Technical Report Documentation Page

1. REPORT No.

Metrans Project AR 05-01

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

An Accurate Monitoring of Truck Waiting and Flow Times at Terminal in the Los Angeles/Long Beach Ports

5. REPORT DATE

December 2007

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Department of Computer Engineering and Computer Science
California State University, Long Beach

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

Department of Transportation, University Transportation Centers Program, and California Department of Transportation in the interest of information exchange.

13. TYPE OF REPORT & PERIOD COVERED

FINAL REPORT

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

The U.S. use thereof. The contents do not necessarily reflect the official views or policies of the State of California or Department of Transportation. This report does not constitute a standard, specification, or regulation.

16. ABSTRACT

The rapid growth in cargo volume at the Los Angeles/Long Beach Twin Ports has led to serious concerns, among others, on port capacity limits, traffic congestion in the surrounding areas and beyond, pollution, etc. A large portion of the operations at the ports involves trucks coming to the terminals for drop off or pick up of containers. Due to the significant impact of these truck operations cannot be over stated. Numerous projects have been, are being, and will be conduced on policy as well as operational issues of truck drop-offs/pick- ups in these twin ports. Many of these studies require a good understanding of the current state of services at the terminals in this regard. In this project we track truck traffic at a specif terminal in the twin ports in an attempt to acquire statistics on truck arrivals, as well as truck waiting and flows at this terminal. The tracking is accomplished using digital photographing technology.

17. KEYWORDS

Truck waiting, Truck flow times, Truck monitoring

18. No. OF PAGES:

32

19. DRI WEBSITE LINK

http://www.dot.ca.gov/newtech/researchreports/reports/2007/met_res_rpt_monitoringtruckflows.pdf

An Accurate Monitoring of Truck Waiting and Flow Times at a Terminal in the Los Angeles/Long Beach Ports

Final Report

METRANS Project AR 05-01

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Abstract

The rapid growth in cargo volume at the Los Angeles/Long Beach Twin Ports has led to serious concerns, among others, on port capacity limits, traffic congestions in the surrounding areas and beyond, pollution, etc. A large portion of the operations at the ports involves trucks coming to the terminals for drop off or pick up of containers. Due to the significant impact of these truck traffics on the roadway congestion and air pollution, the need for efficient service for these truck operations cannot be over stated. Numerous projects have been, are being, and will be conducted on policy as well as operational issues of truck drop-offs/pick-ups in these twin ports. Many of these studies require a good understanding of the current state of services at the terminals in this regard. In this project we track truck traffic at a specific terminal in the twin ports in an attempt to acquire statistics on truck arrivals, as well as truck waiting and flows at this terminal. The tracking is accomplished using digital photographing technology.

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Disclosure

Project was funded in entirety under this contract to California Department of Transportation.

Introduction

The Los Angeles/Long Beach seaport complex is the intermodal gateway to Pacific Rim trade. With the rapid growth of economy in China and other parts of Asia, the cargo volume at the twin ports has experienced tremendous growth in recent years. Just in 2004, the shipping containers passed through the twin harbors increased by 11% from 11.9 million to 13.1 million TEUs. And the growth continued in 2005 to a combined volume of 14.2 TEUs [11, 13]. A crude projection of the current trends estimated that the cargo volume in the twin ports to at least double the present volume by 2020 [7]. Several capital improvement projects have been planned for the next decade to handle the projected growth. For example, for the Long Beach Port alone, three additional terminals and a bridge expansion are in the plan.

The planned capital projects will not be completed for another decade. In the meantime, however, users of the ports suffer from long waiting and extensive delays and their problems must be addressed based on the current facilities alone. Efforts to study the extent of the problem include: METRANS Project 03-18 by Ioannou et al. [3] that develops flow modeling in a container terminal, and Project 04-06 by Giuliano et al. [2] that analyzes queue and transaction times as part of an evaluation of the terminal gate appointment system.

Among other data, these projects rely on accurately measured container truck wait times at various points in the terminal, as well as the flow times through the terminal. Previous attempt at collecting such vital data involved pairs of students, with one in each pair reading out a truck id and other attributes and the second logging information with a timestamp. Unfortunately such a procedure is prone to human errors and a high percentage of unmatched vehicles observed at various points of the terminal is unavoidable. Without reliable and accurate data, building usable analytical and/or simulation models of the port's operation would be infeasible.

In this study we use a different method of data collection. And the data collection took place at a terminal in the Los Angeles/Long Beach Port Complex, which we shall refer to as Terminal X. Specifically, we employ digital cameras to capture trucks at various critical points which include the arrival at the initial waiting line, the entry gate, the bobtail entry, the pedestal, and the exit gate. We then create a database of all the image files and develop a software to enable the matching of each truck from entry to the pedestal then exit. The matching results are then stored in excel files for statistical analysis, plotting and distribution fitting. Based on the observations obtained from the equivalence of one full-day of day-time monitoring of truck movements through the selected terminal, we produce the following data that will be useful in other analytical and simulation studies:

1. A detailed distribution of truck wait times (also known as the queue time, from arrival to admittance with ticket issued), along with the mean, standard deviation and other useful statistics.
2. A detailed distribution of truck flow times (also known as transaction time, from ticket issued at the pedestal stations to the exit gate), along with the mean, standard deviation, and other useful statistics.
3. A detailed distribution of truck turn times (from arrival to the exit gate), along with the mean, standard deviation, and other useful statistics.

4. An understanding of the arrival to the main entry gate as well as the bobtail gate.
5. An understanding of the initial queue lengths outside of the entry gates prior to the opening of the terminal in the morning.

Methodology

The project involved the following five steps:

Step 1. Data collection: This involves the tracking of trucks as each arrives at the terminal, enters the terminal through either the bobtail gate or the main entry gate, passes through the pedestal, and then exits the terminal. The tracking is accomplished by stationing a digital camera at each of those locations to capture each truck as its passes that location.

Step 2. Database setup and data entry: A database is setup and loaded initially with all the truck picture files obtained from data collection. Every truck picture is examined and three attributes of the truck are inserted into the database. The attributes are color of the truck, truck profile (flat or not flat), and load on the truck (bobtail, chassis, or container). The color and profile attributes will be used in the truck matching step, while the load attribute will be used in data analysis.

Step 3. Truck matching: A truck that passes through the terminal captured at several cameras. To identify a truck trip, therefore, requires the identification of that truck on the images taken from either of the entry cameras, one of the pedestal cameras, and the exit camera. The timestamps of these images tell us the time the truck arrives, the time it takes to flow from entry to the pedestal, as well as the truck turn time. The color and profile attributes of each truck in the database will limit the number of possible choice for matching, thus making the matching process more manageable. Each identified truck trip is then inserted into the database.

Step 4. Data extraction: At the completion of the truck matching process a series of database queries are performed and the results are used for plotting and other statistical analysis.

Step 5. Statistical analysis: The truck trip data complete with timestamps at entry, pedestal, and exit can be used for finding statistics on truck wait time (the time from arrival to the completion of the entry procedure and a transaction ticket issued at the pedestal), truck flow time (or transaction time, defined as the time from the pedestal to exit), and truck turn time (the sum of wait time and flow time). The timestamps of all the truck arrivals will also be used to identify truck arrival patterns, and the distribution of interarrival times.

Each step will be elaborated in the following sections.

Data Collection

The data were collected at a marine terminal, referred to as Terminal X in this report, in the Port of Los Angeles in April-May, 2006. Table 1 shows the physical sizes of the 14 marine terminals in the twin ports in terms of acreage and total berth lengths. Terminal X selected for our data collection can be considered mid-sized based on these physical measures. Moreover, Terminal X has on-dock rail facility, as do the majority of marine terminals in the twin ports; and is one of five terminals in the Port of Los Angels that has maintenance and repair facility within the terminal ground. The 2005 cargo handling volume at Terminal X is about the average of all terminals in the twin ports. Given the characteristics of Terminal X as cited above we expect the truck turn time data we collect at the terminal will not be extreme, and hence should be useful indication of where things are at the twin ports.

Terminal	Acreage	Berth Length (ft)
West Basin Container Terminal Berth 100	75	1200
West Basin Container Terminal Berth 121-131	186	3500
Trans Pacific Container Service	173	4050
Yusen Terminal	185	5800
Seaside Terminal	205	4700
APL Terminal	292	4000
APM Terminals	484	7190
California United Terminals	95	2100
Total Terminals International	345	5000
International Transportation Services	246	6379
Long Beach Container Terminal	102	2750
Pacific Container Terminal	256	5900
SSA Terminals, Pier A	170	3600
SSA Terminals, Pier C	70	1800
Median	186	4025
Mean	206	4141

Table 1: Sizes of Marine Terminals in the Twin Ports

We conducted our data collection at Terminal X from 8:00 AM to 5:00 PM for two reasons: (1) to replicate the experiment by Giuliano et al. [2] and (2) more transactions still take place during day time operations than in the extended hours [15]. Our original plan was to conduct the field work in one full day from 8:00 AM to 5:00 PM. However, due to logistic and staffing difficulties as well as the concern of student fatigue in an outdoor and polluted environment, we had decided to split up the experiment into three 3-hour monitoring sessions: 8:00 AM-11:00 AM, 11:00AM-2:00 PM, and 2:00-5:00 PM, which is consistent with the experiment in [2]. As indicated in [2] and from a conversation with an entry clerk at Terminal X, the heavy load is expected in the morning. Hence we chose to start our experiment with the middle time frame from 11:00 AM to 2:00 PM, followed by the 2:00-5:00 PM then the 8:00-11:00 AM time frame.

We had initially planned to conduct the three data collection sessions on three consecutive days in the middle of a week, i.e., Tuesday, Wednesday, and Thursday, as in the Giuliano et al. study [2]. Due to the difficulty of finding sufficient number of students on any Wednesdays within our plan, we had settled with the following days and times: 4/11/06 (Tuesday) 11:00 AM-2:00 PM, 4/13/06 (Thursday) 2:00-5:00 PM, and 4/20/06 (Thursday) 8:00-11:00 AM. We did the field data collection again on 5/25/06 for the morning session 8:00-11:00 AM and a late afternoon session 5:00-7:00 PM. The morning session was repeated since the 4/20/06 monitoring started late at 9:05 AM instead of 8:00 AM as originally planned due to some unexpected delay. We therefore decided to repeat the same time frame 0n 5/25/06.

We collected our data nine months after all marine terminals in the twin ports mandated to implement the Off-Peak program created by PierPass [10]. PierPass is an organization created by marine terminal operators at the Los Angeles and Long Beach ports to address cross-terminal issues such as traffic congestion and air quality. In response to legislative mandates to improve terminal operation efficiency so as to mitigate impact on public health due to surge in international trade and increased goods movement, PierPass created the Off-Peak program to help reduce truck traffic during peak daytime hours by providing monetary incentive, namely, the traffic mitigation fee of $50 per TEU is waived when a container enters or exits the terminals outside of peak hours (Monday through Friday, 3:00 AM to 6:00 PM). During the afternoon monitoring on 4/13/06, we noticed that traffic slowed down substantially after 4:00 PM. Moreover, many trucks even after entering the terminal ground would wait there even when pedestal lanes were available. Explanation we got from a terminal personnel was that trucks arriving close to the off-peak hours (6:00 PM to 3:00 AM) when the fee is waived would prefer to wait till the free entry time. Our expectation was that volume after 6:00 PM should jump to an extent that would worth monitoring. We therefore added a monitoring session from 5:00 to 7:00 PM on 5/25/06.

To find out how representative the volume on these monitoring days are, we obtained the 2005 weekly gate volume data of the terminal under study [16]. The data showed that the weekly average gate volume in 2005 was highest in July and August with volume 5.14% and 5.16% above the mean, respectively, lowest in March with volume 11.6% below the mean. The weekly gate volume in April and May were 0.30% and 1.24% above the mean, respectively. We consider the volume in this period representative for study purpose.

The number of moves tallied on the "Daily Summary by Shift" reports for Terminal X [15] during the 7:00 AM-6:00 PM shift for the four days of our monitoring activities are given in Table 2 below. This table confirms that truck volumes during the selected four days are comparable.

Date	Number of Moves 7AM-6 PM	% Difference from Average
4/11/06	1134	-5.7%
4/13/06	1203	0%
4/20/06	1280	+6.4%
5/25/06	1194	-0.7%
Average	1203	

Table 2: Number of Moves During the Day Shift at Terminal X

The objective of the monitoring activities during these four days of data collection is to record the time at which every truck passes through each of five vantage points through Terminal X. As depicted in Figure 1, six digital cameras were set up at five vantage points around the terminal:

(1) the sidewalk along the truck arrival lanes before entering terminal gate, (2) the bobtail gate, (3) the main entry gate, (4) and (5) the pedestal, and (6) the exit gate. All cameras were synchronized to the minute. Each camera was manned by a student who would capture each truck when it makes a move, with the objective of tracking the time each truck trip through the terminal.

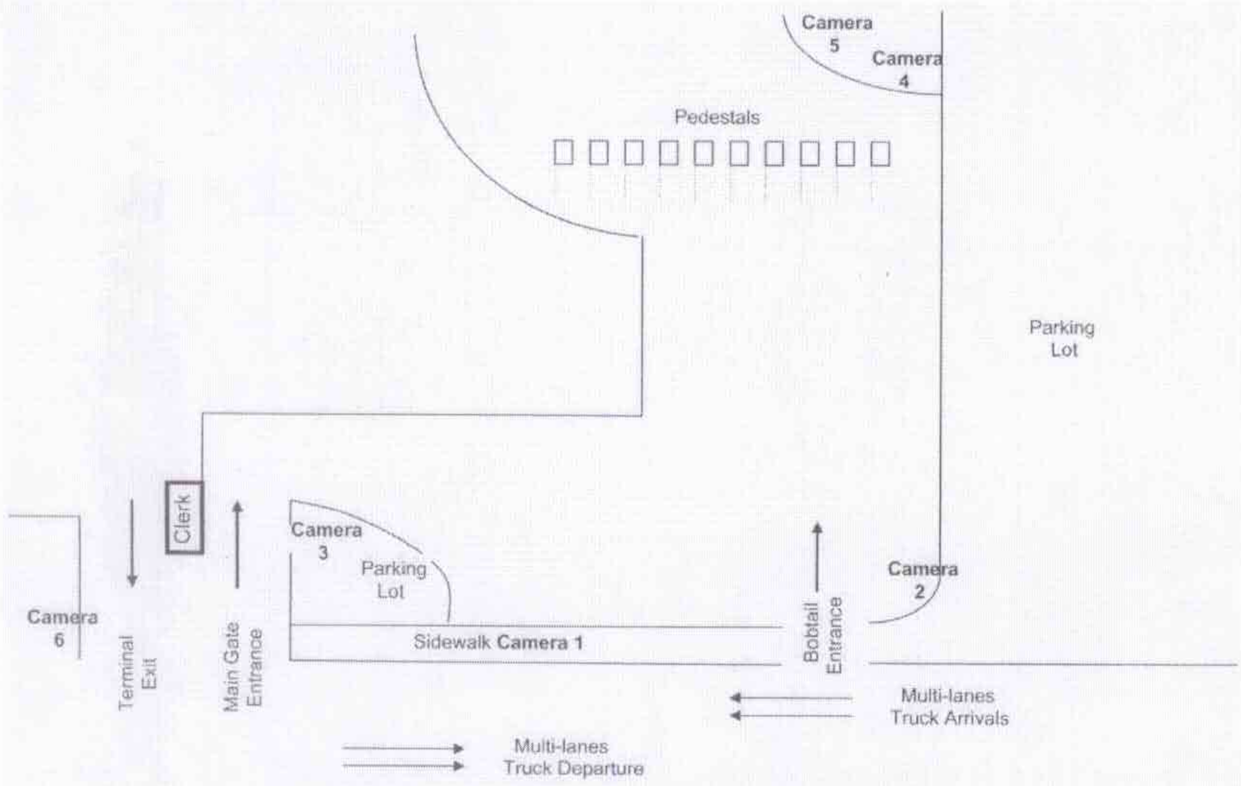

Figure 1. Layout of Cameras for the Monitoring.

A truck trip through the terminal starts at one of the entry gates: the main gate for trucks with chassis or containers or the bobtail gate for bobtails. Students who monitor at the two entry gates (cameras 2 and 3) captured every truck's arrival at the respective gate. Each truck must stop at the entry (bobtail or main) for the driver to show driver's licenses to the gate attendant, making it a perfect setting for picture taking. While there are two entry lanes at the main gate, the far lane from the gate booth was blocked during all our monitoring sessions. The rationale for the lane closure must be the requirement for the presentation of driver's license to the gate attendant. Opposite to the main gate booth is a fenced parking lot with an opening facing the gate booth, a perfect location for photographing trucks as each passes through the main gate. Space at the bobtail gate, however, is a bit tight. Our plan was to take all pictures from the right side of the trucks. On the third day however, as a result of some driver complaints of potential danger, we had to move the student to the left side of the bobtail gate. Hence pictures of trucks at the bobtail gate after that time were taken from the left side of the trucks. Fortunately, all truck profiles, colors, decorations (if any) are typically symmetrical. Therefore, this alteration of plan only caused some inconvenience in truck matching but did not deem it impossible.

Trucks proceed from entry through a pedestal. There are 10 pedestal lanes divided into 2 locations manned by two students, each monitoring five lanes. These students (cameras 4 and 5) captured each truck as it left the pedestal station after completing entry procedure and receiving a ticket for the particular transaction it came for.

Our original plan for the two cameras for the monitoring of the 10 pedestal lanes was to station them behind a chain link fence in the parking lot adjacent to the pedestal area. We had concern that this may cause difficulty in truck matching as some crucial part of the trucks may be blocked by the fence. After some discussion with key terminal personnel, we were allowed to station our two students with their cameras inside the terminal at a secure area facing the pedestals. In situations where two or more trucks were leaving the pedestal simultaneously, the far truck would be blocked, causing the results of finding trucks at entry and exit, but not the pedestal.

A truck that passed through the pedestal will eventually exit the terminal at the exit gate. Every truck exiting must verify transaction with the exit gate attendant before leaving the terminal ground, then stop before making a left turn onto traffic. A student was stationed on the sidewalk by the stop sign to capture every truck there as it exits the terminal.

Camera 1 on the sidewalk was setup to record truck arrivals and was to be used only when a line of trucks was formed on the street before entering the terminal ground. Since no real line was formed during the entire duration on all four days of monitoring, camera 1 was never used. Times recorded at the bobtail gate and the main entry gate were therefore treated as the truck arrival times.

Database Setup and Data Entry

All pictures taken were uploaded onto a computer as picture files. Microsoft Excel spreadsheets were prepared with data about the truck pictures. A spreadsheet was prepared for each camera date and location. The picture file name and timestamp which were on each digital image were added to the spreadsheets using the ACDSee 8 Photo Manager application [1]. Other attributes including color, profile and load data were added by manual inspection and manual input to the spreadsheet. Truck profile used includes flat (cab over) and not flat (conventional) only. It is deliberately made to be simple in order to avoid any judgment error. These attributes combined with the timestamp would be used in truck matching to present a manageable group of trucks for inspection in order to match the entry truck picture to the pedestal and exit pictures. The load data refers to what each truck is seen to carry at entry and exit. The load types are bobtail (no load), trailer (chassis), and container. The load may change during the truck trip. These spreadsheets were used to populate a Microsoft Access database.

This initial database setup along with the outcome of truck matching in Step 3 is a Microsoft Access database where the truck pictures taken at entry, pedestal and exit are connected into truck trips. The relational database structure is shown in Figure 2.

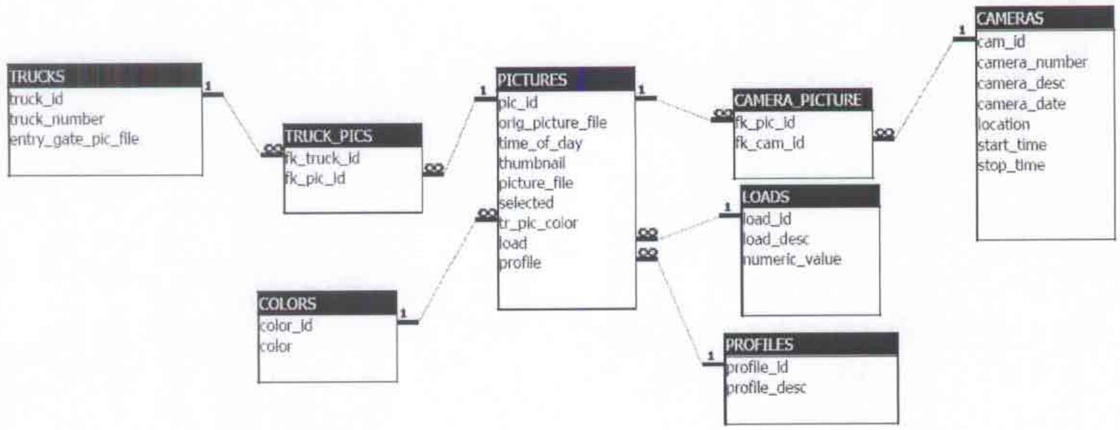

Figure 2. Access Database Used for Truck Data Storage.

The database relates a specific camera session described by the camera location and the camera date to all pictures taken during that session. All the truck pictures are described by picture file number and a timestamp. Additionally each truck picture has a set of attributes described by the related entities, color, profile and load. A specific truck is established by an arrival at the main or bobtail gate. So each arrival truck in the truck table can be matched to the pictures from the pedestal and exit gate to create a trip described by the time-of-day that each truck passed a given location.

Truck Matching

Visual inspection of the pictures was necessary in order to match a truck from entry through the pedestal and exit to identify a truck trip. A web interface application was developed to help such inspection and matching. The interface was implemented using Coldfusion MX 6.1 [5], and used the picture files and the truck database. The purpose of the application was to present a target truck from an entry gate and the possible choices from the pedestal then the choices from the exit gate. With the help of this web application, each student was able to work on truck matching from home, independently, on a subset of the truck data.

Manual inspection would be made to match the entry truck to the pedestal and exit pictures in order to create a trip through the terminal for a specific truck. Upon user selection the application presented an entry truck on the screen. The user then chose to view pictures from one of the pedestal lanes. The most likely choices would be presented for the user to examine and select. The possible matches displayed were those with the same color and profile as the target truck and only pictures with a timestamp later than the target truck. Truck pictures could be viewed as full size images for closer examination. A matching truck picture was selected from one of the pedestals. The exit gate photos of like trucks with a timestamp later than the pedestal were then presented, examined and an exit match was selected. The truck trip was then inserted into the database. Once a picture was selected and inserted as part of truck trip it was no longer presented as a match option for subsequent truck trips. An example of the web interface is shown in Figure 3 below.

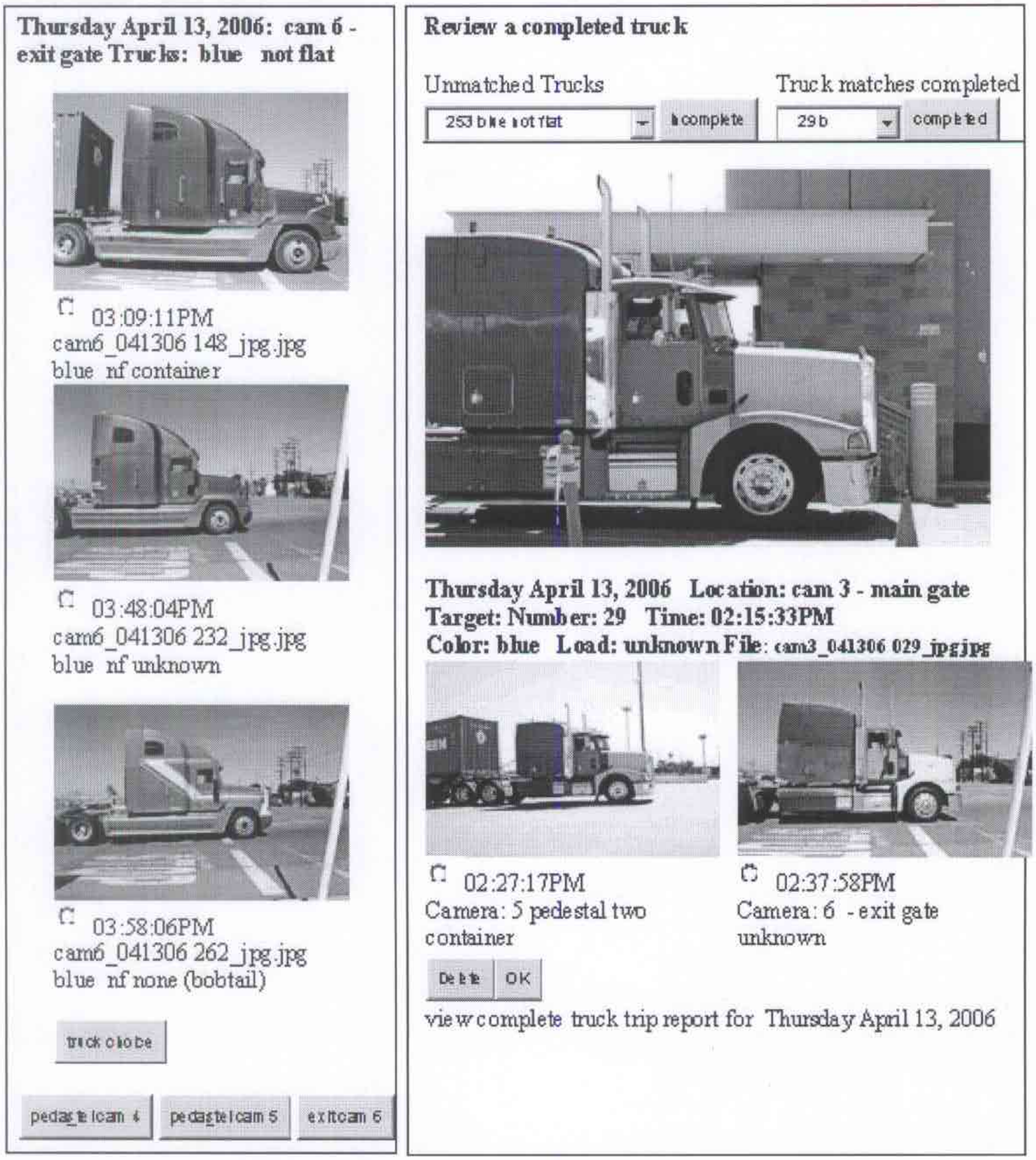

Figure 3. Example of the Web Interface Provided to Users for Matching Truck Trips. The frame on the right shows a completed truck trip. The frame on the left shows the possible choices for this truck. The actual choice has been removed and is shown on the right.

Close examination of a truck may be necessary and could be extremely useful when a matching is in doubt. On close examination of individual trucks there were many different ways to distinguish one truck from another. Some of these distinctions include unique paint jobs, decorations, decals, signage, dents, and distinctive windows.

Some challenges encountered in the truck matching exercise are worth mentioning:

- Due to sunlight effects from different directions, the color of a truck may look very different to human eyes on pictures taken at different vantage points. This had caused some data entry errors in the data for Days 1 and 2 and consequently led to exceptional number of trucks not finding match on those days. A second round of inspection was required to correct these data entry errors. And this result led to the use of a modified and smaller set of colors so as to avoid similar errors in color identification.

- Depending on the complexity of the transactions and the turnaround time, it is possible the same truck may pass through the terminal twice during one 3-hour monitoring session. Indeed, up to 6 trips per day by the same truck is now possible since the implementation of the appointment system and the extended-hour terminal operation, according to a terminal personnel at Terminal X. The possibility of multiple trips by the same truck in the same session, coupled with the potential color coding error as described above, renders the possibility of matching of the entry of the truck's trip 1 with the exit of the same truck's trip 2 and leaving the entry of the truck's trip 2 unmatched, and the exit of its trip 2 not used. The correct color and profile coding and extra attention paid to by students performing truck matching could eliminate or at least minimize such errors.

Data extraction

With the completion of truck matching, the database stores the data of every truck recorded during our monitoring as it arrives at one of the terminal gates, passes through the pedestal and finally exits. Queries were used to retrieve data from the Microsoft Access database for statistical analysis. The retrieved data are produced in table format on Microsoft Excel spreadsheets. Tables produced include the following for each day of monitoring:

- Arrivals at bobtail gate
- Arrivals at main entry gate
- Arrivals at main and bobtail gates
- Complete truck trips and truck loads

Statistical Analyses and Plots

We conducted a total of 5 truck traffic monitoring sessions at Terminal X over four separate days in April and May, 2006, for a total of approximately 13 hours. The monitoring hours are summarized in Table 3 below:

Day	Date	Time
1	4/11/06	11:20 AM – 2:00 PM
2	4/13/06	2:00 PM – 5:00 PM
3	4/20/06	9:05 AM – 11:20 AM
4 AM	5/25/06	8:00 AM – 11:00 AM
4 PM	5/25/06	5:00 PM – 7:30 PM

Table 3: Monitoring Days and Hours

These hours covered the bulk of all day time operations at the terminal. Day 4 AM was meant as a repeat for the session on Day 3, which was shortened due to an unexpected delay in starting the work. Day 4 PM was added when we realized that many truck operators want to take advantage of the fee waiver program for after hour use of the terminal facilities. However, Day 4 PM data were not used in our subsequent analyses for the following reasons:

1. The terminal maintains a separate yard across the street where containers are wheeled and ready for pickup by bobtail trucks. During the day time operations till 5 PM the separate yard has a guard to check trucks in and out there. After 5 PM, however, trucks picking up containers there must first enter the main terminal yard to obtain a ticket, then exit the main yard, goes into that separate yard to pick up the container, then comes through the main yard again to complete the exit procedure. Hence many trucks will pass through the entry and exit gates at the main yard twice in very short duration, making truck matching a very challenging process.
2. The bobtail gate is closed at 5 PM while the main gate remains open. At such time all bobtail trucks are to enter the terminal at the main gate with all other arrivals. The bobtail gate is re-opened at 6 PM for bobtail entries, a fact that we did not realize until 6:45 PM. This mistake caused a substantial number of bobtail entries to be missed.

Therefore, only data obtained from Days 1, 2, 3 and 4 AM are used in subsequent analyses.

In the following sections, we will detail our analysis of the data in terms of (1) truck matching accuracy, (2) truck arrival patterns, and (3) truck turn times.

Truck Matching Accuracy

As explained in the Data Collection section above, a truck that arrived at the terminal during our monitoring session would be captured in three different cameras (camera 2 or 3 at one of the entry gates, camera 4 or 5 at the pedestal, and camera 6 at exit) at various times. We developed a truck matching procedure as described in the Truck Matching section to identify each truck that was captured in our entry cameras (2 or 3) on either camera 4 or 5, and then on camera 6. The result of such matching was to find the complete trip for each truck that came through the terminal, and the times that it passed the critical points (entry, pedestal, and exit) of the terminal. Table 4 summarizes the matching percentages.

Session	Camera	Entry location	# of trucks captured at entry	# of truck matched at pedestal	% matched at pedestal	# of trucks matched at exit	% matched at exit
Day 1	2	Bobtail	82	76	93%	68	83%
	3	Main	215	197	92%	188	87%
	2 + 3	Bobtail+Main	297	273	92%	256	86%
Day 2	2	Bobtail	81	68	84%	72	89%
	3	Main	311	267	86%	278	89%
	2 + 3	Bobtail+Main	392	335	85%	350	89%
Day 3	2	Bobtail	78	76	97%	75	96%
	3	Main	272	257	94%	251	92%
	2 + 3	Bobtail+Main	350	333	95%	326	93%
Day 4 AM	2	Bobtail	117	116	99%	104	89%
	3	Main	260	235	90%	229	88%
	2 + 3	Bobtail+Main	377	351	93%	333	88%
All Days	2	Bobtail	358	336	94%	318	89%
	3	Main	1058	956	90%	947	90%
	2 + 3	Bobtail+Main	1416	1292	91%	1265	89%

Table 4: Truck Matching Percentages

The percentage of match at the pedestal and at exit ranges from 83% to 97%. On a closer look at the unmatched trucks and their timestamps, we conclude that they were not found at the exit gate because camera 6 at the exit gate was stopped before those trucks made it to the exit, despite the fact that camera 6 was stopped a full 30 minutes after those at the entries. This explanation can be verified by Table 5 which shows the matching percentage at exit for trucks that arrived at the terminal in Hour 1, Hour 2, and Hour 3 within a 3-hour monitoring session. Only the matching results for Days 1, 2, and 4 AM are computed since these sessions consist of 3 hours of monitoring. The expectation is that trucks that entered the terminal in Hour 1 had a much higher likelihood to exit the terminal within the monitoring time frame, hence were more likely to have been captured by the exit camera. Results in Table 5 strongly confirm this conjecture.

Session		Hour 1	Hour 2	Hour 3	All 3 Hours
Day 1	# entered	102	86	109	297
	# exit found	98	83	75	256
	% matched	96%	97%	69%	86%
Day 2	# entered	149	140	103	392
	# exit found	147	140	63	350
	% matched	99%	100%	61%	89%
Day 4 AM	# entered	107	106	164	377
	# exit found	103	104	126	333
	% matched	96%	98%	77%	88%
All 3 Days	# entered	358	332	375	1066
	# exit found	348	327	264	939
	% matched	97%	98%	70%	88%

Table 5: Truck Matching Percentage by Hour

The trucks that can be certain as being missed in our recording are those that have been matched at the exit but not at the pedestal, for those trucks must have been passed through our camera locations. Table 6 shows the number of such incidences, which show an overall error rate of 5%. Trucks were not found at the pedestal could be due to two possible reasons: (1) Cameras at the pedestal were stopped too early for those trucks to make it to and pass through the pedestal, and (2) When two or more trucks moved away from the pedestals simultaneously, the truck at the front obscured the one behind it from being captured by the cameras.

Session	# found at exit but not at pedestal	Total # found at exit	% missed at pedestal
Day 1	6	256	2%
Day 2	25	350	7%
Day 3	16	326	5%
Day 4 AM	14	333	4%
All Days	61	1265	5%

Table 6: Error Rates in Finding an Entry Truck at the Pedestal

Arrival Patterns

Compiling the data from these sessions and making sure no time overlaps occur in the counting, we came up with a rough truck arrival pattern as illustrated in the graph in Figure 4. It should be noted that the hourly arrivals at 6 PM are somewhat under-reported due to missing bobtail entries as explained above. They are included in the plot in order to show the jump from 5 PM to 6 PM.

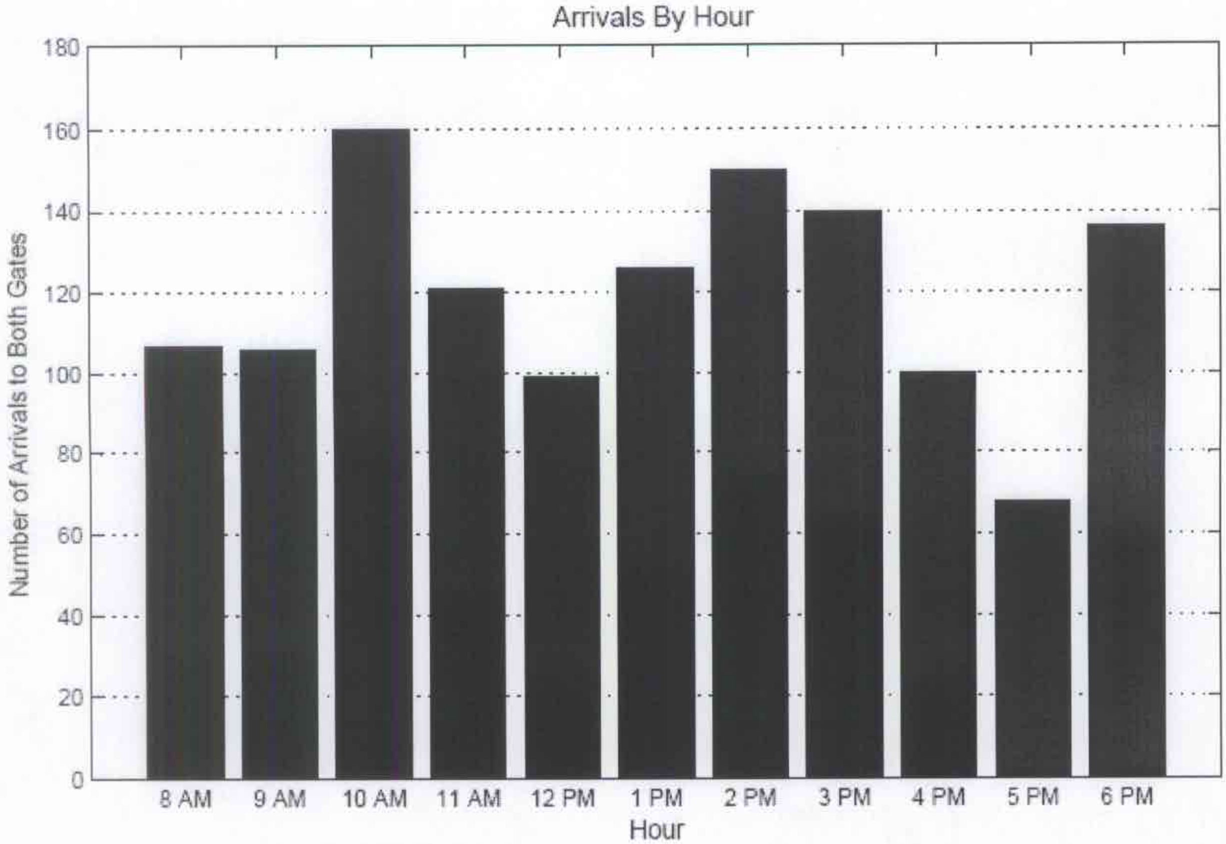

Figure 4: Arrivals by Hour

From this graph we can see that truck arrivals at this terminal are the heaviest during mid morning (10-11 AM), mid afternoon (2-4 PM), and again at the early evening hour (6-7 PM). The heavy traffic at the early evening hour (6-7 PM) with an especially light traffic during the preceding hour may be partially due to the fee waiver incentive implemented as part of the PierPass program. In addition, while there are some highs and lows in the traffic load, the load appears to be fairly flat throughout the day. It would be interesting to find out if this result can be attributed to the appointment system that is currently in place at Terminal X.

The appointment system was implemented at Terminal X for compliance to Assembly Bill (AB) 2650, which was signed into law on September 30, 2002. This bill was a legislative effort in California to force operational changes at marine terminals in an attempt to help reduce health hazard from increased truck traffic in and around port areas by imposing a penalty of $250 on terminal operators for each incidence of truck idling for more than 30 minutes while waiting to enter a terminal gate. Offering an appointment system or extending gate hours were two options marine terminals could adopt to avoid such fines. In theory, the appointment system helps spread truck traffic while extended gate hours enables terminals to handle increased cargo volume. Terminal X chose the appointments option along with additional gate hours as needed. Giuliano et al. [2] provides a detailed background of AB 2650 and a comprehensive evaluation of the gate appointment system at the Los Angeles and Long Beach ports.

Based on the timestamps of the truck pictures captured at the bobtail gate as well as the main entry gate, we have computed the interarrival time data stream for each monitoring session, plotted the frequency chart and fitted the data with several potential distribution functions.

Matlab R14 (version 7.1.0.183) [6] with statistics toolbox was used to calculate and produce statistics and plots. Some important routines used in our data analysis from the statistics toolbox are detailed below.

1. mle : The mle (maximum likelihood estimate) routine returns maximum likelihood estimates for a distribution specified in its argument, computed using sample data. The distributions we gave to the routine for MLE are 'Normal', 'Lognormal', 'Gamma', and 'Exponential.' Estimated parameter(s) were then used in other routines for analysis of the sample distribution.
2. cdf : The cdf (cumulative distribution function) routine returns a matrix of probabilities for a distribution specified in its argument. By supplying the estimated parameters produced from the mle routine, we generated hypothesized cumulative distribution function values, $G(x)$. The $G(x)$ was then used for Kolmogorov-Smirnov test (kstest) to calculate K-S test statistic (this will be explained in more detail in item 4 below). Also $G(x)$ was used in empirical cdf plots to show graphically how close the cdf of estimates are to empirical cdf of the sample data.
3. pdf : The pdf (probability density function) routine returns a matrix of densities for a distribution and parameters estimated from the mle. The densities obtained by this routine for the best fit distribution were used in distribution plots to be displayed along with scaled frequency histogram of sample data.
4. kstest : Once we estimated the parameters of the four candidate distributions, we needed to find out how well the distributions actually fit the sample data. There are several goodness-of-fit tests for this purpose. A goodness-of-fit test we considered first was Chi-Square test which deals with binned data. The use of binned data is a disadvantage of the chi-square test since the values of the chi-square test statistic are dependent on how the data is binned. Kolmogorov-Smirnov test, however, uses raw data thus avoiding the loss of accuracy due to bin treatment of the raw data as in the Chi-square test. So we decided to use Kolmogorov-Smirnov test utilizing the kstest routine. This routine calculates and returns several statistics : (i) K-S test statistic (KSSTAT), the maximum difference of cumulative distribution function values (i.e., the maximum vertical deviation between two curves if we consider the cdf plot) over all x. The smallest KSSTAT was sought in our analysis as the measure for the best fitting distribution among the four candidates. (ii) Does the test accepts or rejects the null hypothesis, H_0, at significance level α, that the data indeed is from a population of the distribution being tested. Unfortunately, as explained in [4, 9] the Kolmogorov-Smirnov test gives invalid critical values in testing null hypothesis test when the same test is used to estimate parameters as in our case. We therefore limited the use of KSSTAT as a quantitative measure for the determination of a best fit among the distributions of our interest.

Table 7 shows the best fit distribution among the four tested for each of the interarrival time data stream, based on the numerical comparison of the computed K-S statistic, without actually performing the test of goodness.

	Best fit for x	
	Lognormal	Gamma
Day1 Bobtail Entry	Best fit	
Day1 Main Entry	Best fit	
Day1 Both Entries	Best fit	
Day2 Bobtail Entry	Best fit	
Day2 Main Entry	Best fit	
Day2 Both Entries	Best fit	
Day3 Bobtail Entry		Best fit
Day3 Main Entry	Best fit	
Day3 Both Entries		Best fit
Day4 AM Bobtail Entry	Best fit	
Day4 AM Main Entry	Best fit	
Day4 AM Both Entries		Best fit

Table 7: Best-fit Distributions for Interarrivals

As an illustration of the frequency distribution of the truck interarrival times to the teminal and the probability distribution fitting of the interarrival time data, the graphs in Figures 5 and 6 show the fitting of a lognormal distribution to the interarrivals for both the bobtail and main gates on Day 2, and the cumulative distribution function to the same data. While it is inconclusive at this time whether lognormal is indeed a right distribution for the depiction of truck interarrival times to the terminal, we do know that the exponential distribution is an inappropriate model for such data.

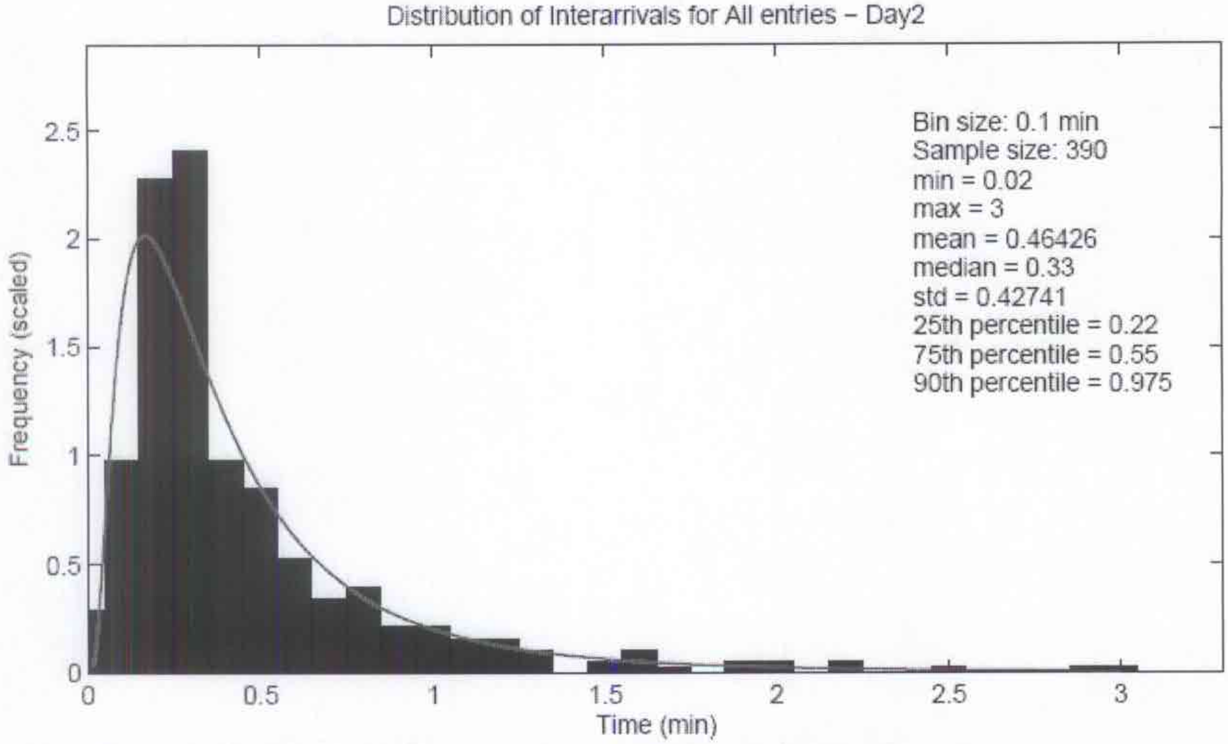

Figure 5: Distribution of Interarrivals to Both Entries on Day 2

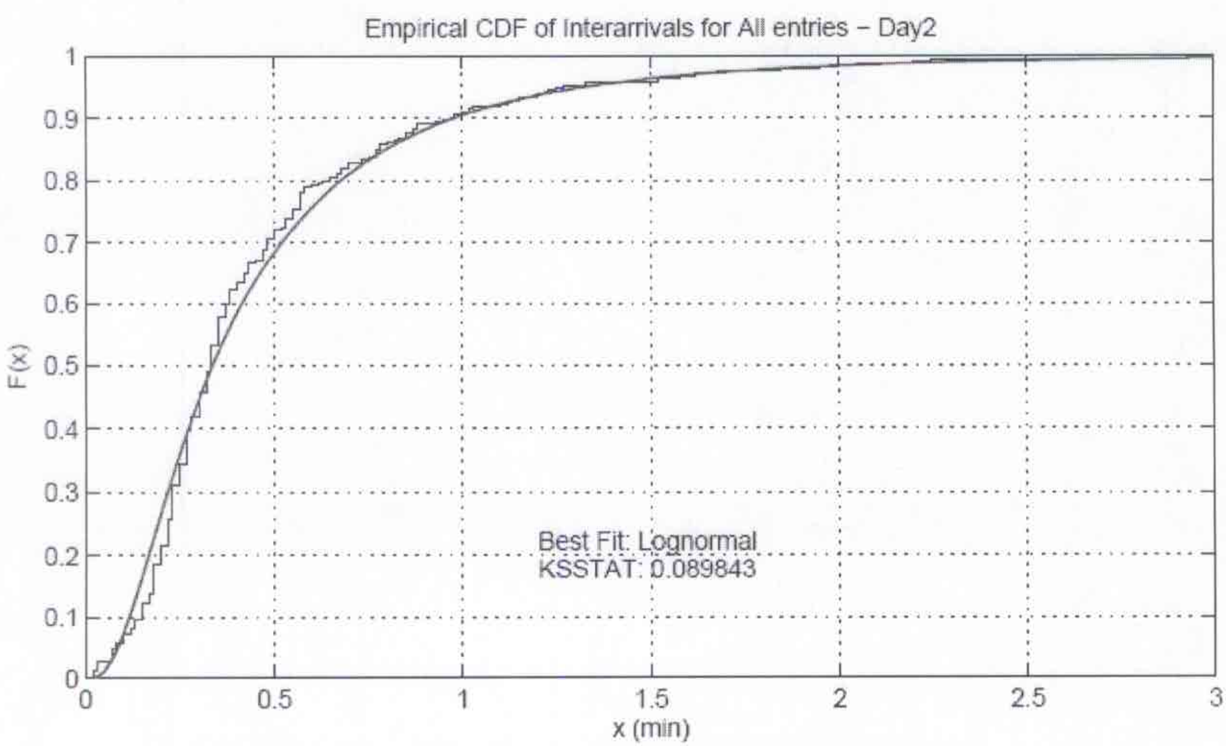

Figure 6: Empirical CDF of Interarrivals for Both Entries on Day 2

Truck Wait Time and Flow Time*

The time between a truck's arrival at the terminal till it completes the entry procedure at the pedestal and receives a ticket for its transaction is defined as its wait time (or queue time). Since no waiting outside of the terminal ground was detected during all our monitoring sessions, we are able to use a truck's entry time as its arrival time. From the pedestal to its exit is the truck flow time (or transaction time). The sum of these is the truck's total trip time (or turn time). Each complete trip that we have identified in the truck matching procedure contains the timestamps at entry, pedestal and exit. Using these timestamps we computed the wait time, flow time, and turn time for every truck we had captured during our monitoring. Noting that our adoption of 3-hour monitoring may have led to a biased result in favor of short turn times, we have examined the capture ratio by the hour of monitoring as shown in Table 5. The results in Table 5 show that 97-98% of the trucks entering during the first two hours of all our 3-hour monitoring sessions (i.e., Day1, Day 2, and Day 4 AM) had completed their trips during those sessions. We therefore have sufficient confidence in using those data for the calculation of wait time, flow time and turn time statistics as shown in Table 8.

Statistic	Wait Time	Flow Time	Turn Time
Mean	9	31	40
Median	6	22	32**
75th Percentile	13	37	49
90th Percentile	20	71	88

Table 8: Truck Wait/Flow/Turn Time Statistics (All Figures in Minutes)

We also noted the load a truck carries at entry and exit from the truck pictures and obtained the wait/flow/turn time statistics by load type. Three types of load were recorded in the database: bobtail, chassis, and container. Due to a combination of factors, including the insufficient distance between the camera and the truck, and the unusually large gap between the truck and its load, there were some truck pictures on which the load could not be determined. In such cases, the load was coded as "unknown." To determine the effect of these unknown cases on the overall statistics, we excluded all those truck trips showing one or more "unknown" loads and computed the same statistics as in Table 8. The results as shown in Table 9 are almost identical to those in Table 8. We conclude that the transactions with "unknown" loads were sufficiently random and did not cause biases in the overall statistics.

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* Also known as queue time and transaction time

** Turn times are computed independently of pedestal times and then ranked. Hence median turn time may not equal to the sum of median wait time and median flow time. Same for the 75th and 90th percentiles.

Statistic	Wait Time	Flow Time	Turn Time
Mean	9	31	40
Median	6	22	32
75^{th} Percentile	12	37	49
90^{th} Percentile	20	70	88

Table 9: Truck Wait/Flow/Turn Time Statistics (All Figures in Minutes).
Transactions with "Unknown" Loads Excluded.

The 3-hour monitoring scheme was expected to result in biases in favor of shorter turn times in the collected data since the long transactions are more likely not to have been completed (hence not captured) by the end of the monitoring session. This is especially true for those trucks that entered the terminal in Hour 3 of a 3-hour session than in Hour 1 or Hour 2. As shown in Table 5, the capture percentage in Hour 3 was only 70%, compared to 97% in Hour 1 and 98% in Hour 2. To eliminate or at least reduce such biases, we used only Hour 1 and Hour 2 data for a more detailed calculation of performance by transaction type. Table 10 shows truck wait/flow/turn time statistics using Hour 1 and Hour 2 data from Day 1, Day 2 and Day 4 AM, the three sessions with about 3 hours of monitoring. The flow time and turn time shown in Table 10 are longer than the corresponding measures in Table 9 as expected. While these statistics are expected to provide a more accurate measure of the truck turn times because of the very high capture percentage (98%) of the truck trips used, they do have a weakness of not including statistics of certain hours of a day (i.e., 10-11 AM, 1-2 PM, and 4-5 PM).

Statistic	Wait Time	Flow Time	Turn Time
Mean	9	35	44
Median	6	24	33
75^{th} Percentile	11	43	57
90^{th} Percentile	22	79	97

Table 10: Truck Wait/Flow/Turn Times (in Minutes) Using Hour 1 and Hour 2 Data.

Using these two hours of data from Days 1, 2, and 4 AM, we computed the truck turn time statistics by transaction type as shown in Table 11. Three transaction types were computed: bobtail in/container out, container in/bobtail out, and container in/container out. These transactions account for 86% of all transactions***, almost the same percentage as reported in [2].

Transaction Type	Bobtail in/Container out	Container in/Bobtail out	Container in/Container out
Mean	50 (40)	36 (38)	60 (61)
Median	39 (42)	24 (38)	54 (61)
75^{th} Percentile	60 (60)	40 (58)	80 (86)
90^{th} Percentile	98 (90)	81 (112)	109 (126)

Table 11: Truck Turn Times (in Minutes) by Transaction Type.

*** Transactions with "unknown" load excluded.

For comparison we have included in Table 11 the corresponding statistics shown in [2] in parentheses. We noted that some of the turn times we obtained are higher while others are lower. The median turn times we obtained are consistently lower than the means, indicating that a small number of transactions experienced exceptionally long turn times. One possible explanation for these exceptionally long turn times is that those trucks required the use of equipment at the terminal during a time when the operators were at a break. A close examination of the transaction time data confirmed that many trucks that entered the terminal between 11:30 AM and 12:30 PM had transaction time over one hour. We also noted that the "Daily Summary By Shift" reports for Terminal X deducted break times and trouble times from their net turn time reporting [15].

Our computed turn times range from a low of 6 minutes to a high of 2 hours and 22 minutes, with a mean of 44 minutes and a median of 33 minutes. These mean and median turn times are much lower than the 72 and 44 minutes, respectively, reported by Monaco and Grobar [8]. Possible reasons for the difference may include: (1) Different terminals were used in the data collection for the two studies, and (2) Turn times have improved since their studies in 2002 and 2003 as a result of the implementation of extended-hour operation and a terminal gate appointment system at Terminal X used in our study.

Turn Time Distribution

We have attempted to fit the turn time data with four different distribution functions, as we did for the interarrival times of truck arrivals. We followed the same procedure as described in the Arrival Patterns section, and computed for each turn time data set the maximum likelihood estimates, the cumulative distribution function, the probability density function, and the K-S statistic (KSSTAT) for a target distribution. Again four distributions were attempted: normal, lognormal, gamma, and exponential. The KSSTAT was used as a quantitative measure for comparisons among the distributions of our interest. The distribution with the lowest KSSTAT was chosen as the best fit distribution for plotting. An example of such as plot where lognormal was found to be the best fit among the four distributions attempted is given in Figures 7 and 8. These plots are for the turn times for trucks entering Terminal X from both the bobtail and the main entry gates during all four monitoring sections (Days 1, 2, 3, and 4 AM). We should note that this plot includes all truck trips identified during all three hours in the four monitoring sessions, thus reflecting some bias in favor or short transactions. There are a number of notable observations from the turn time distribution: (1) A truck trip to Terminal X (from arrival at the terminal to departure) may take as long as 3 hours. (2) The median turn time was significantly lower than the mean, indicating that a small number of transactions experienced exceptionally long turn times. (3) Even with the bias, over 15% of transactions took more than 60 minutes to complete. Hence the failed Senate Bill 761 introduced by Senator Lowenthal in February 2005 that mandated appointments and required a 60-minute turn time [2] may prove difficult to attain and need further study.

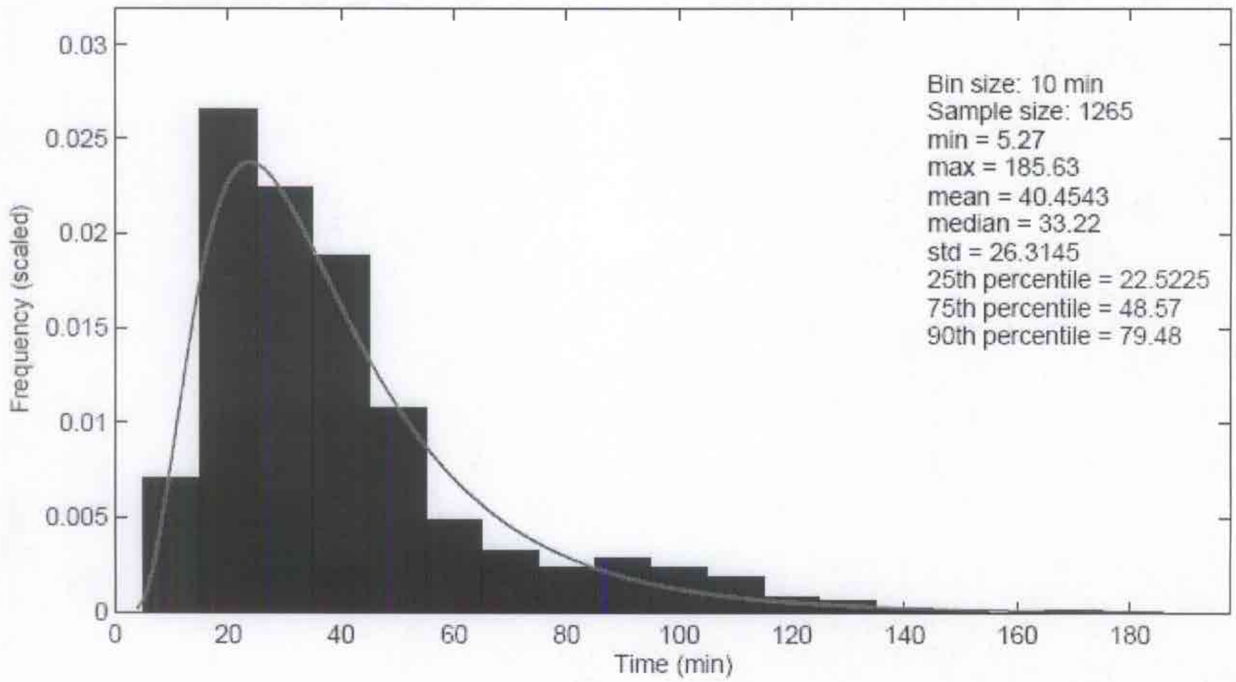

Figure 7: Distribution of Turn Times for Bobtail and Main Entries on All Days.

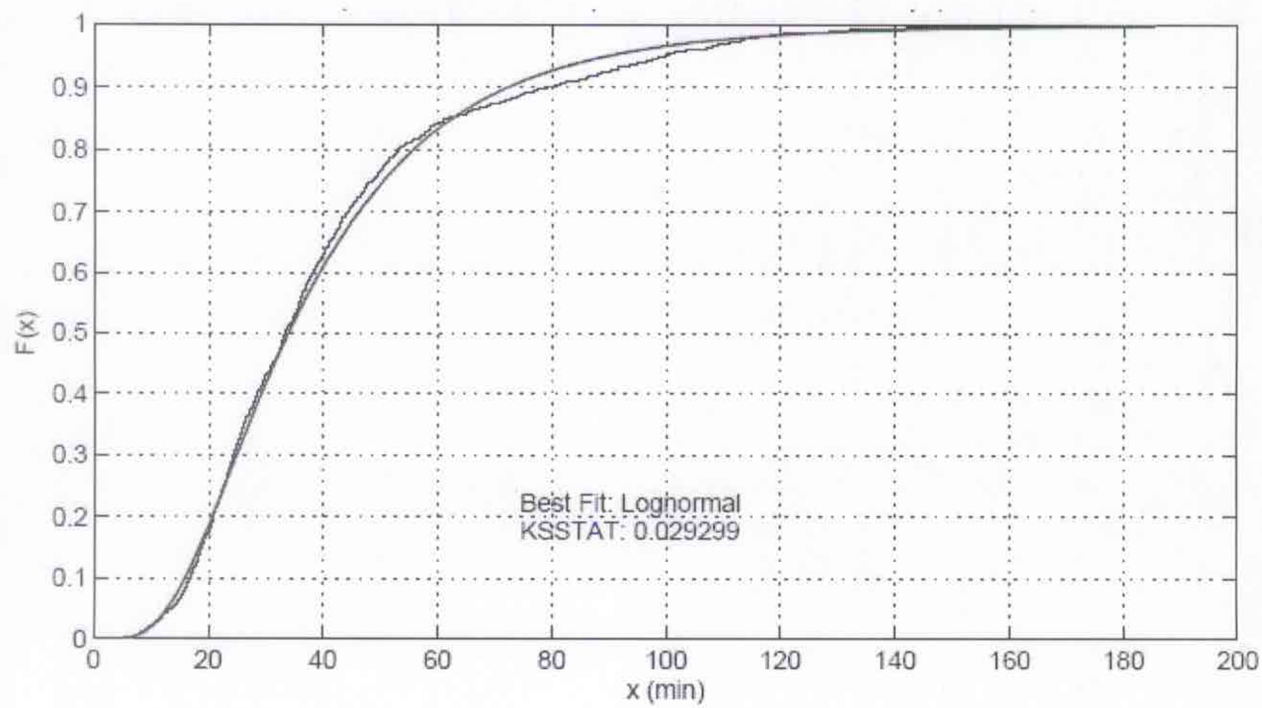

Figure 8: Empirical CDF of Turn Times for Bobtail and Main Entries on All Days.

Table 12 shows that lognormal appears to be the best fit for most of the turn times data set, with gamma a close second. The Lilliefors test is known to evaluate the hypothesis that X has a normal distribution with unspecified mean and variance, against the alternative that X does not have a normal distribution. For those data sets which lognormal was found to be the best fit, we used the lillietest routine in Matlab to test if X = log(*x*) is distributed normally, where *x* is the turn time. Seven out of the 10 test cases accepted H_0, the null hypothesis that the logarithm of the turn times data are normally distributed, at a 0.01 significance level. The remaining three cases rejected the null hypothesis, and the 5 cases where gamma was found to be the best fit were not tested.

Data Set	Best fit for *x*		Lilliefors test on log(*x*)	
	Lognormal	Gamma	α=0.05	α=0.01
Day1 Main+Bobtail		Best fit		
Day1 Main		Best fit		
Day1 Bobtail	Best fit		Accept H_0	Accept H_0
Day2 Main+Bobtail	Best fit		Reject H_0	Accept H_0
Day2 Main	Best fit		Reject H_0	Reject H_0
Day2 Bobtail	Best fit		Reject H_0	Accept H_0
Day3 Main+Bobtail		Best fit		
Day3 Main	Best fit		Accept H_0	AcceptH_0
Day3 Bobtail		Best fit		
Day4AM Main+Bobtail	Best fit		Reject H_0	Reject H_0
Day4AM Main	Best fit		Reject H_0	Reject H_0
Day4AM Bobtail	Best fit		Accept H_0	Accept H_0
AllDays Main+Bobtail	Best fit		Reject H_0	AcceptH_0
AllDays Main	Best fit		Reject H_0	AcceptH_0
AllDays Bobtail		Best fit		

Table 12: Best-fit and Lilliefors Test Results for Truck Turn Times

Conclusions and Lessons Learned

The rapid growth in cargo volume at the Los Angeles/Long Beach Twin Ports in recent years due to the high growth in trade with China and other Asian countries has led to serious concerns, among others, on port capacity limits, traffic congestions in the surrounding areas and beyond, pollution, etc. A large portion of the operations at the ports involves trucks coming to the terminals for drop off or pick up of containers. Due to the significant impact of these truck traffics on the roadway congestion and air pollution, the need for efficient service for these truck operations cannot be over stated.

Numerous studies are being conducted in order to help formulate improved policies and identify operational changes. Such studies, current or future, relies on an accurate understanding of the existing performance in terms of terminals' service to the arriving trucks. In this project, we used digital imaging technology to track truck traffics at a specific terminal in the twin ports. The results of these tracking activities were a series of complete truck trips from arrival to the terminal entry (bobtail or main gate) through admittance with a ticket issued at the pedestal stations and finally departure at the exit gate. Each complete truck trip provides a good picture of the time it took for the truck to wait till admittance, the time for the truck to flow through the terminal ground for the transaction it came to the terminal for, and the total turn time for that particular transaction. A series of monitoring sessions that covered the bulk of the day-time operations of Terminal X where we conducted our data collection activities provided us useful data for a better understanding of the current service level to the truckers. Below are some of the findings from these data:

1. While arrivals to the terminal have highs and lows, and appear to peak around mid morning, mid afternoon and early evening, the arrivals seem to be fairly even throughout the day. It will be interesting to find out if, and to what extent, this result can be attributed to the adoption of an appointment system for truck transaction.
2. No real line was formed outside of the terminal ground during all 5 monitoring sessions we had conducted in April and May, 2006. Based on the terminal's gate moves weekly volume data in 2005, April and May are the months with average volume (i.e., neither particularly heavy nor light). Service level from entry through admittance at pedestal is therefore deemed satisfactory since no truck had to wait for entering the terminal ground during our entire monitoring. Indeed, our statistics show the mean wait time (the time from a truck's arrival to the driver receiving a ticket for the trip's transaction) was 9 minutes, and the 90^{th} percentile was 22 minutes.
3. Trucks spent on the average 35 minutes to flow from the pedestal to exit, with the 90^{th} percentile being 79 minutes. These numbers are a lot higher than the 20-25 minutes average transaction time often cited by terminal operators. We noted that many terminal operators' daily turn time reports deduct break time and trouble time to arrive at a net turn time. For an operation that requires equipment during a break time, the transaction is bound to take a long time due to idle waiting, which is typically not reflected in terminal operators' turn time reports. Our data show that some transactions may take more than 2 hours to turn around.
4. The time it takes before it can get out of the terminal depends on what it needs to do inside the terminal ground. Our statistics show, and confirm the finding in [2], that a container in/container out transaction takes the longest time, compared with bobtail in/container out and container in/bobtail out type transactions. This result is reasonable since a container in/container out type transaction is most likely two operations in one single trip. The truck brings in a container to drop off and then picks up another container before leaving. A dual-move trip is expected to take longer than a single-move trip. The mean turn time for a container in/container out type trip is 60 minutes. An almost identical mean was reported in [2].
5. The lognormal distribution appears to be a good fit, at least visually, for both the interarrival times and turn times data. However, the goodness of fit using lognormal cannot be confirmed statistically for all cases. Our tests of goodness were accepted at a significance level of 0.01 for 7 of the 14 turn time series. More tests will be needed.

Some lessons we have learned from the project are worth reporting:

1. The concerns of student fatigue and exposure to pollution dictate that a 3-hour shift may be an optimal choice for each monitoring session. However, the adoption of the 3-hour shifts caused truck trips captured in Hour 3 (perhaps even Hour 2) of each shift unusable due to consideration of biasness. A compromise may be to still adopt 3-hour shifts that take place all on the same day, and set up two teams to take alternating shifts so that the monitoring can continue for a total of 9 hours, with potentially 8 hours of usable truck trip data for statistical analysis.
2. It turns out trucks are able to make multiple trips within our monitoring duration. Recognizing this possibility should reduce the chance of mismatching the entry of an early trip with the exit of a later trip which will yield an erroneous turn time.
3. The use of truck color and truck profile was found to be extremely helpful in keeping the number of potential choices for a match manageable. However, care must be exercised in providing the color choice and profile choice. When there are too many choices, the odds of judgment errors in picking the right choice could be high, especially when different lighting angles may cause very different colors to appear in the picture.
4. The development of the web interface application enabled the time-consuming task of truck matching to be divided and assigned to multiple users who can work from home, and work independently. For every entry truck displayed on the right frame that the user is to find a truck trip, user first chooses to match trucks captured at the pedestals. The application was designed to present the most likely choices of trucks on the left frame for the user to examine and select. The possible matches displayed are those with the same color and profile as the target truck and only pictures with a timestamp later than the target truck. The exit gate photos of like trucks with a timestamp later than the pedestal are then presented, examined and an exit match was selected. A complete truck trip is then inserted into the database. The current design of the application deletes the truck picture from the choice list once it is selected and inserted as part of a truck trip. However, this design may cause confusion when the user tries to double check his/her selection before finalizing the current truck trip since the actual selection is no longer present on the choice list. The application's usability may improve if we keep the actual selection on the choice list in the left frame while showing the selected truck as part of a truck trip on the right frame.

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