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16. Abstract

Inefficient use of drayage trucks results in negative externalities in the form of pollution and congestion. A clear awareness of the current state of drayage efficiency is especially important in Southern California since the cargo volume at the Ports of Los Angeles and Long Beach has just about recovered to its previous peak since the 2007-2008 financial crisis. A full measure of this awareness can only be obtained through detailed tracking of drayage activities. GPS tracking has been used for fleet and asset management, and can certainly be adopted for tracking truck movements. Data obtained through GPS tracking, however, can provide detailed information of where and when a truck has been, but not what a truck is doing at a particular location. Such information would require driver inputs. Tablet computers provide an ideal platform for the design of an electronic on-board recorder that supports both GPS tracking and touch screen input. In this report we will present our experience with the development of such a device, and findings from the data collected through its deployment.

A thorough understanding of drayage inefficiencies and their causes, and the freight flow pattern in a given area will not only provide useful data for the truck industry to devise strategies for productivity improvement, but also help stakeholders in supply chain management, including the ports and terminal operators, to identify the sources of inefficiency in drayage, quantify the impacts of these inefficiencies and develop solutions. Such understanding would be especially important in the Southern California area where the largest port complex in the United States is located and where a large and growing population resides.

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DISCLAIMER

Tracking Truck Flows with Programmable Mobile Devices for Drayage Efficiency Analysis

Final Report

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Principal Investigator
Shui Lam

Research Assistants
Byung Lee
Jay Patel

California State University, Long Beach
Department of Computer Engineering and Computer Science
Long Beach, CA 90840
Tel: (562) 985-1552
Fax: (562) 985-7823
E-mail: shui.lam@csulb.edu

METRANS Transportation Center USC CSULB

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DISCLOSURE

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INTRODUCTION

Port drayage deals with the short-haul transport of containerized cargo to or from an ocean terminal in a port complex. It is a subsector of the trucking industry and is a vital link in the nation's supply chain. The twin ports located in the San Pedro Bay of Southern California, Port of Los Angeles and Port of Long Beach, represent the largest port complex in the United States [1], and is considered the 9th largest port facility in the world in terms of volume [2]. The Port of Los Angeles has handled an average of 7.8 million 20-foot equivalent container units (TEUs) per year over the last 10 years [3], and Port of Long Beach's average yearly volume over the last 10 years has been 6.4 million TEUs [4]. They represent a combined market share of 61.4% of cargo transportation in all West Coast container ports in 2014 [5].

Containers arriving at a marine terminal may be imports, which will need to be picked up for delivery, or exports, which will need to be loaded onto a container ship and be sent to their destinations. These containers may be loaded with goods, or may be empty. Containers traveling to or from remote destinations are typically moved by rail. The San Pedro Bay twin ports together account for approximately 40% of the U.S. international container volume, and 50% of the cargo unloaded at the ports is bound for local Southern California markets [6]. Those imports for local distributions and exports from local shippers are handled by drayage trucks, which are the focus of this study.

Drayage efficiency is of great interest not only to direct participants in the supply chain but also to the public. Given that all port drayage trucks run between the port complex and surrounding areas within short/medium distance, it is a very visible segment of freight transportation and is often seen as major cause for negative externalities such as pollution and congestion. A measure taken by the Ports of Los Angeles and Long Beach in recent years to counter these negative externalities is the Clean Trucks Program (CTP) as the cornerstone of the Clean Air Action Plan, which imposed phased-in requirements for all trucks to meet EPA emissions standards. The mandate to meet the 2007 Federal Clean Truck Emission Standards has largely been met according to the Port of Los Angeles Sustainability Report 2013 [7].

Compliance with the CTP does not come cheap. The increased costs place even more pressure on the drayage industry to operate efficiently. Moreover, port drayage is still perceived as being relatively inefficient by firms and drivers who bear long delays in their operations and the public who experience congestion on the roadways. In contrast, PierPass, a firm created in an attempt to mitigate congestion by imposing fees on trucks that enter/leave port terminals during "peak" hours, alleges that these trucks are fairly efficient, making approximately 4 trips in and out of the ports daily. This lead us to ask the question, "What is the current state of port drayage in Southern California?" The significance of this question is more obvious than it was a few years ago with container volumes in the twin ports just about to recover to previous peaks, as evident in Table 1 [3,4].

Table 1. Container Volume at the Ports of Los Angeles (POLA) and Long Beach (POLB)
(Numbers shown are in millions of TEUs)

Year	POLA	POLB	Total	Change from previous year	% Change
2003	7.1	4.7	11.8	1.2	11%
2004	7.3	5.8	13.1	1.3	11%
2005	7.5	6.7	14.2	1.1	8%
2006	8.5	7.3	15.8	1.6	11%
2007	8.4	7.3	15.7	-0.1	-1%
2008	7.8	6.5	14.3	-1.4	-9%
2009	6.7	5.1	11.8	-2.5	-17%
2010	7.8	6.3	14.1	2.3	19%
2011	7.9	6.1	14.0	-0.1	-0.7%
2012	8.1	6.0	14.1	0.1	0.7%
2013	7.9	6.7	14.6	0.5	3.5%
2014	8.3	6.8	15.1	0.5	3.4%
2015	6.1 (to Sep)	5.4 (to Sep)	11.5 (to Sep)	0.1 (YTD)	0.7%

A full measure of the current state of drayage efficiency and future changes as trade volume grows can only be obtained through detailed tracking of drayage activities. Drayage efficiency may mean different things for different stakeholders. For a marine terminal, efficiency may be measured by the average number of moves that port drayage can perform in a day. For a shipping company that provides drayage services, it may mean the average number of drayage trips a driver can make in a day. For shippers who are waiting for their goods' delivery it may mean how long it takes from the time they request for the service to the goods' arrival. For the general public it may mean that roadways are not congested by the large number of container trucks on the road and air quality is not degraded by these trucks. Finally, for legislators and government officials it means no complaints about traffic conditions or health issues related to drayage operations at or near the port complex. Some of these measures of efficiency are quantitative while others are subjective. However, they can all be linked to a number of measures that can be quantified. Among these are the turn times at the port terminals and the speed of travel on the road. For drayage firms, the percentage of travel that their drivers make carrying loads would also be an important indicator of the efficiency of their drayage operations. Long-term tracking of these measures will provide all stakeholders a clear understanding of the current state and the trend of drayage efficiency, and a breakdown of these measures by transaction types and work types can help pinpoint the primary deficiencies in drayage operations. Efficient drayage operations can have significant impact not only on the overall costs in the supply chain industry but also the social costs in terms of congestion and pollution.

A prototype tracking technology was developed and tested on a limited number of drayage trips for feasibility investigation [8]. The objective of this project is to further develop this technology based on the pilot experience, feedback from the participating truck driver, and conversations with drayage staff so that it can be deployed in drayage trucks to track the trucks' movements as well as associated drayage events with as little driver interaction as possible. The development efforts and the outcomes of deployment are described in this report.

The remainder of this paper is organized as follows. We first give some background and the motivation for the project. We then follow with a detailed description of the technology development, including hardware selection and software design. These are followed with sections on data collection and detailed analysis of the collected data. We will then offer some observations based on our experience through the project and some concluding remarks.

BACKGROUND AND MOTIVATION

Southern California has been well known for its smog problem for many years, and is the home of the Ports of Los Angeles and Long Beach. Given that all port drayage trucks visit the port complex, drayage is a very visible segment of freight transportation and is often targeted as a major source of common negative externalities that include congestion and air pollution. The issue became especially acute when the twin ports experienced rapid growth due to expanding trade with Pacific Rim countries in the late 1990s and early 2000s. Port authorities at the twin ports responded with a number of measures that included the offering of alternative maritime power for vessels to plug in, so that the engines need not stay on during a vessel call, and the CTP which aimed at gradually phasing out trucks that do not meet the 2007 EPA emission standards. Both measures had the desired effect of reducing air pollution. However, the congestion issue persists. In a presentation at the 2014 Port Stakeholders Summit in Baltimore, Maryland [9], Kellaway presented a pessimistic view of the current state of the drayage industry and referenced a finding in 2012 which showed that delays for trucks at port terminals wasted a total of 15 million hours. A *Journal of Commerce* article in 2015 reported that "Harbor truckers in Los Angeles-Long Beach continue to experience long delays at the ports," and the "worst delays are not spent waiting in long lines at the terminal gates, but rather inside the terminals." [9] The statement was based on turn time statistics released by the Harbor Trucking Association as part of the Association's ongoing truck mobility project.

Many factors may contribute to inefficiency in drayage activities. These include long queuing at terminal entrances, long waits for the delivery of containers in the terminal due to ineffective scheduling of equipment and workers and/or troubles in locating the container, slow driving on the road due to traffic congestion, cumbersome procedures that drivers need to follow to complete their task, and so on. Inefficient drayage leads to low throughput at port terminals and for shipping companies, impacting productivity of the entire supply chain, which eventually translates to high costs for consumers.

Any attempts to fix problems in port drayage and improve its efficiency requires a thorough understanding of the current state of operations. One can acquire a first-hand knowledge of what goes on during a particular drayage operation by accompanying a truck driver in a drayage trip. This approach is of little use, however, not only because an investigator can only tag along on a limited number of trips but also problems may not arise during those trips that the investigator tag along. The next best thing available is GPS tracking devices. Many commercial tracking products and services are available on the market, see [11, 12, 13] for example.

While these tracking devices can allow one to pinpoint where a truck is at each given time, it does not tell an investigator what the truck is there for. Such information would have to be provided by the driver. Therefore, any device to be used for tracking drayage operations would need some mechanism for driver inputs. Browning et al. [8] implemented a prototype application in 2011 on a 7" tablet computer that performed periodic logging of GPS locations and recorded driver inputs for relevant events during drayage trips. The device was used in 18 trips over five days and the logged data was collected for analysis. While the sample size in these test runs is too small to generate reliable statistics, the method suggests that it is possible to collect and produce useful data for a meaningful analysis. The experience in this limited study also tells us that minimizing the interaction between a driver and the application is crucial in any study of this kind. To this end, we have identified three aspects in our design that can help automate significant portions of the logging activities and reduce the need for driver interaction: (i) automate the start/stop of the logging application on the mobile device in response to the start/stop of the truck's engine; (ii) create a geofence[1] of every marine terminal in the twin ports and every warehouse that participating drivers will visit, which will enable us to construct each drayage trip with its points of origin and destination from the GPS data; and (iii) limit the user interface for driver input to one single screen. With these ideas in mind we are able to come up with a design for the recorder that requires driver inputs only for the type of work performed on the trip using a very simple user interface. Besides the mobile recorder, a complete tracking system also requires applications that run on a server to receive, interpret, store, retrieve, organize, and visualize the logged data, and perform various analyses on them. A detailed account of the design and development of the system is given in the next section.

HARDWARE SELECTION AND APPLICATION DEVELOPMENT

Requirements and Functional Specifications

Based on our analysis of the need for such tracking technology, we concluded on the following requirements:

- The technology should involve two parts: a mobile device to be placed inside a drayage truck for collecting event-tracking data and a computing server for the maintenance and analysis of the collected data.
- The mobile device must support location and time tracking.
- Driver input is needed to provide the purpose of each trip as well as to record special events when they arise.
- The mobile device must be programmable so that we can implement applications on it to provide functionalities that include: driver inputs, feedback to drivers, storage of events, and communication with a server via an internet connection.
- The technology must involve as little driver interaction as possible, hence the user interface should be simple, clear and minimal, and communications between the mobile device and server should be automatic without driver involvement.

[1] A geofence is a virtual perimeter around a geographical area. In our case, we create a geofence of a terminal (or a warehouse) as a polygon by identifying the GPS location points of its geographical perimeter. Using an algorithm to determine the whereabouts of a logged GPS point with respect to the polygon, we can infer if a truck is entering or exiting a terminal (or warehouse) and the time that this occurs.

- A computing server is needed to provide three types of services: (i) receive data from mobile devices and save data in a database; (ii) provide remote access to stored data in the database; and (iii) provide functionalities for the extraction, visualization and analysis of the collected data for drayage efficiency investigation.
- As part of the goal to minimize the need for driver interaction, every logged GPS location should be interpreted automatically to determine its relative position with respect to the port terminals and warehouses that the driver may visit. With these interpretations we can identify the timing of such events as entering and exiting a port terminal (and which terminal) as well as arriving at and departing from a warehouse (and which warehouse). These interpretations require information about relevant port terminals and warehouses, and the creation of geofences for these sites.
- Also as part of the goal to minimize the need for driver interaction in the tracking, the start and stop of the data logging on the mobile device should be automated in response to the start and stop of the truck engine that represent the beginning and end of a drayage trip from a point of origin to a point of destination.

We designed the software and selected the mobile device based on the above requirements. Our development and selection results are reported in the remainder of this section.

Mobile Devices

We have decided to use a tablet for our tracking for two reasons:

- It provides a large touch screen for easy driver input as relevant events occur.
- Software development tools are readily available.

The main platforms for tablets include iOS and Android, with Microsoft's mobile Windows OS running as the third contender. The market share of the mobile Windows OS for tablets in the beginning of 2012, when our prototype device was designed, was a minuscule 1% [14]. We had therefore at that time focused our consideration on the two major players, iOS and Android. To build an application on iOS, we require an Apple MacBook and its own IDEs (Integrated Development Environments), such as XCode. Applications on iOS can only run on Apple products. On the other hand, Android Software Development Kit (SDK) [15] is open-source, and applications are built to run on products that conform to this open standard. Many companies, including Samsung, LG, Amazon, Google, etc., make mobile devices on the Android platform. Therefore, it would be easy to change devices as new hardware becomes available. IDEs such as Eclipse and Android Studio [16], and both Java and C++ programming languages can be used for the mobile app development. We had thus settled on the Android platform for the development of our prototype tracking technology.

The market share of the mobile Windows OS for tablets has increased slowly since 2012 to 7% in the first quarter of 2015, with those of Android and iOS being 69% and 24%, respectively [17]. Windows OS' current and projected market shares to the year of 2019 place it in a distant third place in tablet computing. With the dominance of Android in the market, and our consideration on the development environment as well as the use of Android in our prototype, we decided to stay with Android for our current attempt. Our final choice came down to the 10.1" LG GPad LTE after a comparison among competing alternatives based on the essential features and price. The LG GPad 10.1 is equipped with Snapdragon 600, a quad-core processor with 1.5 GHz aped, 1GB RAM and 16 GB storage. It runs the Android 4.2.2 Jelly Bean operating system, and supports SD card up to 64 GB, LTE, GPS, and Google Maps [18]. The device's support for LTE (for Long-Term Evolution), a standard for wireless communication for high-speed data for mobile devices, and the acquisition of data service from an ISP are required since the mobile application must work anywhere in the United States.

To achieve the automation of the start/stop of data logging on the mobile device, we purchased a Kinivo BTC450 Bluetooth that signals a mobile device when the truck engine is turn on/off. Once the Bluetooth and the mobile devices are paired, the Bluetooth device plugged into the vehicle's cigarette lighter automatically initiates connection to the mobile device, which triggers the start of the mobile application and GPS service.

Software Developments

Three applications have been developed for this project: a mobile application for the Android device, a server application that responds to requests from the mobile device and to a web client, and a Java program for the extraction, organization, filtering, and exporting of the logged data into Excel files for easy analysis.

Mobile Application

Software is needed on the mobile device to track activities and to send the collected data to the server either in real time (if internet connection is available) or in deferred mode. Activities tracked and logged include the truck's GPS location in regular intervals (one minute used in our implementation), inputs on the device by driver as relevant events occur (e.g., load picked up/delivered, empty picked up/delivered), as well as voice recording by the driver as needed. All logs are time-stamped. Figure 1 shows a high-level architecture of the mobile application.

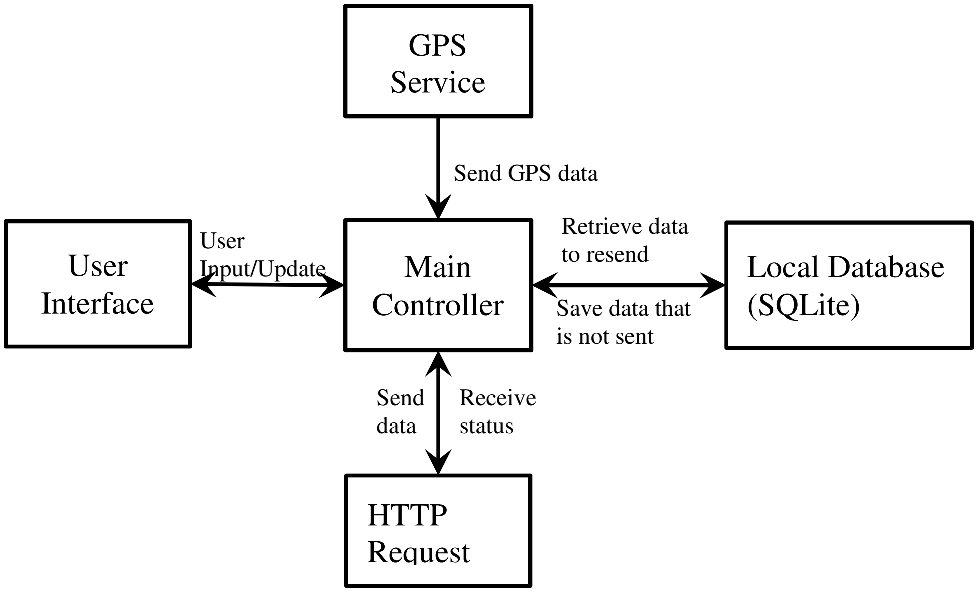

Figure 1. A High-Level Architecture of the Mobile Application.

As shown in Figure 1, the main controller instantiates the GPS service, the user interface (UI), HTTP request and local database. The GPS service creates a GPS datum in some predefined regular intervals, saves it in a data structure and sends a message to the main controller so that it can signal the UI component to display the GPS log event. The UI receives a user input from the touch, and signals the main controller to handle the input. HTTP request tries to send data to the server; however, if it fails to send, it saves the data in the local database which is a temporary storage until the data is sent.

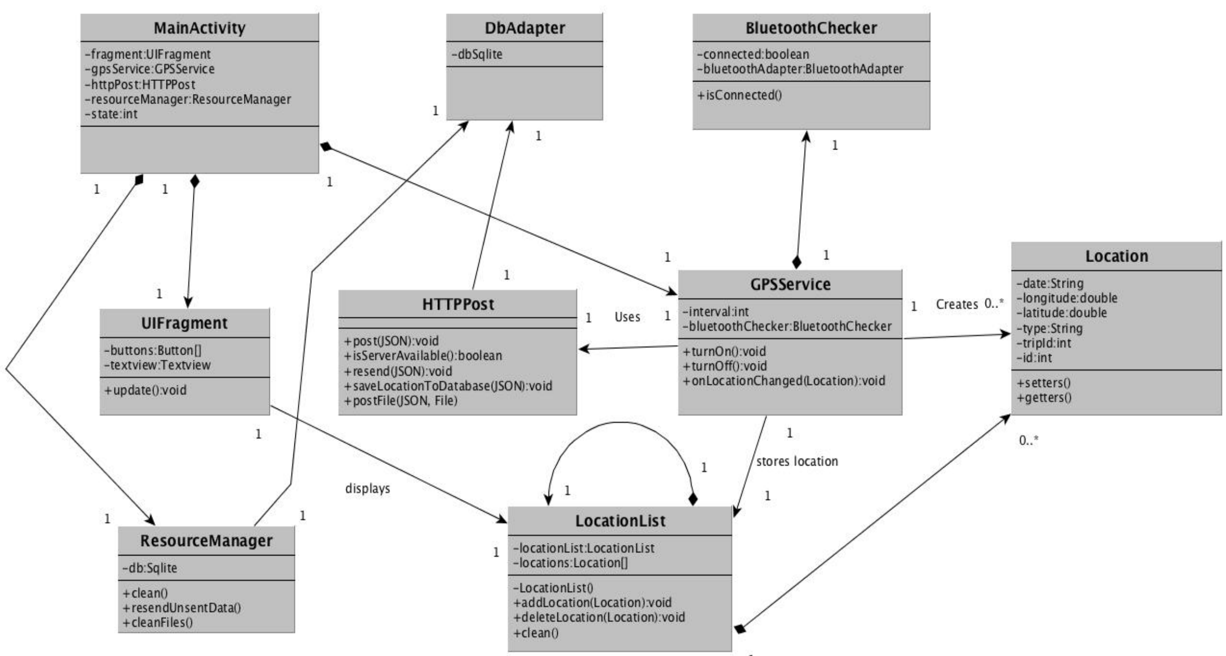

Figure 2. A Class Diagram for the Mobile Application.

A class diagram that depicts the logic in the mobile application is given in Figure 2. A main activity is executed first by Android when the application is on. The main activity instantiates a UI fragment, a GPS service and a resource manager. A UI fragment shows buttons for user input of events and a text view to display current logs as depicted in Figure 3. When buttons for events are clicked or touched, it sends a message to GPS service to manually request a current location. GPS service runs in the background and tracks a location. When the GPS service object manually or automatically logs an event, it creates a JSON object that contains data in a Location object with the MAC address and calls the post method in the HTTPPost object using another thread so that the main thread does not block for updating the user interface. At the same time, the Location object is saved in the LocationList object, and GPS service calls onLocationChanged method which broadcasts a message so that the UI fragment can update the text view. When the post method in the HTTPPost object is called, it tries to send the data created by GPS Service to the server. If it fails to send data due to internet connection or server problems, it creates a DbAdapter object which handles the database connection to Sqlite3 database and saves the unsent data by calling a method in DbAdapter. Also, files that are recorded are saved in the local storage. The unsent data is handled by Resource Manager which tries to send data again when GPS Service is not running. If Resource Manager successfully sends, it will delete sent data and files. Bluetooth Checker checks the connection between a Bluetooth device and a mobile device. Location and location list classes act as a model. Location encapsulates date, longitude, latitude, type, id and trip id. Location list is a data structure using an array list of location and provides application program interfaces (APIs).

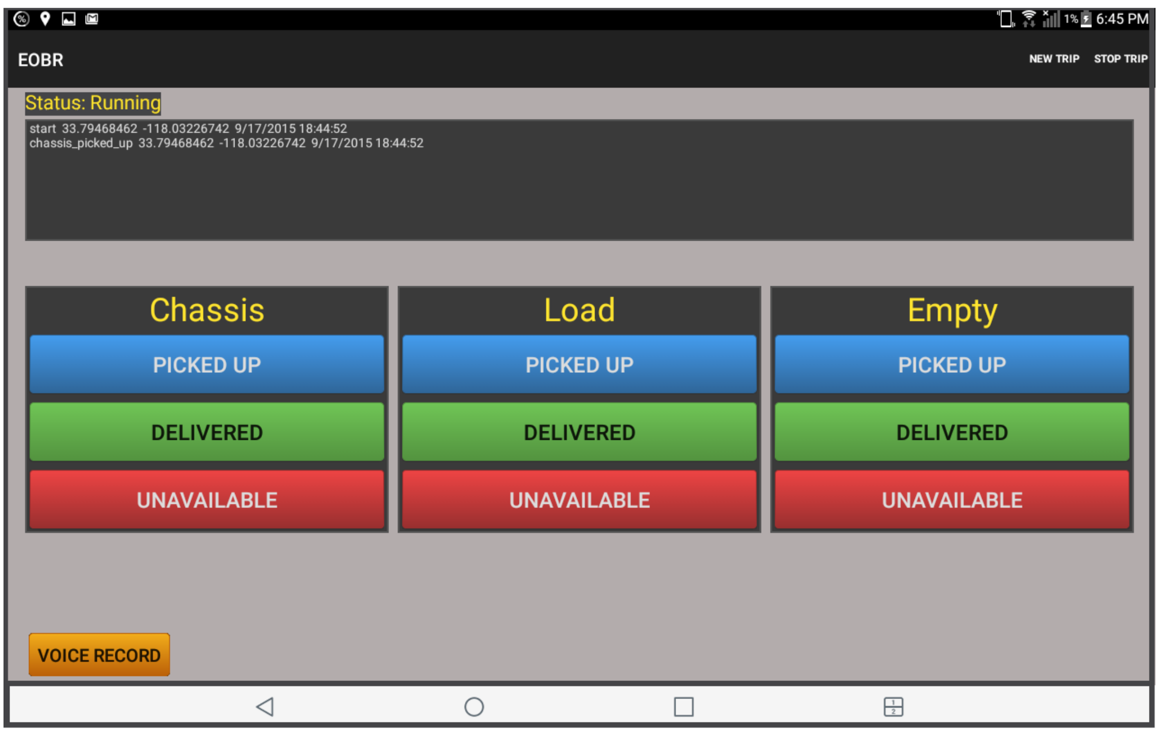

Figure 3. User Interface for the Mobile Application.

The touch screen as shown in Figure 3 was designed for use by drivers to record the task they performed on each drayage trip. It is the only UI that drivers need to handle. The tasks are grouped into three categories: chassis, load (loaded container), and empty (empty container). Each category has three buttons for the three major events: the item is picked up, the item is delivered, or the item is unavailable, and the buttons are colored for easy identification. A text area is allocated to display every log as it takes place. It can serve as a feedback to the driver so that he would know whether the button he pressed was in effect.

In addition, a “Voice Record” button at the lower left corner of the UI screen can be used by the driver to take a voice recording on some event that should be noted. A recorded voice message is saved as a file, which will be a part of an event logged with a GPS location and a timestamp. At the upper right corner is a pair of buttons that the driver can use to manually start and stop the application, when such manual operation is necessary.

Server Application

A server application is needed to respond to two different types of requests. The first type is for data sent to it from the mobile device, and the second type represents requests from a client to access the stored data using a web browser. The application is designed based on a client-server architecture as depicted in Figure 4.

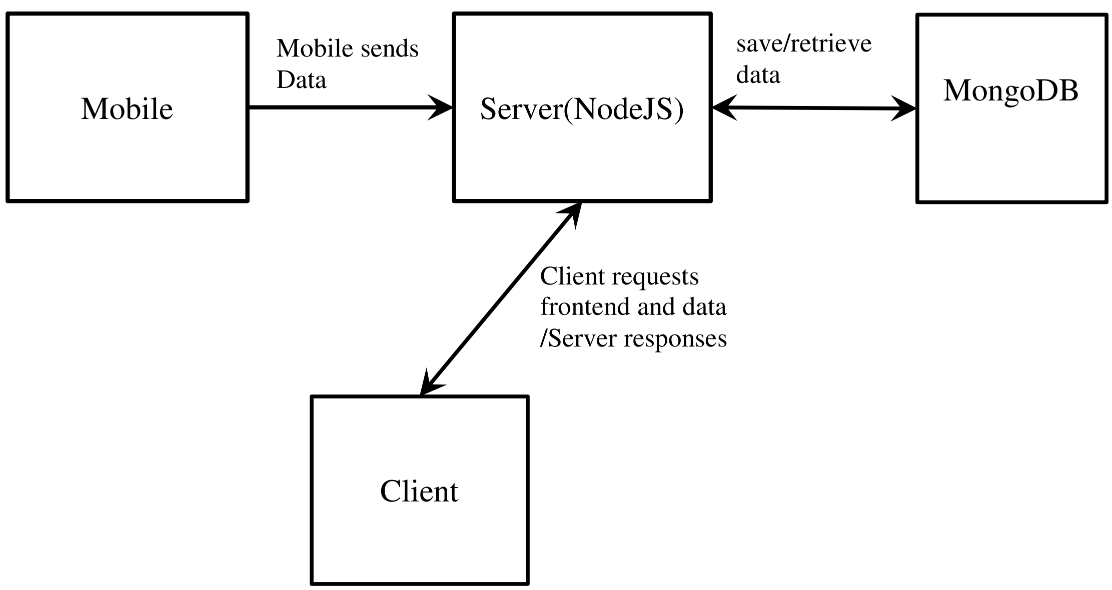

Figure 4. A Client-Server Architecture for the Server Application.

Upon arrival of data from a mobile device, the server application interacts with MongoDB [19] to store the data. All data sent from the mobile client contains a GPS location. The server application first interprets the location to determine the whereabouts of this point with respect to terminals in the ports as well as warehouses that the truck drivers may visit, using the Ray-casting algorithm [20] with pre-defined geofences. Proper interpretation of the GPS locations enables correct sequencing of state transitions as the truck continues to move.

To create geofences, we obtained addresses for terminals at the Ports of Los Angeles and Long Beach, and the warehouses and other consignees serviced by the drayage company where our participating drivers work. Given the addresses, we gather boundary points for those facilities using Google Earth, and create JSON objects for each geofence.

For the second type of request, a client makes the request using a Web browser. A request to retrieve data from a client results in a query to MongoDB for the retrieval. The retrieved data is passed to the server application, which manipulates the data, if needed, and sends it to the client. HTTP protocol is used for communications between client and server. The server application also provides a front end for data visualization on web browsers.

A user of the web application may select a trip from a trip list that identifies each trip with a "trip_id," from which all data associated with it can be retrieved. The data for the selected trip are displayed in a table as well as on Google Map. Google Map APIs [21] are used to load and manipulate the google map on the Web client. The selected trip data will be drawn and superimposed on the appropriate part of Google map. Moreover, the application also computes the distance the truck traveled between every two logged points, using the Haversine formula [22]. The UI of this Web client is shown in Figure 5.

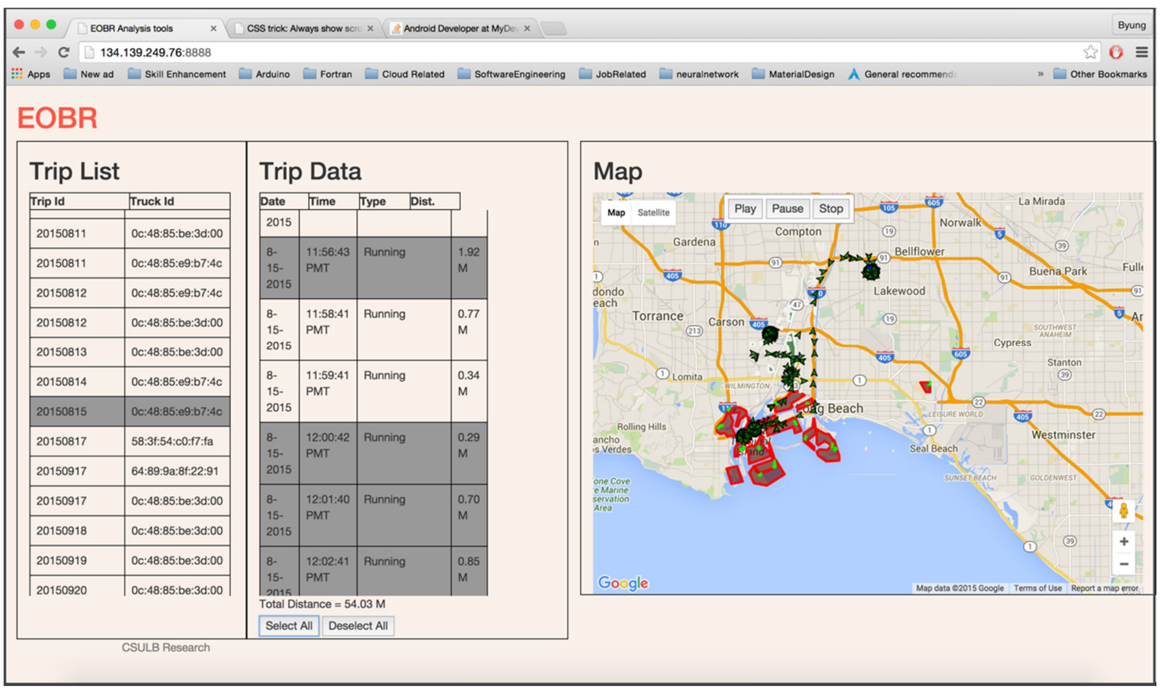

Figure 5. User Interface for the Web Client.

Application for Data Extraction and Organization

The third application we built is a Java program designed to help organize logged data into transactions, and extract selected data into CSV files which can then be displayed on Microsoft Excel. The application provides two tabs for its UI: the "Add Record" tab for the user to build transaction records, and the "All Data" tab that provides filtering options for the user to select transactions to display and to export the selected data to a CSV file. UIs for the two tabs are shown in Figures 6 and 7.

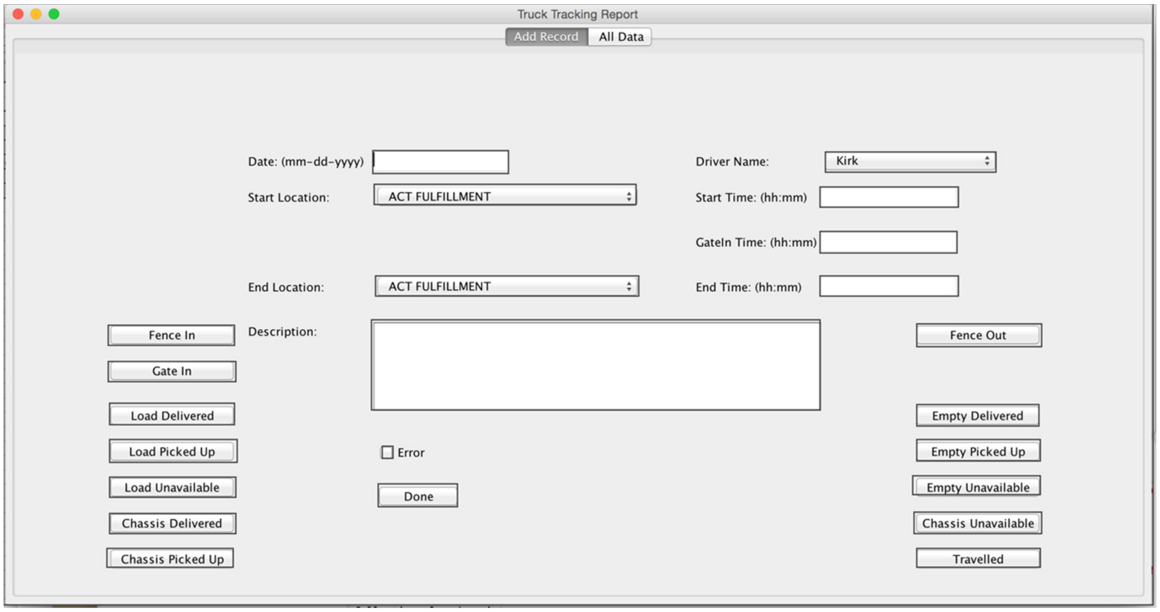

Figure 6. "Add Record" Tab of the Data Extraction and Organization Application.

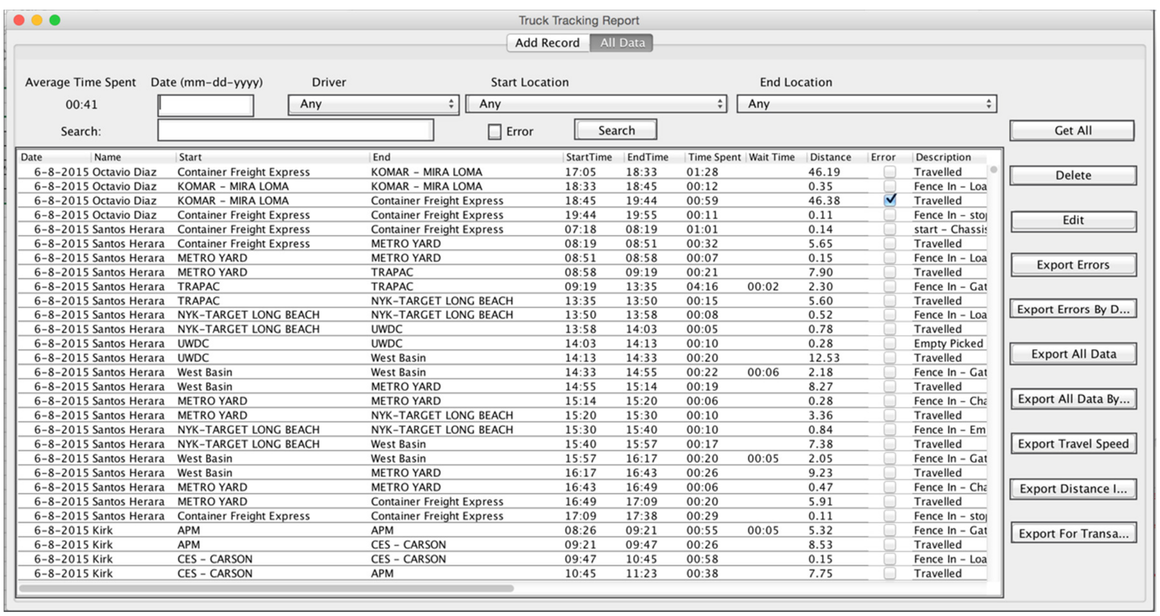

Figure 7. "All Data" Tab of the Data Extraction and Organization Application.

DATA COLLECTION

We have acquired an agreement with a drayage company to provide five drivers to use our device for tracking. The company has one of the largest drayage fleets in Southern California and has provided drayage services in the region for over six decades. Besides the transportation of loaded or empty containers to/from the Los Angeles metropolitan area, they also specialize in heavy container moves and volume transportation of marine containers to rail ramps. Moreover, they provide contract services to individual retailers such as Target for their drayage needs.

Our five drivers consist of two that run the heavy container corridor[2], one drays to near-dock rail ramps, one services Target warehouses, and one performs general store delivery in the Southern California region. We met with all five drivers on the morning of June 8, 2015, explained to them the objectives of our project, and gave simple instructions on how to use the mobile device. Tracking began on June 8 and spanned for a total of 9 weeks until August 12. We should note that not all five drivers have collected data for the entire 9-week duration for the following reasons:

1. Some drivers took vacations during that period.
2. Our plan to use a Bluetooth device to automatically start/stop GPS service on the device did not work out because the cigarette lighters on the drayage trucks have power regardless of whether the truck engines are on. Once this was realized, we asked the driver to use the manual start/stop button provided on the UI. Those who did not discover this issue missed the first day of tracking.
3. On a few occasions, a driver may have forgotten to recharge the device, preventing the day's tracking from taking place.

We monitored the data that the server received and found that the data collection was by and large smooth. The effect on the validity of the results caused by certain drivers missing tracking on certain days has not been assessed but may not be very significant since our analysis is not by driver or by day. However, in computing some of the statistics that require breakdowns of the data by various categories, the available sample became too small due to the limited duration and number of participating drivers in the tracking experiment. This problem can only be overcome when the tracking technology is fully automated so that drayage drivers would be willing to adopt it and missing data due to human errors would be avoided. We will elaborate on this point in later sections.

A button for "Voice Record" was provided on the touch screen in case of abnormality, e.g., driver having to wait for hours. Unfortunately this feature was rarely used, even when the collected data indicated exceptionally long transaction times were not uncommon.

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[2] To aid the movement of overweight ocean going containers, a number of city streets in and around the Ports of Los Angeles and Long Beach are designated as the heavy container corridor. Overweight vehicle special permit must be obtained for a truck to transport heavy load on the corridor. A map of the Port of Los Angeles heavy container corridor can be found in https://www.portoflosangeles.org/pdf/heavy_container%20_corridor.pdf. Trucks permitted to haul overweight containers on the heavy container corridor are sometimes referred to as heavy tags.

DATA ANALYSIS

Efficiency from the perspectives of marine terminals, drayage companies, and citizens concerned about traffic congestion and health issues related to air pollution can be linked to quantifiable measures that include terminal turn times and travel speeds of drayage trucks. These measures can be obtained readily from our GPS tracking data and driver inputs. While drayage companies may not have direct control over turn time at port terminals and travel speed on the road, a long-term tracking of these statistics will provide them with a trend of their operational efficacy. A breakdown of these statistics by transaction type and work type may also enable them to identify weakness in their work scheduling method and devise strategy for improvement. These statistics will also provide powerful concrete evidence that can prompt terminal operators to upgrade their facilities to lower turn times and legislators to enact laws that can help mitigate the negative impact of traffic congestion on health. In this section we describe the statistics that we have obtained from our collected data.

From the nine weeks of tracking by the five drivers, we have extracted a total of 2,405 transactions. A transaction can be a cycle in a port terminal or a warehouse, or a travel from one location to another location. All transactions have the driver's name, date of the transaction, from/to locations, start and end time, and distance traveled. A transaction in a port terminal includes the terminal name, entry time, exit time, turn time, and queue time. Queue time in a terminal transaction refers to the time from the truck's entry to the terminal till the time it gets past the pedestal and proceeds to the job area, and turn time is the elapsed time from a truck's entry to its exit from the terminal. A transaction in a warehouse does not have queue time since we are unable to define where queuing at a warehouse begins. We also computed the total distance a truck traveled while in a terminal.

Terminal Transactions

Some general information about these transactions are:

- A terminal transaction begins when a truck enters the geofence of a terminal and is queuing to proceed to the pedestal, and ends when it moves outside of the terminal's geofence.
- 12 terminals are covered in these transactions. They are listed in Table 2.
- Arrival times at these terminals in these transactions are between 7:00 am and 8:30 pm.
- These transactions include 5 single move types and 4 dual moves types:

  Single moves
  1. Load picked up
  2. Load delivered
  3. Empty picked up
  4. Empty delivered
  5. No specific job (Some transactions are found to relate to chassis, others have no specific job stated. Hence they are not placed in any category.)

  Dual moves
  1. Load delivered and load picked up

2. Load delivered and empty picked up
3. Empty delivered and load picked up
4. Empty delivered and empty picked up

Table 2. List of Terminals Covered in Collected Data.

	Terminal
1	APM
2	Eagle Marine Services (APL)
3	Seaside Transportation Service
4	West Basin
5	TraPac
6	Total Terminals
7	SSA Terminals
8	Pier C Berth C60-C62
9	Long Beach Container Terminal
10	International Transportation Service
11	Pacific Container Terminal
12	Yusen Terminal

Of the 2,405 transactions extracted, 533 are terminal transactions. However, due to human errors in the use of the mobile devices, 41 transactions were found to be misleading and hence excluded from our analysis.

The human errors include:

- Driver started the mobile application after the truck was already inside a terminal.
- Driver stopped the mobile application right after the job but before exiting the terminal.
- Device ran out of battery.
- Driver forgot to press the button or pressed the wrong button on the mobile device to indicate the work performed.

With the remaining 492 transactions we computed turn time statistics, turn time and queue time by time of arrival at the terminal, as well as turn time and queue time by transaction type. The details are given in the following subsections.

Turn Time Statistics

Table 3 shows turn time statistics for all 492 terminal transactions as well as for individual terminals. The distribution of the turn times for all transactions is plotted in Figure 8. The plot also shows the data fitted with a lognormal distribution function.

Table 3. Turn Time Statistics. (All times are in minutes.)

Terminal	Sample Size	Mean	Standard Deviation	Median	25th Percentile	75th Percentile	90th Percentile	Min	Max
All terminals	492	88	64	68	40	124	182	9	409
Eagle Marine Services	52	38	27	30	24	46	58	9	182
West Basin	42	45	34	32	21	56	71	13	165
Pier C Berth C60-C62	2	46	18	46	39	52	56	33	58
Long Beach Container Terminal	35	64	48	52	27	90	123	14	196
Seaside Transportation Service	25	71	46	62	37	115	140	15	157
Total Terminals	39	94	59	76	49	128	176	20	247
Yusen Terminal	51	97	50	98	49	136	159	20	203
APM	80	100	62	90	54	137	189	16	336
SSA Terminals	71	108	69	93	54	145	209	15	331
International Transportation Service	17	109	62	104	62	116	184	29	268
TraPac	38	114	69	109	54	165	210	11	267
Pacific Container Terminal	40	122	83	108	56	175	207	16	409

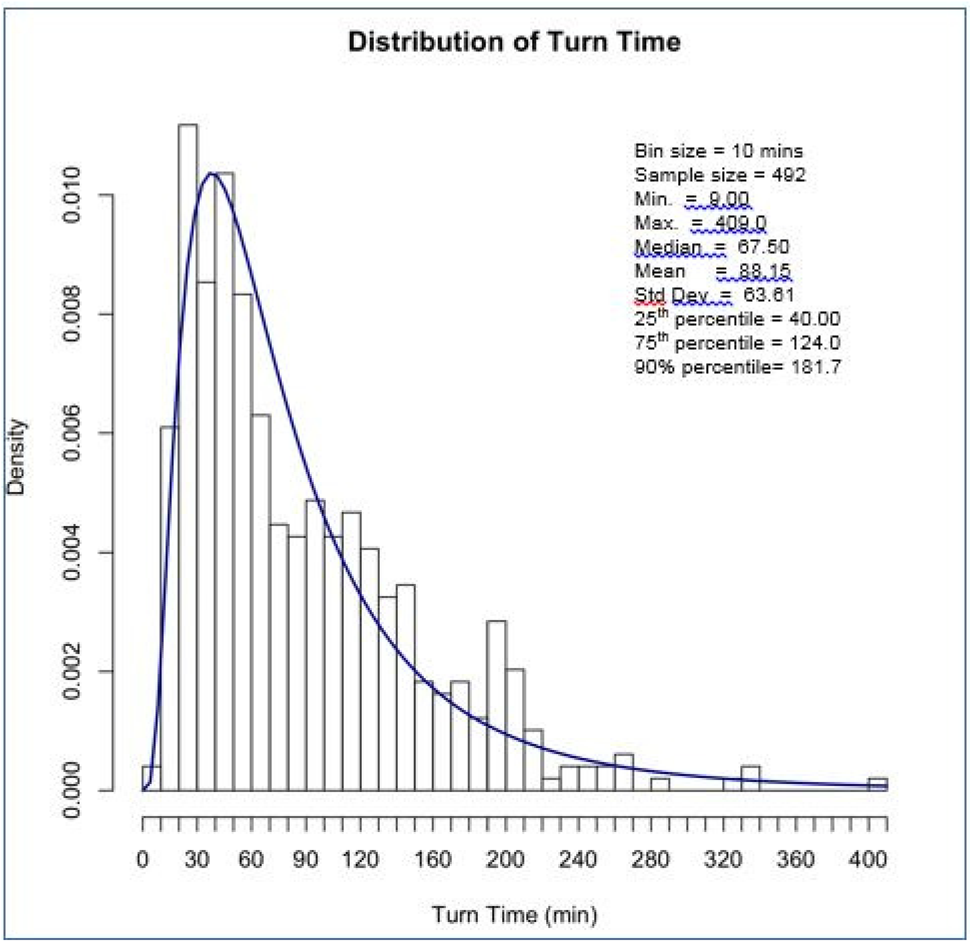


Figure 8. Turn Time Data Fitted with a Lognormal Distribution Function.

The overall average turn time based on these tracked transactions was 88 minutes, while the median turn time was a lot lower at 68 minutes. This is an indication that the turn time distribution has a long tail, as evident in the distribution plot. One quarter of the transactions in the port terminals took more than 2 hours, and 10% took more than 3 hours. These exceptionally long turn times are likely the results of certain trouble tickets the drivers encountered in completing the transactions. The "Voice Record" button on the touch screen of the mobile device was created to allow drivers to record instances of this kind. Unfortunately, this feature was rarely used, and hence we have not been able to identify the real reasons behind these extreme turn times.

These turn time statistics are much worse than the results found in several previous studies. The average turn time reported in [23] was 40 minutes and that in [24] was 38-61 minutes depending on the type of moves. Both results were based on monitoring of truck movements in the same terminal at the Port of Los Angeles. The average obtained by Monaco and Grobar [25] was 72 minutes.

PierPass, in its October News & Updates posted on Oct. 30, 2015, reported the average in-terminal turn times for truck transactions at the Ports of Los Angeles and Long Beach to be 47.0 minutes during day shifts and 51.2 minutes during night shifts [26]. The PierPass website states that these numbers were derived from RFID data, and excluded lunch hour, break time and trouble tickets.

A September 2015 article in the *Journal of Commerce*, however, reported that "The average truck visit in Los Angeles-Long Beach in August, from the time the driver arrived at the queue outside the gate until the transaction was completed and the driver pulled out of the terminal, was 89 minutes." [10] The average was obtained from the Harbor Trucking Association's ongoing truck mobility project. This average is comparable to our average of 88 minutes.

The turn time statistics for the 12 individual terminals in Table 3 are shown in increasing order of their average turn times. The shortest average turn time, as recorded during the tracked period, was 38 minutes at Eagle Marine Services, while the longest was 122 minutes at Pacific Container Terminal. We should note that the breakdown into individual terminals resulted in some terminals having very small sample sizes. For example, Pier C Berth C60-C62 has only 2 transactions and International Transportation Services has 17. The statistics obtained for those cases may not be very reliable.

Turn Time and Queue Time by Arrival Time at the Terminal

Just like traffic conditions are different at different times of the day, congestion at the ports may also be different in the same way. To confirm this, we break down the time during the arrival hours into 30-minute intervals, and find average turn time for trucks arriving during each interval. The results are shown in Table 4 and in a histogram in Figure 9.

Table 4. Average Truck Visit Performance by Time of Arrival.

Arrival Time	Average (minutes)			Count
	Turn Time	Queue Time	Flow Time	
7:00	83	6	77	4
7:30	80	14	69	25
8:00	85	11	76	40
8:30	64	15	54	29
9:00	70	7	61	28
9:30	87	21	79	33
10:00	86	21	62	27
10:30	109	17	89	30
11:00	107	20	82	34
11:30	128	24	105	28
12:00	105	38	70	27
12:30	71	40	36	14
13:00	93	21	80	18
13:30	99	29	60	26
14:00	101	28	73	19
14:30	71	17	57	18
15:00	86	28	63	13
15:30	42	15	31	16
16:00	54	16	28	9
16:30	106	52	54	12
17:00	85	40	56	11
17:30	63	24	52	6
18:00	104	58	55	5
18:30	51	22	29	4
19:00	106	36	64	7
19:30	45	17	28	3
20:00	23	4	19	3
20:30	13	5	8	1
21:00				0
21:30	15	4	11	1

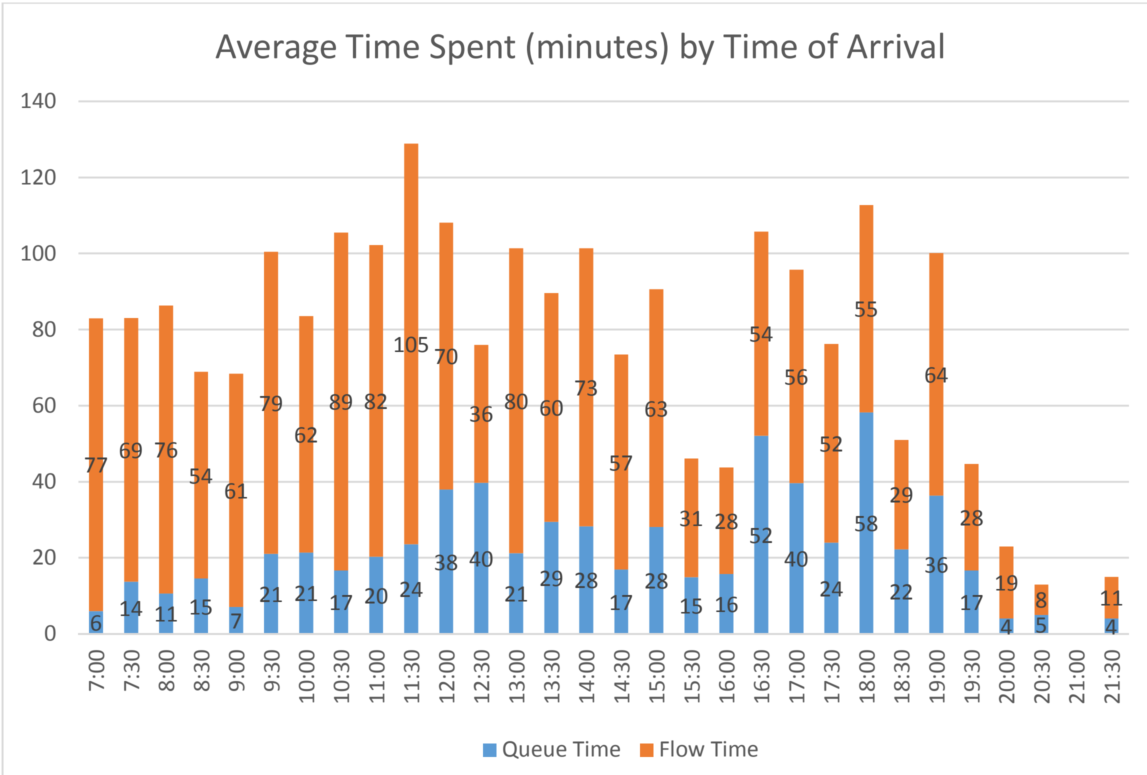


Figure 9. Average Time Spent at Terminal by Time of Arrival.

It should be clear from Figure 9 that the best time to arrive at a port terminal for a transaction is mid-afternoon, 3:30-4:30 pm, or evening when short queue times and short turn times can be expected. Trucks arriving around noon hours, 11:30-12:30, tend to suffer exceptionally long delays, possibly due to lunch breaks at the terminals. Congestion conditions at individual terminals may vary. Charts for average time spent at each of the 12 terminals covered in this tracking are given in Appendix A.

Turn Time and Queue Time by Transaction Type

We have cataloged five single moves and 4 dual moves transactions in all the terminal transactions. Some of the single-move transactions are related to chassis. However, the data collected for those were sometimes unclear and inconsistent so we labelled those as "No Specific Job" and excluded them in this section. For each of the remaining transaction types, we computed the average turn time and its components: queue time and flow time, and the results are shown in Table 5 and depicted in a bar chart in Figure 10. Flow time is defined as the time from when a truck gets past the pedestal until when the truck exits the terminal. Turn time is the sum of queue time and flow time.

From the count of each transaction type, we see that picking up load is the dominant type of work that drivers go to port terminals for. As shown in Table 5, there were 226 single-move transactions for "pick up load", 71 dual-move transactions for "deliver empty & pick up load", and 7 dual-move transactions for "deliver load & pick up load". Together they account for 64%

of all transactions. And these transactions tend to take the longest time, 100 minutes for the single move, and 126 and 106 minutes for the two dual moves. They occupy the top three positions in the ranking of turn times. The maximum turn time of 409 minutes also happened for a "deliver empty & pick up load" dual-move transaction. Average turn times for all other transaction types are much lower when compared to these top three.

Delivering empty containers also had a substantial count, a phenomenon that reflects the trade imbalance between the Pacific Rim and the U.S. The counts for the remaining 4 transaction types are relatively small.

Table 5. Average Turn Time and Queue Time by Transaction Type.
(All times in minutes.)

Transaction Type	Count	Average Queue Time	Average Flow Time	Average Turn Time	Maximum Queue Time	Maximum Turn Time
Load Picked Up	226	18	82	100	144	336
Empty Delivered	114	23	41	64	170	286
Empty Picked Up	7	16	44	60	43	125
Load Delivered	39	28	28	56	111	184
Empty Delivered - Load Picked Up	71	28	97	126	106	409
Load Delivered - Load Picked Up	7	27	79	106	89	256
Empty Delivered - Empty Picked Up	9	47	32	79	110	165
Load Delivered - Empty Picked Up	3	7	59	66	7	127
All Types		22	68	90		

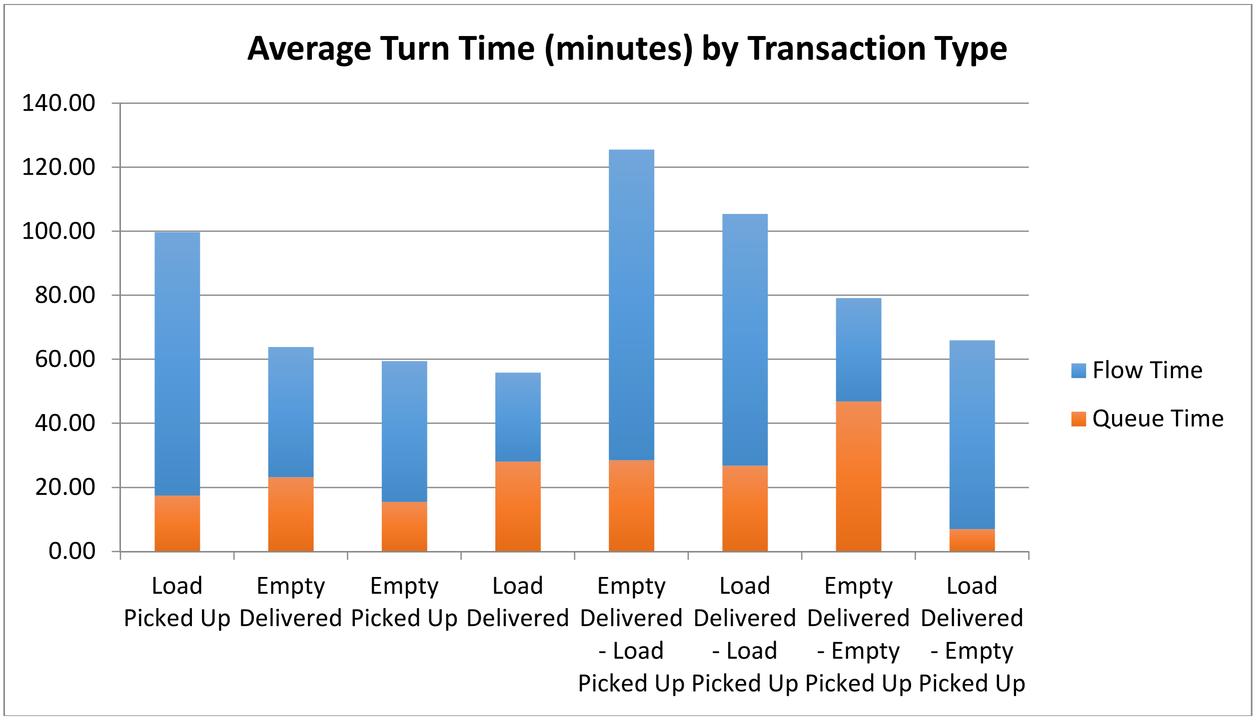


Figure 10. Average Turn Time and Queue Time by Transaction Type.

Travel between Two Locations

Each drayage truck driver makes a number of trips every working day. From our collected data we have identified all trips the participating drivers have traveled, and found a total of 1,045 useful trips that consist of 323 paths of unique origin and destination pairs. We should note that drivers may use different roads for different trips of the same origin/destination location pair. For each trip we compute the distance the driver traveled, the time the trip took, and the average speed on the trip. We then find the average of these parameters for each path, and show the top 20 paths in Table 6, in terms of frequency of travel. In order not to disclose the business dealings that this drayage firm engages in, we labeled those consignees involved in these frequent trips with numbers 1 through 10, along with the ZIP codes of their locations. The travels the five drivers made in these top 20 paths account for 34.5% of all travels in terms of numbers.

Table 6. Top 20 Paths Traveled.

Origin of Trip	Destination of Trip	Number of Travels	Average Time (min)	Average Distance (miles)	Average Speed (mph)	Min Speed (mph)	Max Speed (mph)
APM	1 (90745)	42	26	9	20	8	33
SSA Terminal	2 (90745)	32	14	4	17	13	23
2 (90745)	SSA Terminal	25	13	4	17	8	25
Yusen Terminal	1 (90745)	23	26	7	19	3	25
3 (90810)	Long Beach Container Terminal	22	15	5	20	10	25
1 (90745)	6 (90805)	21	23	8	22	11	30
West Basin	4 (90810)	19	22	8	25	15	40
TRAPAC	3 (90810)	17	14	4	20	11	25
5 (90745)	Pacific Container Terminal	16	19	8	26	19	30
1 (90745)	APM	16	25	9	25	12	33
7 (90810)	4 (90810)	14	8	2	17	9	22
SSA Terminal	1 (90745)	14	20	6	18	15	22
4 (90810)	West Basin	14	21	9	26	16	37
1 (90745)	3 (90810)	13	14	3	16	9	22
Eagle Marine Services, Ltd	3 (90810)	13	14	5	22	16	29
4 (90810)	Eagle Marine Services, Ltd	13	20	7	23	15	31
Pacific Container Terminal	5 (90745)	13	29	8	18	9	21
8 (90733)	9 (91761)	12	72	55	46	42	51
1 (90745)	10 (90040)	11	33	16	30	22	39
Total Terminals	1 (90745)	10	21	8	22	19	30

As shown in Table 6, the vast majority of travels these drivers made were within 10 miles from the ports. This is expected due to the work types that they are assigned to perform, i.e., two run the heavy container corridor, one drays to near-dock rail ramps, one services Target warehouses, and one performs general store delivery in the Southern California region. The driver that performs general store delivery has the longest distance to travel per trip, with his most frequently traveled path taking 72 minutes at an average speed of 46 mph, the highest of all in the table. Travels on all other paths shown in Table 6 attain average speeds ranging from 17 mph to 30 mph, a solid evidence that the roads within the vicinity of the port area are congested.

We have also computed the average travel speed by work type as shown in Table 7, in order of average speed. The heavy tags that run on the heavy container corridor are the slowest, achieving only 19 mph on the average. The minimum speed tracked on those trips was 3 mph. Deliveries to the rail ramps and to Target warehouses are not much faster, with average speeds of 22 mph and 23 mph, respectively. Destinations of these deliveries are in Carson, CA, in the same general areas as those reached by the heavy tag trucks. The driver who handles the general store deliveries travels the longest distance. He was able to reach an average speed of 35 mph for an average distance of 34 miles.

Table 7. Travel Speed by Work Type.

	From Tracked Data					Google Estimation with No Traffic		% Actual Speed Below Google Estimation
	Average Time (min)	Average Distance (miles)	Average Speed (mph)	Min Speed (mph)	Max Speed (mph)	Average Time (min)	Average Speed (mph)	
Heavy	23	7	19	3	33	15	31	39%
Rail	18	6	22	4	43	14	30	28%
Target Warehouses	21	8	23	7	40	15	32	29%
Store Delivery	58	34	35	12	55	39	47	26%

For comparison, we also show the expected time and estimated speed without traffic on the travel transactions in our collected data using Google tools. The results clearly indicate that the slowdown on the heavy container corridor is most significant. For all drivers performing all work types, it took an average of 25 minutes to travel these paths at an average speed of 23 mph. Google estimates the expected time to complete these paths to be 18 minutes at a speed of 34 mph without traffic. Therefore, the drayage trucks were traveling at 32% below ideal speeds during these monitoring weeks.

Productive vs. Non-productive Travel

A drayage truck's travel is productive if it carries a container while traveling, regardless if the container is loaded or empty. Otherwise the travel is considered non-productive. In our data, we would consider a travel as productive if the action at a terminal or warehouse prior to this travel is a container (load or empty) pickup, and non-productive if the action is a single transaction of container delivery and the travel is not returning to the company lot. We extract from our collected data all travels that satisfy the productive definition and those that satisfy the non-productive definition, and cumulate the distance of all travels in each category. The ratio of non-productive travel vs. the total distance of both categories provide a good indication of how much travel (and therefore driver time and other incidental costs) is spent on truck repositioning. Table 8 shows the amount of productive and non-productive travel made by different work types.

Table 8. Productive vs. Non-Productive Travel by Work Type.

Work Type	Productive Travel (miles)	Non-productive Travel (miles)	Non-productive (%)
Target Warehouses	840	723	46%
Rail	1832	996	35%
Heavy Tag	1172	259	18%
Store Delivery	4809	655	12%
Total	8653	2632	23%

Table 8 shows that Target delivery has the highest percentage of non-productive travel (46%). This means nearly half of the travel made by this driver were empty moves. The second highest percentage occurred in the delivery to rail ramps at 35%.

The high percentage of non-productive travel for Target warehouse delivery may be due to the particular business model that Target is following, in that they import goods from overseas and produce little or nothing for exports while the empty container pickups at the warehouses may have been handled by someone else. As for the rail delivery, the import containers the driver picked up were delivered to rail facilities for long-haul transportation and the driver picked up very few exports or empty containers there in return. The non-productive travel in heavy tags and store delivery are much lower.

It should be noted that the non-productive travel as defined above cannot be classified as wasted travel since they are necessary in the truck repositioning in overall drayage operations. However, this non-productive travel percentage could be a useful efficiency indicator that alerts the need for an examination of the company's job order scheduling.

Cumulative Travels within Terminals

For all transactions within port terminals, our data not only logged the transaction types and turn times, they also provided details on the amount of travel the trucks made within the terminal ground. Figure 11 shows the average distance that trucks traveled within each of the 12 terminals ranging from 1.13 miles at PIER C BERTH C60-C62, the smallest terminal, to 4.85 miles at APM, the largest, in terms of land area.

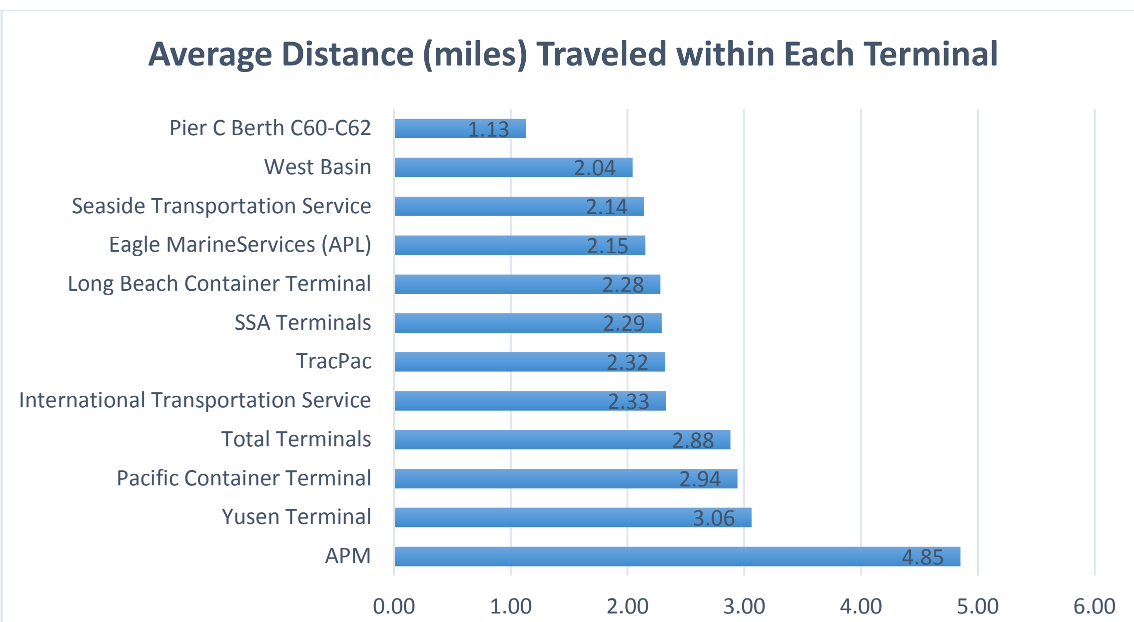


Figure 11. Average Distance Traveled within Each Terminal.

It is perceivable that trucks may need to travel a longer distance in a larger terminal than in a small one, and our results do validate this intuition. However, there are exceptions to this rule.

For example, Yusen Terminal has the second-longest average travel, even though it is the fourth smallest among the twelve terminals covered in our collected data, whereas Eagle Marine Services, being the third-largest terminal, ranked ninth in terms of travel distance. The rankings by the average distance traveled and by land area are shown in Table 9. Land areas of individual terminals at the Ports of Los Angeles and Long Beach are extracted from [27, 28]. When trucks have to make large amount of travel within a terminal to complete a job, it may be an indication of inefficient layout or procedures.

Table 9. Ranking of Terminals by Average Distance Traveled in Each vs. Ranking by Land Area.

Terminal	Average Distance (miles)	Ranking by Distance (Large to Small)	Land Area (acre)	Ranking by Area (1=Largest to 12=Smallest)
APM	4.85	1	393	1
Yusen Terminal	3.06	2	185	9
Pacific Container Terminal	2.94	3	256	4
Total Terminals	2.88	4	385	2
International Transportation Service	2.33	5	246	5
TraPac	2.32	6	185	8
SSA Terminals	2.29	7	200	7
Long Beach Container Terminal	2.28	8	102	11
Eagle Marine Services (APL)	2.15	9	292	3
Seaside Transportation Service	2.14	10	205	6
West Basin	2.04	11	136	10
Pier C Berth C60-C62	1.13	12	70	12

OUR EXPERIENCE

There are a number of observations we have made through our 9 weeks tracking of port drayage using the device we have developed.

- GPS tracking does provide information on each truck's location at any time and the direction it is heading. However, the actual task that the driver performs at a given location (e.g., deliver load, pick up empty) cannot be detected by GPS signals. We designed a simple UI with relevant buttons on touch screen for truck drivers to supply such information, which renders our data subject to human error. The most common errors were due to either the driver forgetting to press a button or pressing the wrong button. When this happened, the work performed for that particular trip cannot be determined.

- We understood the need to limit drivers' handling of the tracking device, and therefore decided to use a Bluetooth connection and the truck's cigarette lighter to control the start/stop of the tracking application on the mobile device according to the engine status. Unfortunately this idea did not pan out since the cigarette lighters on the trucks that we were engaged with for our tracking are always on. Consequently we had to ask the drivers to either use the start/stop button on the touch screen to manually start/stop the mobile application, or simply leave the application on at all time. This then became another source of errors in the data collection. In particular, one driver habitually started the application after he was inside a terminal, and another driver often stopped it after a job of, say, picking up a load or delivering an empty, before he exit the terminal. Transactions where these occurred became useless and had to be excluded from computations of turn time and queue time.

- Drayage companies are highly interested in tracking their drivers' progress in performing their drayage job orders as part of their fleet and labor management. In fact, the drayage company that supported our project with their drivers' participation has been using a commercial service for the tracking of their truck fleet. The company provides each driver a smartphone loaded with an app, which the driver uses to communicate with the company's job dispatcher and to receive job order. GPS tracking of the truck's location takes place every 10 minutes on the phone. Driver is instructed to log the completion of each job and any other relevant event on the phone as they happen. Unfortunately, the logs produced by the drivers are not always complete, and are often untimely. Sometimes they will delay the data entries and enter several events all at once at a later time. Consequently, the actual timing of events are lost. The commonly offered reason was that the signal was too weak in the area.

- When we realized errors in our recorded data, we asked the company for their assistance by allowing us to access their database. Through careful matching of the two sets of data, we were able to clean up and correct many errors from our collected data.

CONCLUSIONS

The Ports of Los Angeles and Long Beach had experienced remarkable growth during the decade prior to the 2007-2008 global financial crisis. The trade between the U.S. and the Pacific Rim countries slowed down substantially as a result of the financial crisis but has by now almost returned to the previous peak. Import goods arriving at the twin ports from overseas via ocean carriers have to be transported to their final destinations, and exports to be shipped to the Pacific Rim have to be transported to the ports. Drayage trucks are responsible for short-haul transportation within 100 miles of the ports. As the twin ports represent the largest port complex in the U.S. and the 9th largest port facility in the world in terms of volume, drayage is recognized to be a significant industry in the U.S. in general and Southern California in particular. Drayage efficiency not only is important to the players that include terminal operators, drayage companies and shippers, it also has huge impact on the Southern California economy.

The general impression that drayage trucks are major source of congestion and pollution is deeply ingrained in the public's minds. Truck drivers and the trucking industry have long complained about the serious congestion at and around the ports that causes long delays and high costs in drayage operations. In contrast, marine terminal operators paint a much brighter picture of the status of their operations by showing reasonable turn times and queue times during the day as well as the night shifts, though it is a common knowledge that their turn time statistics exclude lunch and break times, and time spent at the trouble windows.

The real picture has yet to emerge. We believe that a technology that can readily be adopted by drayage operators will provide an unbiased answer. To this end, we have built a truck tracking device using commercially available tablet computers and custom software applications, and deployed it on a fleet of five trucks for a total duration of 9 weeks. The collected data have been analyzed and our findings are summarized below:

- The GPS-tracked location data are very useful in producing a fairly clear picture of every trip that a driver makes, from origin to destination. From the 9 weeks of tracking by five drivers, we extracted a total of 2,405 transactions covering 12 port terminals at the San Pedro Bay port complex with arriving times at the terminals from 7:00 am to 8:30 pm. The transactions are grouped into three categories: terminal transactions, travel between two locations, and others.

- Terminal transactions record what task a driver enters a terminal for and for how long. The time a driver spent in a terminal can be extracted from the GPS data, and is broken down into two components: queue time and flow time, the sum of which would be the turn time. Based on these transactions we have found an average turn time of 88 minutes, a result that appears to be much longer than findings in several previous studies based on monitoring at single terminals [23-25]. It should be noted that average turn times at individual terminals may vary greatly. For example, a breakdown of our terminal transactions by terminal show a smallest average of 38 minutes at Eagle Marine Services to a largest of 122 minutes at the Pacific Container Terminal. Our sample sizes for some of the terminals are relatively small, however. The 88-minute turn time is comparable to the August visit time reported in a September 9, 2015 article on *Journal of Commerce* [10]. The average was obtained from the Harbor Trucking Association's ongoing truck mobility project.

- The distribution of our turn time data shows a very long tail, indicating that there are a few extremely long turn times that have obscured the average. Indeed, the median turn time was substantially lower at 68 minutes. One-quarter of the transactions in the port terminals took more than 2 hours, and 10% took more than 3 hours. These exceptionally long turn times are likely the results of trouble tickets in completing the transactions. Had the driver at those instances used the "Voice Record" feature of the device, the real reasons for these extreme turn times would have been revealed.

- The job performed in each terminal transaction relies on driver inputs using the touch screen on the device. The accuracy of this information is less than satisfactory due to human errors. However, by matching our records and the database of the drayage company where the five drivers work, we were able to clean up and correct many of the questionable entries. At the end, 41 terminal transactions out of a total of 533 had to be excluded, resulting in a 7.7% error rate.

- The time it takes to complete a terminal transaction varies by the time that a truck arrives at a terminal. The best times in terms of fast turnaround appears to be mid-afternoon, 3:30-4:30 pm, and the evening after 7:00 pm. The distribution of average turn time over time of arrival is consistent with that reported by Haveman [6] on data extracted from the Harbor Trucking Association's truck mobility project.

- Different types of transactions take different amounts of time to perform. Our data confirm that the dual-move transactions take longer than the single-move transactions, as expected. Our data also show that picking up load is the dominant type of work that drivers go to port terminals for. All the three transaction types that include this work account for 64% of all transactions, and these transactions tend to take the longest time, 100 minutes or more. Average turn times for all other transaction types are much lower when compared to these top three. Delivering empty container also had a substantial count, a phenomenon that reflects the trade imbalance between the Pacific Rim countries and the U.S.

- Besides terminal transactions, our data also allow us to find the travel conditions that drayage drivers are enduring. A careful examination of the data produced a total of 1,045 trips that the drivers made during the monitoring period. From these trips we identified the 20 most frequently used paths that account for 34.5% of all travel. Due to the specific nature of the work types that 4 out of the 5 drivers are assigned to perform, these paths mostly covered an area within 10 miles from the ports. The fifth driver that runs general store delivery has the longest distance to travel. His most frequently traveled path has a distance of 55 miles that takes him an average of 72 minutes to complete at an average speed of 46 mph. The average speeds on all other frequently traveled paths that surround the ports range from 17 mph to 30 mph, giving a solid confirmation that the roads in the vicinity of the port area are indeed congested.

- The travel speeds vary by work type, as shown in our findings. The averages from low to high are 19 mph for the heavy tags, 22 mph for rail delivery, 23 mph for the Target delivery, and 35 mph for the general store delivery. Compared to the Google estimated speed without traffic on these travel transactions, these averages are 26-39% below the speeds under ideal conditions.

- A drayage truck's travel is productive if it carries a container, otherwise the travel is considered non-productive. Our findings show that the percentage of non-productive travel vary by work type, ranging from the highest for the Target delivery (46%) to the lowest for the general store delivery (12%). While the non-productive travel is mostly needed for truck repositioning, a high percentage of its occurrence increases the cost of drayage, reduces driver productivity, and adds to road congestion and potential pollution. Cutting down this type of inefficiency requires proper scheduling of job orders, which would be a challenging proposition in light of the fact that visit times at port terminals are highly unpredictable.

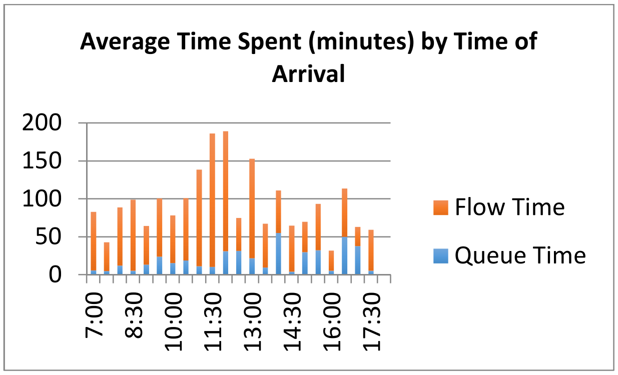
- Our data also provided us some potentially useful information about the amount of travel that trucks made within each terminal. The average amount of travel per visit to individual terminals ranges from a high 4.85 miles at APM to a low 1.13 miles at Pier C Berth C60-C62. APM is the largest terminal in terms of land area in the Twin Port Complex and Pier C Berth C60-C62 is the smallest. Our results, which show trucks tend to drive a long distance within a large terminal and a short distance within a small terminal are logical. However, there are exceptions to this rule. For example, Yusen Terminal has the second-longest average travel, even though it is the fourth-smallest among the twelve covered in our collected data. An unusually long travel length within terminal grounds may be an indication of suboptimal terminal layouts and/or terminal operation procedures.

- GPS location data are prone to inaccuracy in urban centers with a concentration of tall buildings and in the interior of buildings. Therefore, our data on the entry and exit of a warehouse location may be subject to errors. A technology that combines the capabilities of inertial sensors and GPS is expected to reduce the degree of error [29].

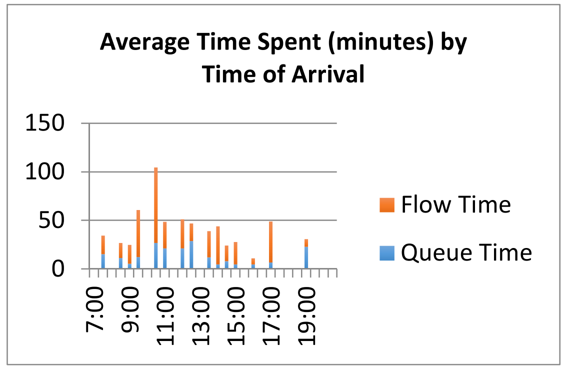
- While GPS tracking, with or without inertial sensors, provides a wealth of data on truck movements, does not solve the challenging problem of determining the task performed on each trip and the time at which the task is executed. Our experience illustrates that accurate and timely driver inputs cannot be relied on in large scale tracking. We believe that some forms of weight sensing could be of potential use to eliminate the need for driver involvement in logging what task is performed and when it is done in a drayage trip. With such complete automation, the touch screen UI will no longer be needed and a much more compact and special purpose device can be built at a lower cost, and will have a much greater chance of acceptance by the drayage operators and drivers. We should note that the change or recharge of batteries on such device still require driver involvement and hence may still be a potential issue, and the special circumstances that cause exceptionally long delays in terminals may still be difficult to know without driver inputs.

APPENDIX

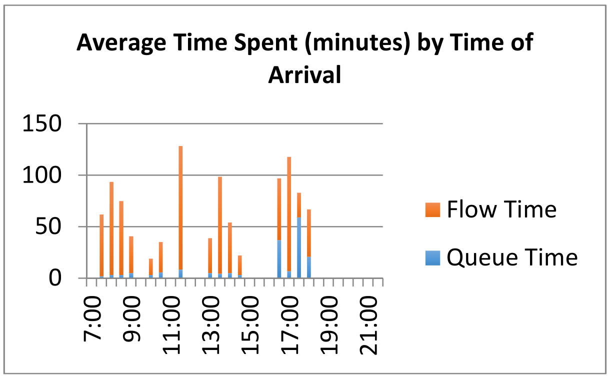
Average Time Spent (Turn Time/Queue Time) at Individual Terminals by Time of Arrival



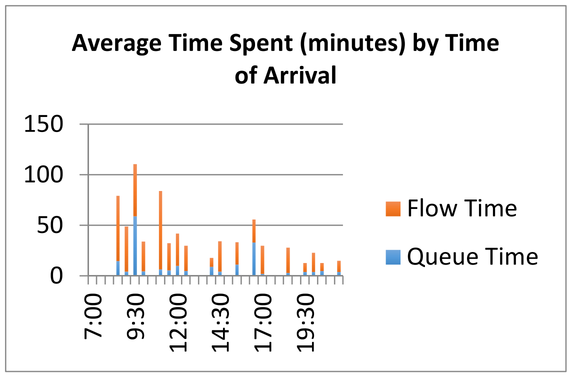
APM



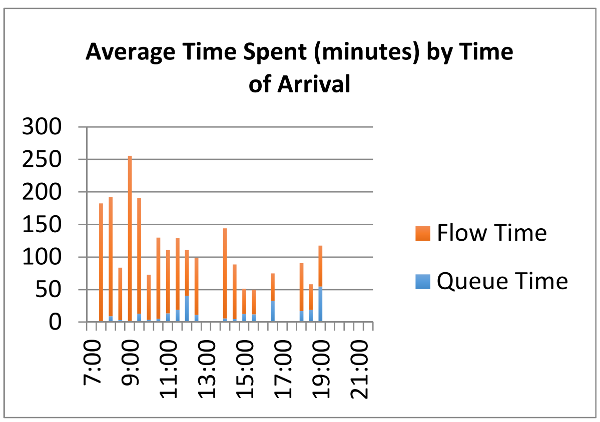
Eagle Marine Services (APL)



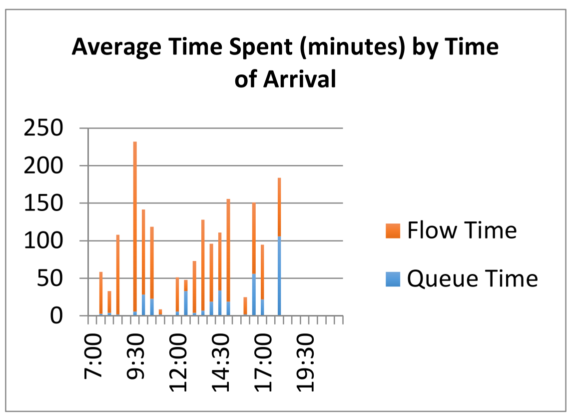
Seaside Transportation Services



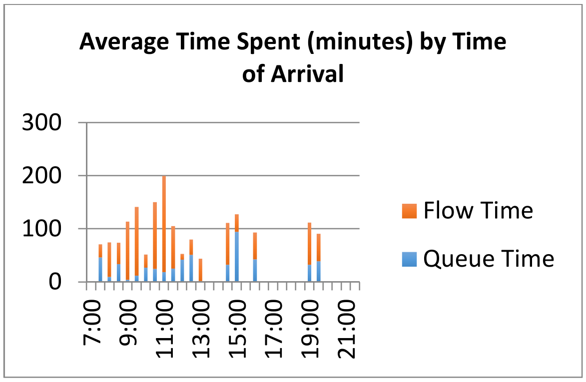
West Basin



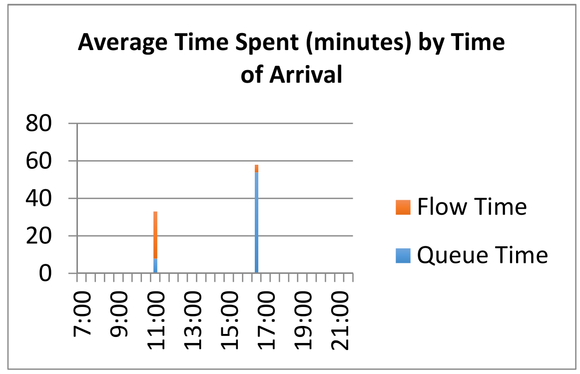
TraPac



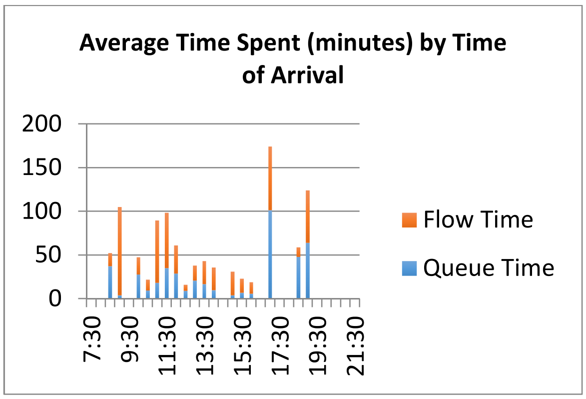
Total Terminals



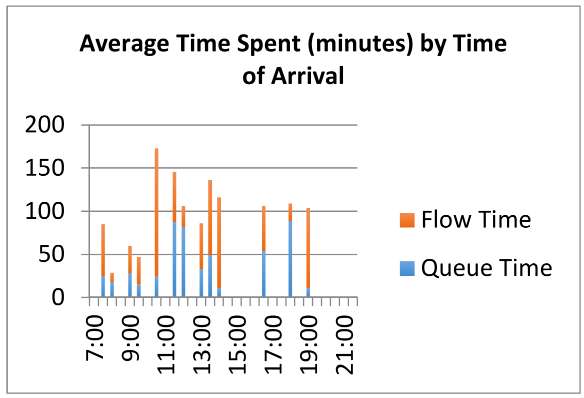
SSA Terminals



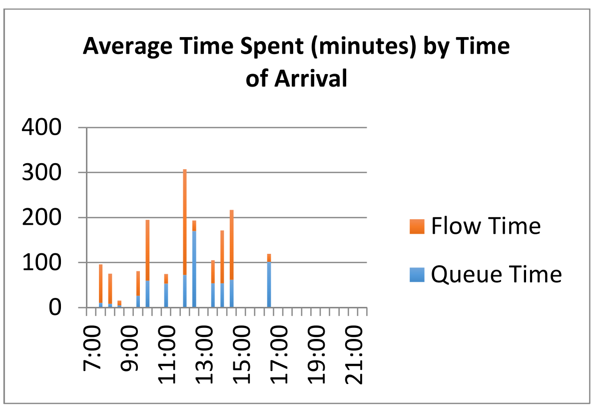
Pier C Berth C60-C62



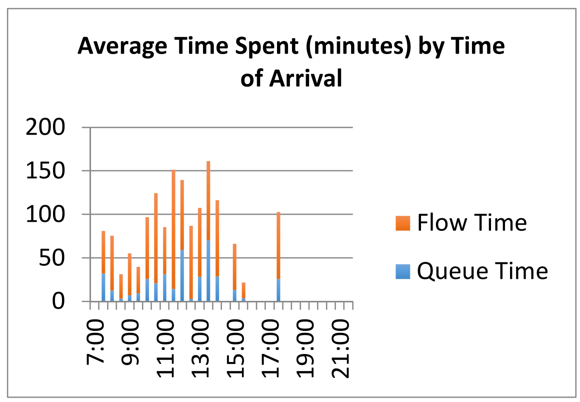
Long Beach Container Terminal



International Transportation Service



Pacific Container Terminal



Yusen Terminal

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