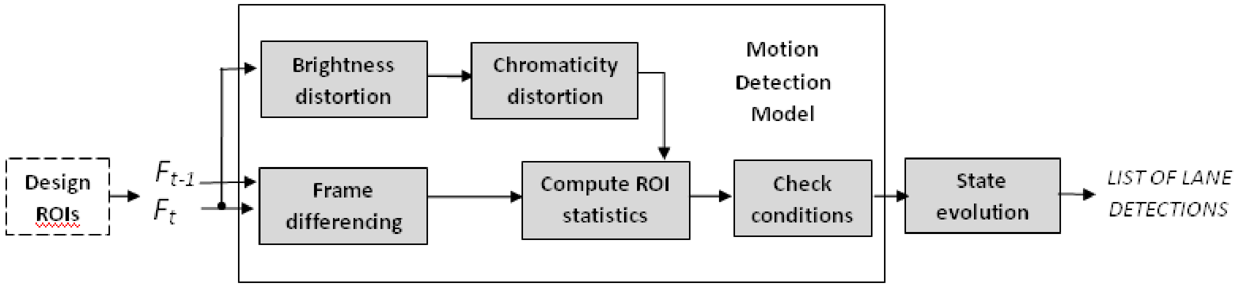


Figure 3.2 Algorithm flow chart

3.2.2 Algorithm Details and Refinements

3.2.2.1 ROI Determination

The design of ROIs is a critical aspect of the proposed algorithm because the ROIs are the basis for detecting a truck in each lane. Two ROIs were designed for each lane for tracking and determining the type of a truck movement, which leads to a truck departure detection. The ROIs were carefully determined because the geometry of the lanes is known. Figure 3.3 shows the two-RIOs-per-lane design. The pre-detection ROIs near the waiting line were designed to detect a truck leaving/crossing the waiting line. The pre-detection ROIs were carefully sized to avoid the perspective effect and the occlusion effect. The ROIs can be very small to ensure that only a truck departure from the associated lane can lead to a detection, as shown in Figure 3.4. The validation ROIs were designed in the area between the waiting line and the gate to verify a truck movement. The texture of the trucks is major concern when position the ROIs. The pre-detection ROIs should be placed in a way that the front parts of the trucks pass on. The validation ROIs should be large enough to include the biggest part of the truck as shown in Figure 3.5 (without being impacted by the next lanes departure if possible). This design scheme allows the proposed algorithm to detect the presence of a truck in a lane and verify the type of the truck movement, which leads to the detection of a truck departure.

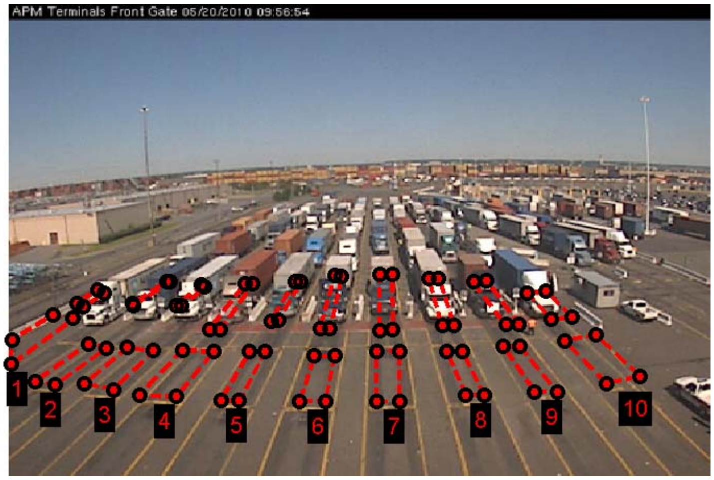


Figure 3.3 Two ROIs designed for each lane

Figure 3.4 Pre-detection ROI (lane 2)

Figure 3.5 Validation ROI (lane 2)

3.2.2.2 Motion Detection Model

A frame-difference based motion detection model incorporating with color distortion was developed to detect the presence of a truck in each ROI. The brightness distortion and the chromaticity distortion were introduced to address the color distortion in the images caused by lighting, shadow, and weather. A set of conditions were developed to describe the texture of a truck presenting in the ROIs based on the frame difference and the color distortion and to detect a truck in each ROI. In this section, the computation of the color frame difference, the brightness distortion, and the chromaticity distortion are first described, and the conditions for detecting a truck in the pre-detection and validation RIOs are presented.

Computation of Color Frame Difference, Brightness Distortion, and Chromaticity

The color frame differencing, the brightness distortion, and the chromaticity distortion are the basis for detecting a truck in an ROI; and their computation are introduced in subsequent paragraphs.

The color frame differencing value is computed by summing the absolute difference between the current and the previous frames' intensities for each channel (Equation **1)**.

$$CFD_t(x) = \sum_{c=1}^{3} |I_t^c(x) - I_{t-1}^c(x)| \qquad \text{(Equation 1)}$$

CFD stands for the color frame difference; I^c_t refers to the intensity of the channel c (red, blue, or green) of the color image at time t; x is the pixel position. The mean allows decreasing the influence of noisy pixels or small, moving object (e.g. pedestrians) inside the ROI. However, the mean can be affected by the outliners. The saturation concept is introduced to reduce the impact of these outlier values. The mean computation formula becomes:

$$\frac{1}{N} \sum_{x \in ROI} min(CFD(x), CFD_{max}) \qquad \text{(Equation 2)}$$

N is the number of pixels inside the ROI; x is the pixel position, CFD is the color frame difference, and min is the minimum function.

The use of the saturated mean color frame difference alone is not enough to deal with the cast shadows. Indeed, the shadows' cast may be associated with large changes in color intensity and results in false positive detections. To address this challenge, the global distortion is separated into a brightness and chromaticity distortion (Horprasert et al, 1999, Zhang et. al, 2007). This separation enables differentiation of the changes in color from the changes in illumination. Figure 3. shows the brightness distortion (α_i) and chromaticity distortion (CD_i) between the current RGB values I_i and the expected value E_i in the RGB color space. In these notations, the index i refers to the pixel position.

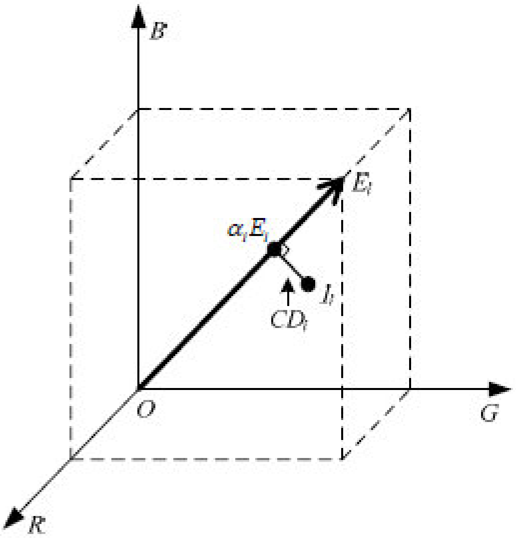


Figure 3.6 The RGB color space with the brightness and chromaticity distortion

The brightness distortion (α_i) is defined as the scalar value such that $\alpha_i E_i$ is the projection of OIi on OEi. It is obtained by minimizing the function Φ.

$$\phi(\alpha_i) = (I_i - \alpha_i E_i)^2 \qquad \text{(Equation 3)}$$

α_i is 1 if the brightness of the pixel in the current image is the same as in the reference image. It is less than 1 if it is darker and greater than 1 if it is brighter.

The color distortion is defined as the orthogonal distance between OI_i and OE_i. It is computed using Equation 4.

$$CD_i = ||I_i - \alpha_i E_i|| \qquad \text{(Equation 4)}$$

Cameras may have unequal sensitivity among color bands. Therefore, the pixel values are normalized by the standard deviations of each band. This leads to the following formula for the brightness and chromaticity distortion:

$$\alpha_i = \frac{(\frac{I_R(i)E_R(i)}{\sigma_R(i)}) + (\frac{I_G(i)E_G(i)}{\sigma_G(i)}) + (\frac{I_B(i)E_B(i)}{\sigma_B(i)})}{(\frac{E_R(i)}{\sigma_R(i)})^2 + (\frac{E_G(i)}{\sigma_G(i)})^2 + (\frac{E_B(i)}{\sigma_B(i)})^2} \qquad \text{(Equation 5)}$$

$$CD_i = \sqrt{(\frac{I_R(i) - \alpha_i E_R(i)}{\sigma_R(i)})^2 + (\frac{I_G(i) - \alpha_i E_G(i)}{\sigma_G(i)})^2 + (\frac{I_B(i) - \alpha_i E_B(i)}{\sigma_B(i)})^2} \qquad \text{(Equation 6)}$$

The index i is still referring to the pixel position. The standard deviations are noted σ.

Conditions for Motion Detection

The texture of the truck presenting in an ROI is described based on the color frame difference along with the brightness distortion and the chromaticity distortion. The conditions for detecting a truck in the pre-detection RIOs and the validation ROIs are presented below:

C_1: $meansat^1(CFD, CFD_{max}) > CFD_1$
AND
$[(min^1(BD) < BD_{m1}$ ***AND*** $max^1(BD) < BD_{M1})$ ***OR*** $(min^1(BD) < BD_{m2}$ ***AND*** $max^1(BD) < BD_{M2})]$

C_1 represents the condition for the pre-detection ROI (exponent 1 for the operations). CFD refers to color frame difference; BD refers to brightness distortion. Meansat, min, and max stand, respectively, for mean value with saturation, minimum value, maximum value. CFD_{max}, CFD_1, BD_{m1}, BD_{M1}, BD_{m2}, BD_{M2} are the thresholds obtained through analyzing the ROIs. This condition ensures that intensity changes are present in the whole ROI and that the changes are not uniform. The non-uniformity is translated in term of brightness distortion. A shadow produces a uniform darkening (i.e. BD < 1). The brightness distortion term of the criterion ensures that a detected region includes both dark and light changes. In other words, this global criterion corresponds to a textured object passing on the whole ROI.

C_2: $[meansat^2(CFD, CFD_{max}) > CFD_2$ ***OR*** $(meansat^2(CFD, CFD_{max}) > CFD_1$ ***AND***
$(max^2(CFD) > CFD_{max}$ ***OR*** $max^2(CD) > CD_{M1})]$
AND
$[(min^2(BD) < BD_{m3}$ ***AND*** $max^2(BD) < BD_{M1})$ ***OR*** $(min^2(BD) < BD_{m2}$ ***AND*** $max^2(BD) < BD_{M4})]$

C_2 represents the condition for the validation ROI. The notations are the same as the ones introduced in C_1. The chromaticity distortion (CD) is introduced to address the shadow issue. The validation uses either a larger mean threshold or the same threshold as C_1 associated with other conditions on the maximum chromaticity distortion or the maximum color frame difference. In other words, a smaller mean can lead to a detection only if other clues strengthen the detection confidence. The criterion on the brightness distortion minimum and maximum value is also more restrictive. The use of larger brightness distortion thresholds is possible, since the validation ROIs are wider and include more truck texture. At the same time, larger brightness distortion thresholds allow eliminating false positive detections due to shadows.

3.2.2.3 State transition model

A state transition model, as shown in Figure 3.7, consisting of a set of decision rules for determining truck movements (e.g. stop and truck departure) was designed to verify a truck departure. Each lane is associated with one of the four states, “undetected”, “waiting validation”, “detected”, and “blocking period”, and initialized as “undetected.” When the pre-detection ROI is detected with a truck (C_1), the lane’s state is changed into “waiting validation.” A truck departure is validated if the validation ROI is detected (C_2) within a few frames (C_3). This design is to ensure the truck is leaving the waiting line and moving toward the station, not stops at the waiting line. The lane’s state is, in this case, changed to “detected.” The state is directly (no condition) modified to “blocking period” in the next frame. This “blocking period” state corresponds to a transitional state in which the lane cannot be detected again during a certain number of frames (C_4). In a way, a minimum duration between two truck departures on the same lane (i.e., a minimum service time) is ensured. The conditions for the state transitions are noted as C_i and discussed in the following:

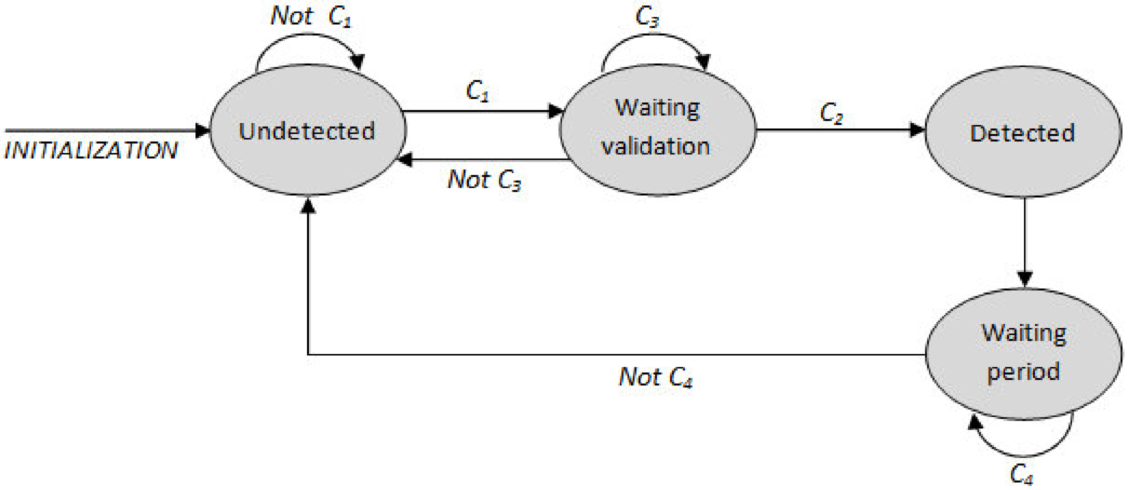


Figure 3.7 The state transition model

C_1: a truck detected in the pre-detection ROI (see C_1 section 3.2.2.3)

C_2: a truck detected in the validation ROI (see C_2 section 3.2.2.3)

C_3: (not C_2 **AND** (nVF > 0 **OR** (nVF = 0 **AND** C_1)))

The validation can be done only if a truck is detected in the pre-detection ROI (C_2). nVF is a variable that refers to the number of validation frames remaining. This variable was initialized with a certain constant *nVFi* when the state changes from "undetected" to "waiting validation." It is decremented for each new frame and serves as a counter. In other words, it allows fixing a maximum number of frames for the validation to occur. If it goes to zero, the pre-detection ROI (C_1) is checked again. The "waiting validation" period can continue if a truck is detected in the pre-detection ROI. This enables to increase the "waiting validation" period for a truck with very slow motion or stop-and-go behavior.

C4: nWF > 0

nWF is a variable which refers to the number of waiting frames remaining. It is initialed as 4 and decremented for each new frame. When it goes to zero, the state is changed to "undetected," and a new detection can occur.

Figure 3.8 illustrates a truck movement and the associated states in lane 7 at different times. The lane is initialized as "undetected" when the truck is behind the waiting line, as the ROIs shown in red in the figure. The state is changed to "waiting validation" (blue) when the truck crossing the waiting line and triggering a detection in the pre-detection ROI. The state is changed to "detected" (greed) when the truck is detected in the validation ROI. Then the state is set to blocking period (black) to ensure no detection in lane 7 within next few frames.

Figure 3.3 State color representation

3.2.2.4 Thresholds Determination

The conditions presented above are complex and require many parameters. This is necessary to take into account the statistical variability due to the changes in weather conditions, image contrast, and truck appearance. To illustrate this variability, two examples of statistical value with the associated images are presented below. As before, CD, CFD, BD refer, respectively, to chromatic distortion, color frame difference, and brightness distortion. Table 3.1 shows the statistical values for a sunny day (Figure 3.9). Table 3.2 shows the statistical values for a low-contrast image (Figure 3.10). The statistical values in these two conditions (sunny day and low-contrast image) are significantly different.

Table 3.1 Statistical values for a sunny day

Lane 7	Pre-detection ROI	Validation ROI
Max CD	66.3	29.7
Mean CD	24.6	6.1
Max CFD	491	515
Mean CFD	72.5	55
Min BD	0.3	0.1
Max BD	21.1	3.1

Figure 3.9 Example of ROI statistics for a sunny day

Table 3.2 Statistical values for a low-contrast image

Lane 5	Pre-detection ROI	Validation ROI
Max CD	9.4	13.7
Mean CD	4.8	4.2
Max CFD	147	254.0
Mean CFD	30.8	43.7
Min BD	0.5	0.4
Max BD	1.2	2.4

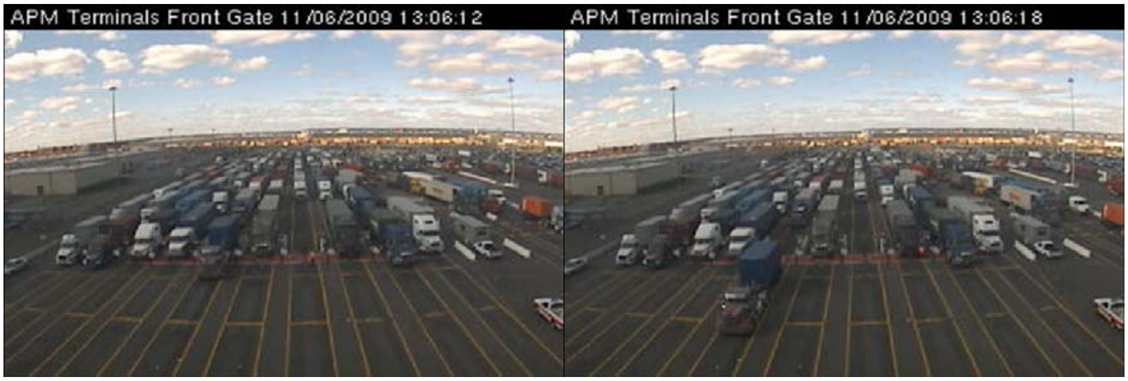


Figure 3.10 Example of ROI statistics for a low-contrast image

A high color distortion in Table 3.1 can be an important clue for truck detection on a sunny day in a high contrast image (see Figire3.13). However, this rule cannot be applied to a low-contrast image (see Table 3.2 and Figure 3.14). In other words, the color distortion can be highly discriminative only in certain cases. After analyzing the truck texture in different lighting conditions and weather conditions, the final thresholds have been determined and presented in Table 3.3 below.

Table 3.3 Threshold values used in the algorithm

	Value
CFD_{max}	100
CFD_1	35
CFD_2	55
BD_{m1}	0.6
BD_{m2}	0.85
BD_{M1}	1.15
BD_{M2}	1.4
BD_{m3}	0.4
BD_{M4}	1.9
CFD_{max}	150
CD_{M1}	15

CHAPTER 4:
PROPOSED MULTI-CAMERA SYSTEM FOR AUTOMATIC GATE DATA EXTRACTION

A vision-based sensing system, including an enhanced image processing algorithm and a multi-camera system, is proposed to effectively collect truck arrival time, wait time, and service time at the detailed level in Phase 2. The multi-camera system collects images at the gate to support the development and validation of the image processing algorithm. A multi-camera system, including camera position, resolution, angle, and focal length, etc., was designed to capture the truck movements at various critical locations (portal, pedestal and inspection canopy) at the gate for extracting truck arrival time, wait time, and service time. The research team is in discussions with the Georgia Ports Authority to conduct an experimental test at the Port of Savannah to collect images using the proposed multi-camera system to support the development and validation of the enhanced image processing algorithm in Phase 2. This chapter presents (1) a review of the gate business processes at the Port of Savannah that support the multi-camera system design and the algorithm development and (2) the design of the multi-camera system for collecting images that will be used for extracting truck arrival time, wait time, and service time.

4.1 Review of the Port of Savannah

A review of the Port of Savannah, with a special focus on the business processes at the gate, was conducted to provide a better understanding of the layout of the gate, detailed steps in the gate business processes, and the truck traffic flow. This information supports the design of the multi-camera system and the development of the image processing algorithm. In this section, the Port of Savannah and its terminals are briefly introduced. The detailed gate business processes are presented. Finally, the rapid dispatch service is also described.

4.1.1 Port of Savannah

Since 1991, the Port of Savannah, operated by Georgia Ports Authority (GPA), has experienced 17 years of consecutive container throughput increases with an average increase rate of 15% (GPA, 2009) making it the fastest growing port in the nation. Encompassing 1,400 acres, the Port of Savannah includes container and breakbulk facilities (GPA, 2009). The extensive facilities for oceangoing vessels line both sides of the Savannah River approximately 18 miles from the Atlantic Ocean. In 2007, the port ranked fourth in terms of container volume and moves nearly two million TEUs (GPA, 2010a). This volume accounted for 17 percent of the container traffic on the East Coast and 7 percent nationally. On average, around 92,000 tons of cargo moved through the port daily in 2007, with the top five commodities consisting of petroleum, salt and stone, wood pulp, paper products, and plastics. The port features 2,404,965 TEUs in 2009 and is the fourth largest seaport in the U.S. The projected gross container throughput in fiscal year 2020 is 6.5 million TEUs (GPA, 2010a).

4.1.2 Terminals

Two major ports, the Garden City Terminal and the Ocean Terminal, serve the Port of Savannah. In this section, both terminals are introduced, with a special focus on the Garden City

Terminal. The type of transactions, operation hours, equipment, and capacity of the gates in the Garden City Terminal were reviewed, and Gate 4 is proposed for conducting the experimental test to collect images using the proposed multi-camera system to support the development and validation of the enhanced image processing algorithm in Phase 2.

4.1.2.1 Garden City Terminal

Garden City Terminal, a secured, dedicated container terminal owned and operated by the GPA, is the fourth-largest container port by TEU volume in the U.S. and the largest single-terminal operation in North America. The facility's single-terminal design allows the port to operate in an environment of maximum efficiency and flexibility, as well as increased security, due to the concentration of all manpower, technology, and equipment in one massive container operation. The 1,200-acre single-terminal facility features 9,693 feet of continuous berthing and more than 1.3 million square feet of covered storage. The terminal is equipped with 25 high-speed container quay cranes with 40.2 to 65 lt. capacity, 46 rubber-tired gantries (RTG) with 40 lt. capacity, 24 five-high loaded toplifts with 80,000 lb. capacity, 21 four-high loaded toplifts with 67,400 lb. capacity, as well as an extensive inventory of yard handling equipment.

There are six gates that are used at Garden City Terminal, including Gates 1, 3, 4, 5, 6 and 7. Gates 3 and 4 are for containerized transactions only. Gates 1 and 5 are for commercial vans, loose freight and bobtails to proceed to the internal kiosk and exits. Gate 7 is for internal jockey trucks to proceed to the rail yard. Figure 4.1 shows the locations of the gates, and the relative positions of the terminal are illustrated in the red boxes. The lane configuration, equipment, and operation hours of each gate are described in the subsequent paragraph.

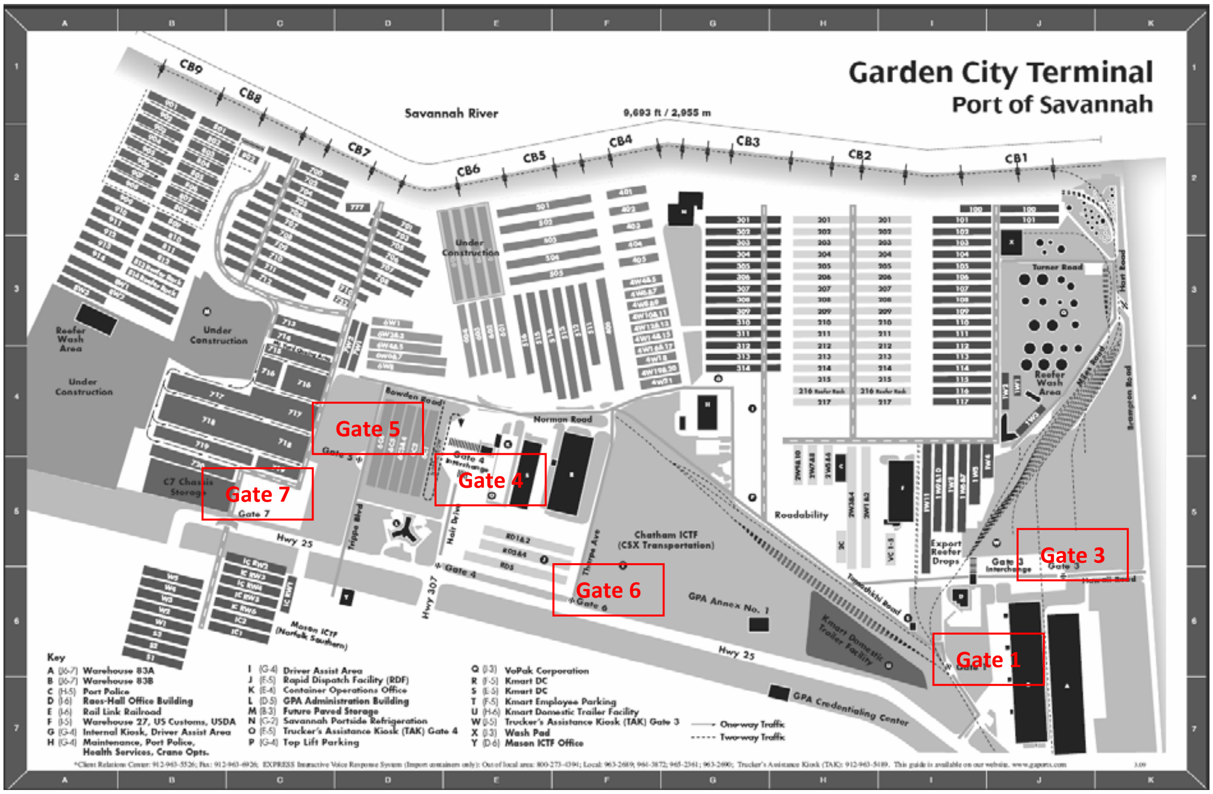


Figure 4.1 The location of each gate at Garden City Terminal (Source: GPA 2010b)

- Gates 1 and 5 serve bob-tail trucks. Bob-tail trucks enter through Gate 1 or Gate 5 and proceed to the Internal Kiosk for pick-up ticket processing, then exit through Gate 1 or Gate 5.
- Gate 3 is equipped with 14 lanes with 10 pre-check lanes, a 2-lane entry portal with OCR-smart cameras and RF-reading equipment. The OCR-smart cameras and RF-reading equipment is configured to electronically capture data from arriving trucks, including truck numbers, chassis numbers, etc. The operation hours for Gate 3 are from 0700-1800 Monday to Thursday, and 0700-1700 for Friday. The cut-off time for pick-up is 1630 and for drop-off 1700 for regular containers; the cut-off time for reefer services is 1615.
- Gate 4 is equipped with 17 lanes with 13 pre-check lanes, a 6-lane entry portal with OCR-smart cameras and RF-reading equipment. Gate 4 covers two third of the daily container transactions at the Port of Savannah. The operation hours for Gate 4 are 0700-1800 Monday to Friday. The cut-off time for pick-up is 1630; and drop-off for regular containers is 1700 and the cut-off time for reefer services is 1615 Monday to Friday. The operation hours for Gate 4 are 0800-1200 and 1300-1700 on Saturday. The cut-off time for pick-up is 1600 and for drop-off 1630 for regular containers and the services must be authorized by the line;
- Gate 6 is equipped with 6 lanes with 2 pre-check lanes, a 2-lane entry portal with OCR-smart camera and RF-reading equipment.

Gate 4 is a containerized transactions only gate and processes two-thirds of the daily container transactions at the Port of Savannah; therefore, it is proposed as the test gate for conducting the experimental test to collect images using the proposed multi-camera system to support the development and validation of the enhanced image processing algorithm in Phase 2.

4.1.2.2 Ocean Terminal

The Ocean Terminal, owned and operated by the GPA, is a secure, dedicated breakbulk facility specializing in the rapid and efficient handling of a vast array of forest and solid wood products, steel, RoRo (Roll-on / Roll-off), project shipments, and heavy-lift cargoes. Covering 208 acres, the Ocean Terminal contains ten berths with 5,768 feet of deepwater berthing, approximately 1.5 million square feet of covered storage, and 73 acres of open storage. This terminal is equipped with two gantry cranes with 156.3 lt. and 89.3 lt. capacity respectively, and a container quay crane with 40.2 lt. capacity, as well as an extensive inventory of yard handling equipment, including forklifts, over-height container crane attachments, reefer plugs, scissor lifts, etc. This terminal is also equipped with a dedicated RoRo facility covering a 19-acre paved area and a dedicated container field covering a 47-acre paved area.

4.1.3 Gate Operation

In this section, Gate 4 at the Garden City Terminal is used to illustrate the gate operation at the Port of Savannah. The review of detailed gate business process provides a better understanding of the layout of the gate, detailed step in the gate business processes, and the truck traffic. This information is essential to the design of the multi-camera system and the development and validation of the proposed algorithm.

4.1.3.1 Gate Business Processes

In this section, gate business processes and the layout of the gate and are reviewed to identify which processes should be monitored using the vision-based sensing system and how to monitor them. Gate 4, processing two-thirds of the daily container transactions, is the largest and busiest container transaction gate at the Garden City Terminal. The operation at Gate 4 reflects the typical GPA gate business processes. Gate 4 adapts a conventional two-stage gate operation. Figure 4.2 shows the physical layout of Gate 4. The main entrance is located at the intersection of Bourne Avenue and South Costal Highway. Before a truck arrives at the gate, a pre-advise process is needed for submitting information regarding the transaction in advance to speed up the process. This process occurs remotely before the truck physically arrives at the gate. A truck arrives at the gate from the local network and sequentially enters portal, pedestal, and inspection canopy for security check, pre-gate information validation, and container inspection, respectively. After these processes, the truck can proceed to the yard to drop off or pick up the desired containers. Occasionally, if a truck does not pass the pre-gate validation, a trouble ticket will be issued and the truck has to enter the Trouble Kiosk to solve the issue, which is described in the trouble ticket resolution process. After the issue is solved, the truck will return to the inspection area and move into the yard. Detailed business processes, including pre-advise, portal, pedestal, gate inspection, and trouble ticket resolution, at Gate 4 are presented subsequently.

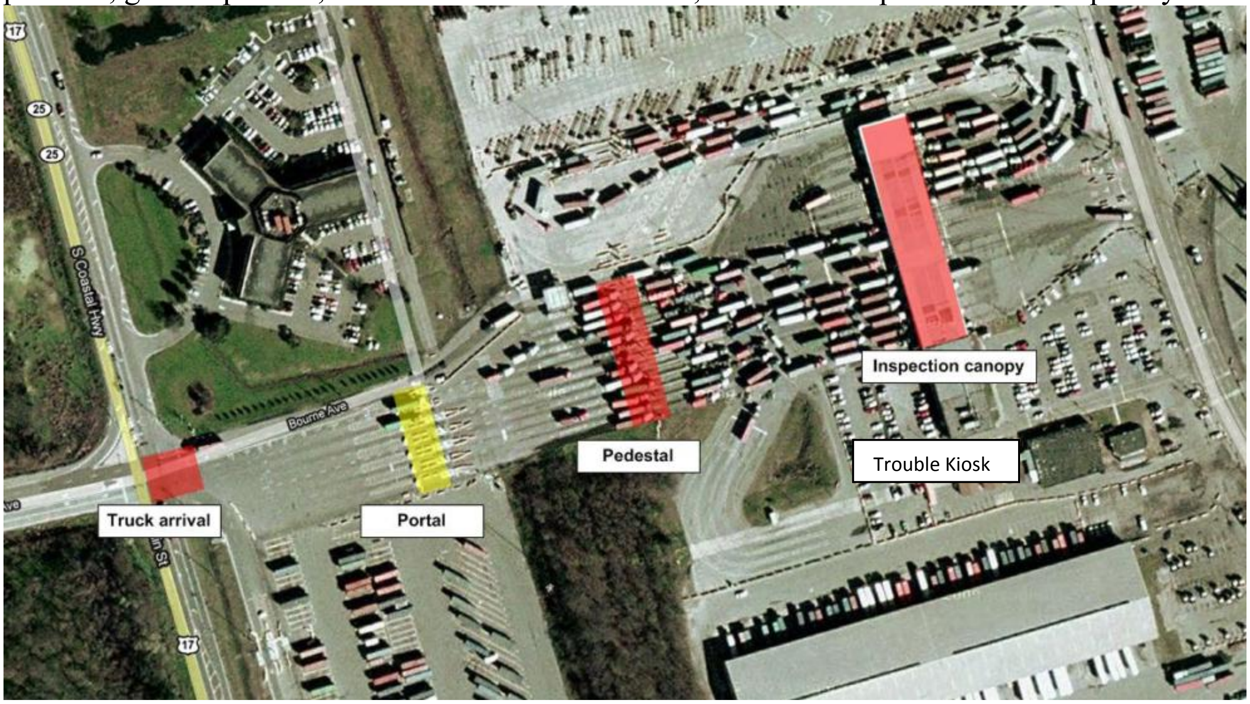


Figure 4.2 Layout of Gate 4

<u>*Pre-Advise*</u>

Pre-advise is the process of submitting gate transaction information before a truck arriving at the gate and seeking access to the port. This process increases security and helps speed the gate process. Transaction information is entered to the WebAccess system prior to a truck's arrival at the gate. The truck and driver are then validated against the information before being allowed entry to the port.

The user (e.g. trucking company) logs into the WebAccess before the truck physically arrives at the gate. According to the system instruction, the user is instructed to fill in all the necessary transaction information, including the truck license number, trucking company, container number, chassis number, etc. After the submission of the input information, the system will confirm it and generate a personal identification number (PIN) for each transaction. The truck driver will use the PIN to uniquely indicate the transaction when the truck arrives at the gate. The PIN is valid for 72 hours, and there is no lead time for obtaining a PIN. This means the earliest time the user can obtain a PIN for the transaction is 72 hours before truck arrival.

Portal

Portal is a process established after the implementation of the automated terminal asset management system (ATAMS) in the GPA. The portal process includes two steps: manual GPA credential check and automatic truck and container identification, including truck ID, container number, and chassis number.

At the first step, a security officer will check the truck's GPA credential (a badge issued by GPA that allows the drivers to enter the GPA facility) and match the face with the photo on the credential. This check takes approximately 5 to 10 seconds.

At the second step, the truck will proceed at a slow speed (typically 5 mile per hour) to the ATAMS lanes. There are six ATAMS lanes at the portal and the number of open lanes is determined by the arrival truck volume observed by the gate officers. Each lane is equipped with OCR-smart cameras and RFID-reading equipment to capture the container number, chassis number and the truck ID. Three cameras at different heights and angles are used to capture the container number and chassis number on the truck, and the OCR is used to automatically recognize the numbers. A typical RFID is mounted under the truck. About 95% of trucks are equipped with this type of RFID, storing the basic truck information. Approximately 80-90% of the trucks equipped with a RFID tag can be identified automatically at the portal.

Pedestal

Pedestal is a check-in process before a truck allowed entry to the port. The pedestal is equipped with a telecommunication system that allows the truck drivers to communicate with the terminal, to validate the pre-advised transaction information, and to acquire the necessary tickets for the designation of container pick-up and drop-off locations. There is no security inspection required at this stage. The operation process at the pedestal consists of the following steps:

- Driver drives on to the scales at the pedestal after waiting in line in the queue and the weight of the truck can be acquired.
- Driver then scans an ID card (i.e. GPA credential). If the ID card is recognized by the system as being valid, the truck will continue to the gate process. If an invalid card or no card is presented, the gate clerk at the remote office will generate a trouble ticket and the driver will be sent to the Trouble Kiosk.
- Driver continues to press the call button to communicate with the gate clerk over the phone by providing his truck's tag (state license) number and the PIN number generated during the pre-advise process. Meanwhile, at the gate clerk's office, the information is collected and identified at the portal, including container and chassis number, will be displayed.

- The gate clerk will compare the information provided by the driver through the phone with the information collected at the portal. If the information matches, the gate clerk commits the transaction and the system will print a ticket for the driver. With the printed ticket, the truck will proceed to the gate for inspection. If the information does not match, the gate clerk will make necessary corrections to the container number, size and type. If the truck has multiple transactions, both drop-off and pick-up, a separate ticket for each transaction will be printed following the aforementioned procedures.

Trouble tickets are issued at the pedestal from time to time due to the lack of an ID card from the driver, lack of PIN, etc. Approximately 5% of the tickets printed at the pedestal are trouble tickets. The processing time at the pedestal varies depending on the communication between drivers and the gate clerks. Based on observation, the average processing time for a truck at the pedestal (including non-trouble tickets and trouble tickets) is 2 to 3 minutes.

Gate Inspection

The gate inspection process is to inspect incoming equipment (chassis and container) to note any damage or broken seals. GPA liability is reduced when damage that occurred before the truck entered the port is discovered and noted. The inspection is performed by an International Longshoremen's Association (ILA) clerk. For the bobtails, the inspection is not required. The operation procedures for the gate inspection process are described below:

- Driver arrives at the inspection canopy and gives the drop off ticket to the clerk (for Gate 4 without bobtail entrance).
- The clerk enters the truck information from the drop off ticket into the radio data terminal (RDT), a remote handheld terminal owned by the port, including ID number and transaction number.
- The clerk then physically inspects the chassis and container and enters any damage found into the RDT. Based on the inspections, the clerk inputs different damage types into RDT, including reefers, for which the clerk will need to enter the temperature to the RDT, the undamaged container, the undamaged container with special handling (e.g. hazardous materials) and damaged container, for which the clerk will need to enter all the damages to the container and/or chassis.
- The clerk commits the transaction and equipment the interchange receipt (EIR) is printed for both damaged and undamaged containers and/or chassis and for a truck requiring special handling.
- The truck proceeds to the location designated on the EIR.

Trouble Ticket Resolution

The driver is sent to the Trouble Kiosk to resolve the matter if a trouble ticket is issued at the pedestal. The gate operation officers will work with the driver to resolve the issue and correct the information in the system. The location of the Trouble Kiosk is shown in Figure 3.2. The operation procedures at the Trouble Kiosk are described below:

- Driver arrives at the Trouble Kiosk and uses a specific phone to make calls to resolve the trouble ticket. If the trouble ticket is due to an invalid ID card, the security phone is first used to obtain a visitor's pass before the trouble ticket can be solved. In other cases, the driver needs to call the gate operation office using the house phone and let the office contact the shipping line for additional information. The driver might need to phone his dispatcher to correct or receive numbers or other information to present to gate operation office.

- After the data is collected, the gate operations office performs research and determines whether the trouble ticket can be resolved. If not, the driver must exit the port.
- The clerk accesses records using the transaction number and corrects the information in the database following instructions from the Gate Operations Office. A valid drop-off or pickup ticket or both are printed.
- Driver receives the newly printed tickets and proceeds to the inspection lanes.

4.1.3.2 Gate Performance

One month of container transaction data was obtained from the GPA and analyzed to show gate throughputs and the daily pattern. An analysis of the transaction data shows that Gate 4 handles more than 65 percent of the gate container transactions. Figure 4.3 shows the percentage of the container transactions among the three gates (Gates 3, 4, and 6). The average throughputs, including inbound and outbound, is 201.2 containers per hour (0.3 minutes per container) in February, 2010 (28 days); and the throughputs at Gate 4 is 339.2 container transactions per hour (0.18 minutes per container). Figure 4.4 shows the container transaction pattern at Gate 4 in February, 2010 (28 days) based on weekdays. The number of containers shown in Figure 3.4 includes both drop-off and pick-up containers. The two peak hours are 1000 to 1100 and 1500 to 1600 . Site visits were conducted during the peak hours to observe the queue at the gate and to identify the location for observing truck arrivals.

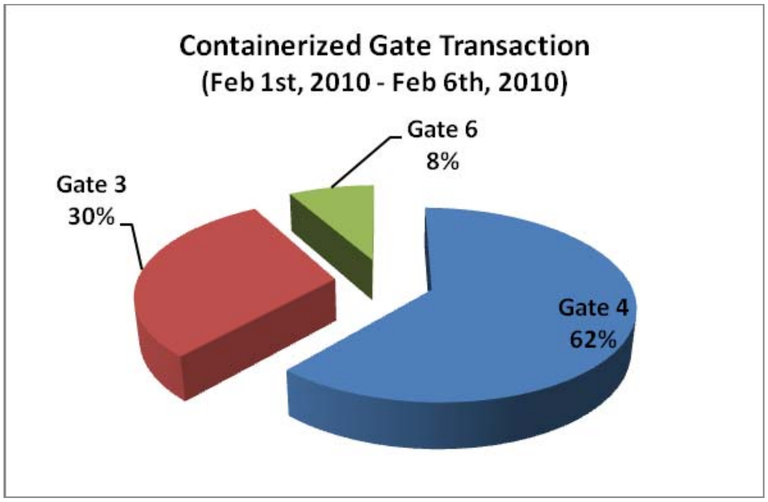


Figure 4.3 Container transactions among different gates

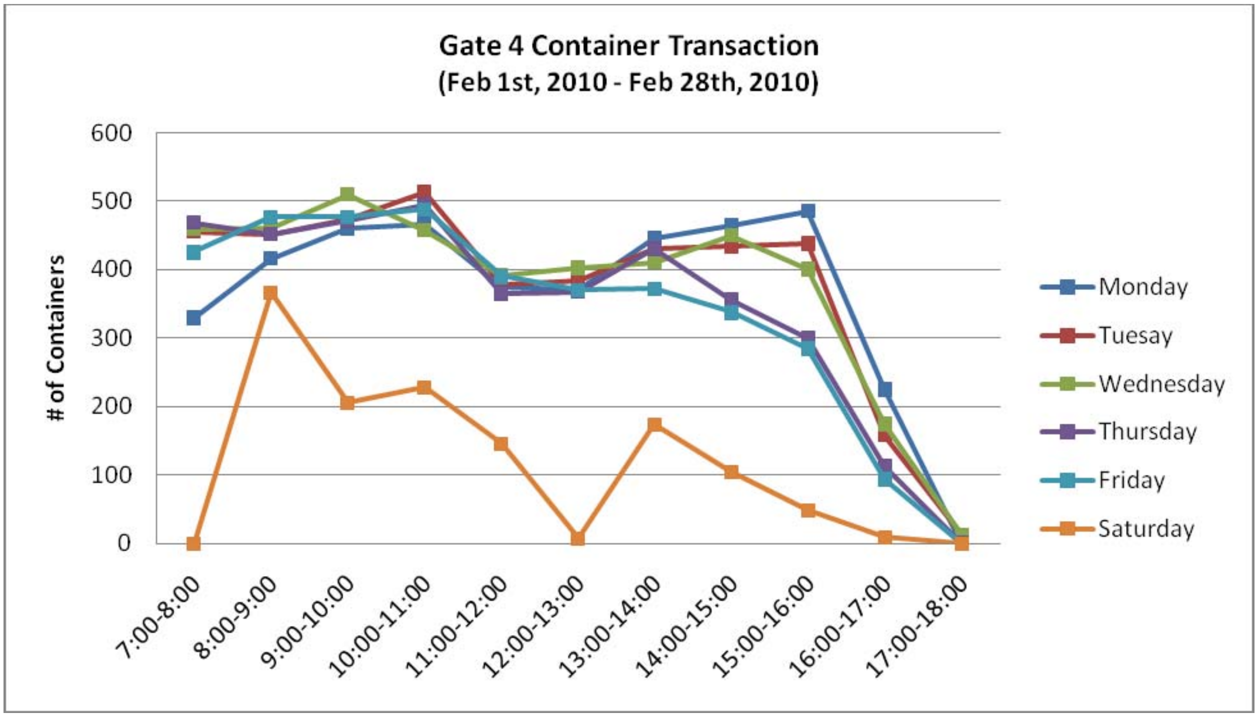


Figure 4.4 Container transactions at Gate 4

4.1.4 Rapid Dispatch Service

Rapid dispatch is a process designed to provide fast services for the local retailers, such as Home Depot, Wal-Mart, and Dollar Tree, which have special arrangements with the port. Their containers are all stored on chassis in the rapid dispatch yard in slots designated for the particular retailers. The gate business processes are similar to the regular truck traffic with the following minor differences:

- After checking in at the pedestal, the truck bringing in an empty container goes to the section of the rapid dispatch yard devoted to the particular retailer and drops the container with chassis in the assigned slot;
- Driver proceeds to an assigned slot in the rapid dispatch yard and picks up the container, which is already on wheels, passes the gate out inspection, and exits the port.

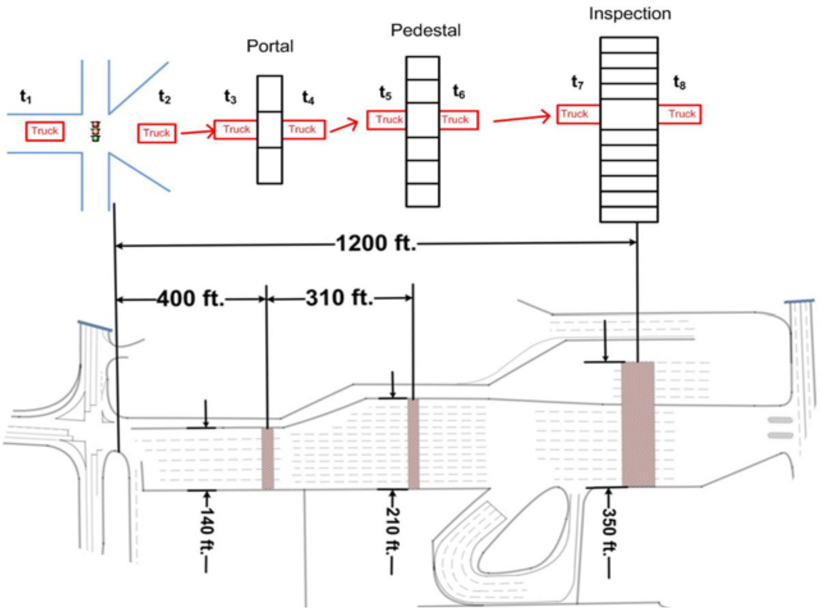
All the trucks will have to go through the regular gate processes to enter the port. The difference between the regular truck and the rapid dispatch truck is rapid dispatch trucks do not need to exchange chassis, but directly pick up the containers on the chassis and leave the terminal. This rapid dispatch service helps retailers improve their truck operation speed. Currently, rapid dispatch is operated by Gateway Terminals, Inc., a consortium of the four stevedoring companies doing business at the GPA facilities. The rapid dispatch facility at Garden City Terminal handles 200 to 300 containers per day, 3-4% of the total container handling.

4.2 Multi-Camera System Design

A multi-camera system was designed to collect images that capture truck movement at various critical points at Gate 4 at the Port of Savannah for extracting truck arrival time, wait time, and service time. The images are to support the development and validation of the image processing algorithm. This section presents (1) the requirements for image collection that were identified through the review of the gate operation and (2) the design of multi-camera system, including camera position, resolution, angle, focal length, etc.

4.2.1 Requirements

A multi-camera system was designed for collecting images that capture truck movement at various critical points, including portal, pedestal, and inspection at Gate 4. Figure 4.5 illustrates the truck traffic flow at the gate. The majority of the trucks enter the gate traveling west from Bourne Avenue. The truck then goes through the portal, pedestal, and inspection to verify the information (e.g. truck ID, container No., chassis No, license plate) to complete the transaction as discussed previously. The performance measurements, including service time, and wait time at each station (i.e. portal, pedestal, and inspection), are measured for studying the characteristic and exploring the solutions for maximizing both port and freight industry productivity. The table in the Figure 4.5 shows how to record and compute the arrival time, service time, and wait time.



	Arrival Time	Departure Time	Service Time	Wait time
Entering Sys.	t2	-	-	-
Portal	t3	t4	t4-t3	t3-t2
Pedestal	t5	t6	t6-t5	t5-t4
Inspection	t8	t7	t8-t7	t7-t6

Figure 4.5 Truck flow at Gate 4

- Truck arrival time: According to the interview with the GPA and field observation, most of the trucks enter the gate from west-bound Bourne Avenue, and the queue does not extend beyond the intersection. The truck arrival times will be measured at the point where the truck crosses the intersection and enters the gate (t2 in Figure 4.1).

- Service time: Service time is the amount of time needed to serve a truck at a service station (e.g. portal, pedestal, and inspection). Service time is the difference in time between a truck arriving at a service station and leaving the station. To measure service time, the truck arrival time (e.g. t3, t5, t7) and departure time (e.g. t4, t6, t8) need to be recorded, and the difference between arrival and departure time (t4-t3, t6-t5, t8-t7) is service time, as shown in Figure 4.1.
- Wait time: Wait time is the time a truck waits in the queue for the service. In this study, it is assumed a truck is either being served or waiting to be served. The travel time between the stations is assumed to be zero. Therefore, the wait time is the difference in time between a truck leaving the previous service station and the truck arriving at the very next station and being served. For example, the wait times are t3-t2, t5-t4, t7-t6 at the portal, pedestal, and inspection station in Figure 4.1. To measure wait time using the sensing system, the truck arrival time (e.g. t3, t5, t7) and departure time (e.g. t4, t6, t8) need to be recorded, and the difference between the departure time from the previous station and the arrival time at the very next station, (t3-t2, t5-t4, t7-t6), is wait time, as shown in Figure 4.1.

4.2.2 Multi-Camera System

The design of the location and the camera configuration for the multi-camera system is discussed in this section. The location for setting the multi-camera system is proposed based on the distance to the observed points (e.g. portal, pedestal, and inspection canopy) and the availability of the locations. The camera configuration, including resolution, angle, and focal length, was designed based on the requirements and the proposed location for the multi-camera system.

4.2.2.1 Location selection

There are three criteria for selecting an appropriate location for setting up the multi-camera system. First, the gate operation must not be interrupted or distracted by the multi-camera system. Second, the truck movements (arrival and departure) at the four observation locations must be covered by the multi-camera system from the proposed location. Finally, the proposed location should be on a flat ground that provides stability to the multi-camera system. Based on the criteria, a location, shown as a red dot in Figure 4.6, is proposed. The proposed location is at the corner of the rapid dispatch yard with an open view to the four observation locations, including the intersection, the portal, the pedestal, the inspection canopy, and their respective queues. The proposed location is the closest available location from the inspection canopy, with a distance of 750 feet from the center of the canopy; the distance to the intersection is about 700 feet. The proposed location is within the paved the rapid dispatch yard and can provide a stable base for the multi-camera system.

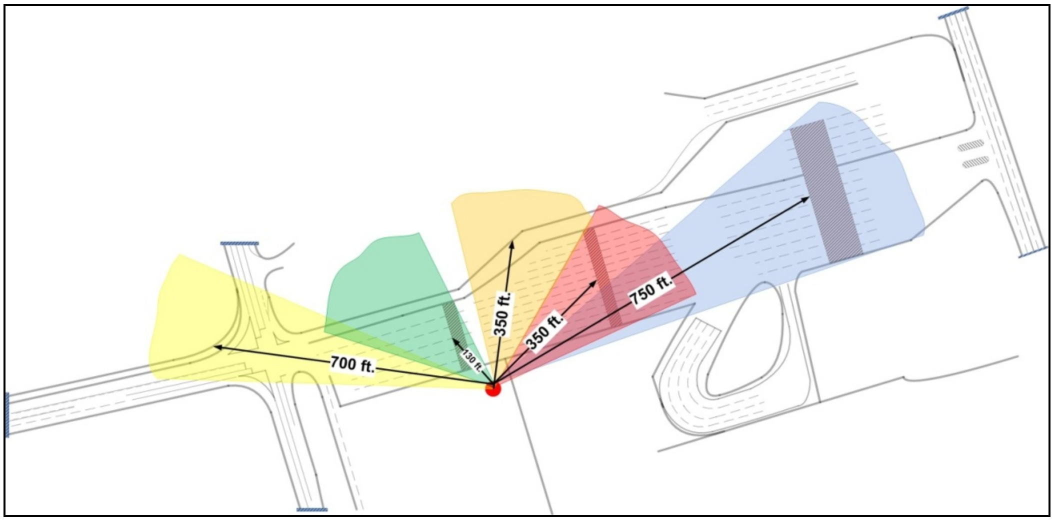


Figure 4.6 Location for the proposed vision-based sensing system

4.2.2.2 Camera Configuration

A five-camera system is proposed to satisfy the needs for monitoring the truck arrival and queue at four critical locations, including the intersection, the portal, the pedestal, and the inspection canopy. As shown in Figure 4.3, five cameras are proposed to cover the whole area to extract the required arrival and departure times. Camera 1 is dedicated to capturing the truck arrival from the local network (t2 in Figure 4.1). Camera 2 is dedicated to capturing the service time at the portal and its respective queue (t3 and t4). Camera 3 is dedicated to capturing the service time at the pedestal (t5 and t6). Camera 4 is dedicated to capturing the service time at the inspection canopy and its respective queue (t7 and t8). Camera 5, together with Camera 3, is dedicated to capturing the queue at the pedestal (t5).

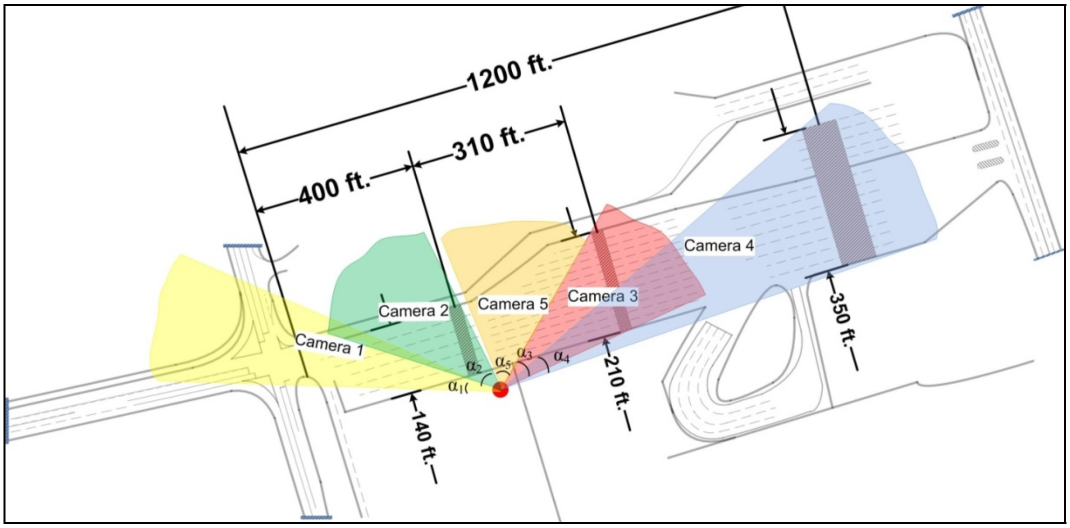


Figure 4.7 Camera configurations for the proposed vision-based sensing system

Camera system configuration, including orientation, lens, and resolution, are chosen to cover the area and capture an individual truck at different stations.

Selection of horizontal angle and focal length

Table 4.1presents a typical angle selection based on the layout of Gate 4. Assuming a camera height of 36 feet, which is the height of our lift equipment can reach, and the cameras with 2/3” sensor, the camera configurations can be computed and presented in Table 4.1. The height of the camera, the sensor size, and the object percentage can be changed.

Table 4.1 Typical selection of camera horizontal angle and focal length

Height: 36 ft.		Sensor Size: 2/3"		Object Percentage: 3%	
Location	Distance	Vertical Angle	Horizontal angle (α)	Focal length	Downward angle
Camera 1 (t2)	700 ft.	14.98°	19.97°	25mm	9.78°
Camera 2 (t3 & t4)	130 ft.	71.51°	95.35°	4.8mm	48.28°
Camera 3 (t5 & t6)	350 ft.	24.1°	32.13°	15mm	16.45°
Camera 4 (t7 & t8)	750 ft.	11.67°	15.56°	30mm	7.74°
Camera 5 (t5)	~350 ft.	24.1°	32.13°	15mm	16.45°

Selection of camera resolution

The inspection canopy, which is the most distant location from the camera location, is considered when determining the camera resolution. A truck at the inspection canopy occupies fewer pixels compared to a truck at other observation locations. Therefore, the requirement for camera resolution at the inspection canopy is higher than the requirements at other observation locations. Thirty pixels is considered a typical value for detecting a truck using the image processing algorithm. Table 4.2 shows the minimum resolution requirements for each of the five cameras to satisfy a 30-pixel truck occupation in the images with expected queue length. A 1024*768 resolution for all the five cameras in the multi-camera system is proposed.

Table 4.2 Requirements for camera resolution

Location	Queue Width	Truck Pixel (Horizontal)	Minimum Resolution (4:3)
Camera 1 (t2)	90 ft.	30 pix.	320x240
Camera 2 (t3 & t4)	140 ft.	30 pix.	480x360
Camera 3 (t5 & t6)	210 ft.	30 pix.	640x480
Camera 4 (t7 & t8)	350 ft.	30 pix.	1024x768
Camera 5 (t5)	~210 ft.	30 pix.	640x480

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