Intermodal Container Ports: Application of Automatic Vehicle Classification System for Collecting Trip Generation Data

TATHAGATA GUHA AND C. MICHAEL WALTON

With the evolution of containers and growth in intermodalism, intermodal seaports have experienced a tremendous growth in containerized trade associated with international and domestic trade. With the increase in port activity has come a comparable increase in port landside traffic. The results of a case study of a container port (Houston's Barbours Cut) are reported, and the impact of existing container port operations on urban infrastructure and mobility is addressed. The application of an automatic vehicle classification system used to collect the necessary traffic data is presented. Commercially available photoelectric sensors were used to collect accurate traffic volume and classification data over a period of 7 days. The data collection procedures provide quantitative information on the traffic characteristics of the container port. Mathematical models were then developed to accurately forecast travel demand for use in planning and designing transportation facilities. The results of the analysis provide trip generation rates for both average weekday and peak hour of generator, and they show the variation in traffic demand by vehicle types. The existing trip rates calculated were consistent with the ITE trip generation rates. The other interesting finding is that only 30 percent of the total traffic were container trucks; the rest were two- and three-axle vehicles.

Intermodal freight transportation involves the movement of goods using various modes of transport. The concept of intermodal freight transportation began to be used widely in the late 1950s (*1*). It eased the transfer of freight from one mode of travel to another. An intermodal transfer is the movement of goods or commodities between two modes. The modes are as follows: by water, ocean vessels, coastal vessels, and inland waterway barges; by air, airplanes and helicopters; and by land, rail freight trains, highway trucks, belt conveyers, and pipelines (*1*).

One of the most significant forms of intermodal shipping is containerization. The cargo is packed in a container, which can be used for several modes of travel: ship, railroad, truck, and airplane. The use of these containers has improved intermodal transfer of general cargo to a great extent. After the 1956 "container revolution," containerization of ocean cargo for intermodal purposes was widely practiced (*1*). Well over 60 percent of the world's deep-sea general cargo is containerized (*1*). Recent studies indicate that containerized traffic would grow to 430 million mt in 1990 and 607 million mt by 2000 (*2*). Figure 1 shows an optimistic forecast of container growth by world port regions in 20-ft equivalents (TEUs) between 1978 and 1998 (*3*).

T. Guha, Carter & Burgess, Inc., 1717 W. Sixth Street, Suite 210, Austin, Tex. 78703. C. M. Walton, Department of Civil Engineering, ECJ 4.2, University of Texas at Austin, Austin, Tex. 78712.

Container movements have continued to increase at United States ports and are expected to rise in the future. Today about 80 percent of all U.S. liner trade by volume is containerized. In 1991 the ports of Los Angeles, New York, and Long Beach were among the top three in the United States with 2.03 million, 1.86 million, and 1.76 million TEUs throughput, respectively. Port of Houston handled 0.53 million TEUs in 1991 (*4*). Figure 2 shows the increase in container throughput for a few selected container ports in the United States between 1983 and 1991 (*4*).

As ocean carriers seek to reduce costs and receive higher percentages of open ocean operation from their ships, they confine their operation to fewer ports of call, relying on the ground transportation network for more of the cargo's movement (*5*). Inland transport to and from the ports may be by coastal waterways, road, rail, or a combination of road and rail. Providing access for coordinating the interface of two or more different modes of transportation systems is essential (*1*). The inland distribution of the cargo depends on the local market area of each individual port (*6*). Railroads' intermodal service is price competitive with that of trucks on traffic movements of more than 500 mi for containers and 700 mi for trailer on flatcars (*7*). The modal split at Port of New York–New Jersey is 96 percent truck and 4 percent others (*6*) (pipeline, barge, or on-site use). At San Francisco, 71 percent is carried by trucks, 20 percent by rail, and the remaining 9 percent by other modes (*8*). At Houston's Barbours Cut container facility, 95 percent of containers use trucks and only 5 percent rail (T. Guha, unpublished data). The landside network must be extensive for the cargo to be moved at higher peak volumes and for greater distances.

International and domestic trade through seaports has increased to a great extent, and containerized freight movements have facilitated this growth. Trucking continues to dominate the movement of containers to and from ships at U.S. ports (*5*). Good ground access facilities are needed to move the goods quickly and efficiently through the ports (*9*). The rise in container traffic has increased landside traffic to and from the port terminals. Traffic congestion due to the increased truck and automobile volumes near the port is becoming an issue that should be addressed.

CASE STUDY SCOPE AND OBJECTIVES

To plan an efficient ground access system, it is first necessary to determine the impact of port-related traffic on the urban

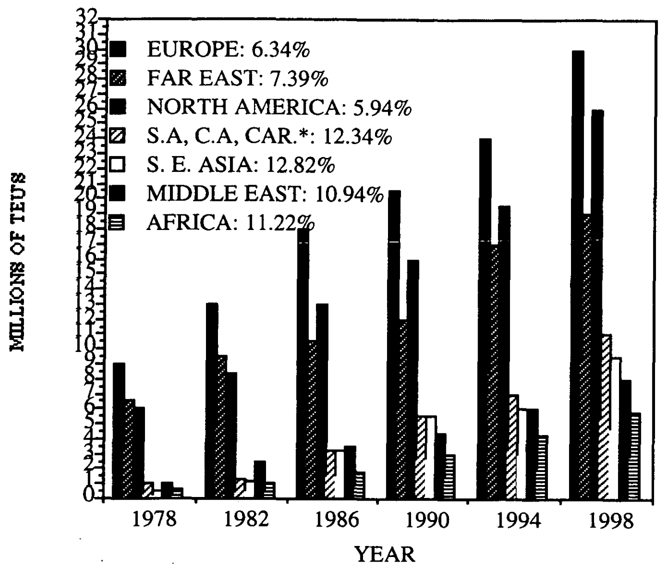

FIGURE 1 Containers handled by world port regions 1978–1998, optimistic forecast.

roadway network to ascertain the extent to which the existing system can accommodate the increased movement of containers and other traffic. The objective of the paper is to present the findings of a case study of the landside traffic characteristics of an existing container port. The research that provides the basis of the paper explored the traffic generation associated with a container port, the methodologies and techniques of collecting landside traffic and vehicle data, and the association with typical container port components. From this study, recommendations are made for further, more detailed experiments necessary to characterize container ports and their landside traffic characteristics.

Container port operations in the Port of Houston were observed and documented. Containers are usually 20 or 40 ft in length. However, containers of other sizes—45, 48, and 53 ft—are also being used. The containers are carried by five-axle tractor-trailers to and from the port, yet they represent only 30 percent of the total traffic typically using the terminal *(10)*. Therefore, it is necessary to consider all types of vehicles that make up port traffic. Traffic volume and classification data can be collected manually or automatically. Though manual collection seems to be the most accurate, it is labor intensive and expensive. Automatic counters are used to obtain a larger data base for vehicle counts and are being supplemented by manual classification and vehicle occupancy data. Recently, infrared sensors *(11)* have been used to count and classify vehicles accurately. These sensors, when properly designed and installed, can be used to obtain a variety of information about traffic characteristics. In an effort to collect data regarding vehicle volumes and classification for this study, such sensors were used to count and classify vehicles entering and exiting the site at Houston's Barbours Cut Terminal *(10)*. The classification criteria used for design of photoelectric sensors in this study include number of axles per vehicle and number of containers carried per vehicle.

After the data were collected, the impact of port-related traffic on the surrounding highway network was assessed. Many mathematical models have been developed by transportation professionals to describe various relationships between land use and travel. The ultimate goal of the modeling is to replicate actual travel and facilitate the forecast of traffic volume ousted by similar land usage.

There are traffic-generating characteristics associated with various land use categories, and appropriate roadway facilities to accommodate the trip demands are required *(11)*. Transportation demand is affected by a number of factors, such as land use character, intensity of land use, and location. The amount of travel and its characteristics are functionally related

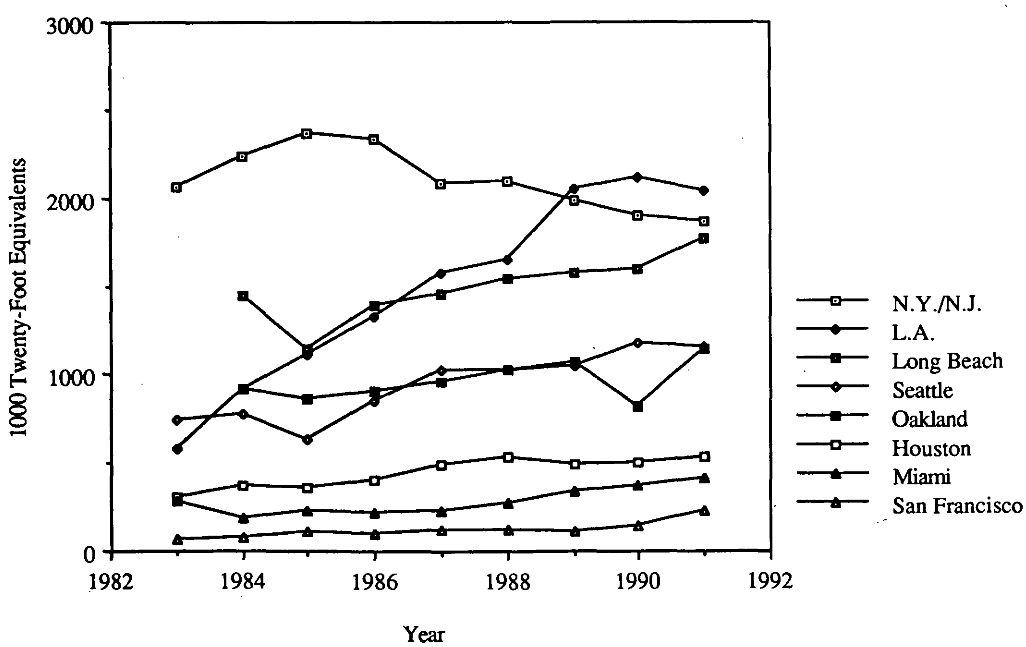

FIGURE 2 Total container movements by selected U.S. ports.

to the use of land. Trip generation analysis is important in a number of phases of transportation planning and traffic engineering activities. One of the uses of trip generation is to assess the impact of a new or existing development on surrounding transportation infrastructure (*12*).

Land development also has an impact on the existing facilities because of the increase in trip attractions and productions, which can create the need for transportation system improvements.

By collecting data on trip generation rates at existing sites of a particular land use category (or categories if a mixed use site), the information can be used, within certain limits, to estimate vehicle trips expected to be generated by other similar land development projects (*13*). Likewise, container terminals affect the roadways adjacent to the port area because of the traffic that is directly associated with the terminal. It is necessary to calculate and document trip rates of these types of land uses for use by transportation professionals in the same manner in which trip rates for other land use categories are used.

Only seven trip generation studies have been documented for seaports (*14*). Trip generation studies on seaports have used only land area, number of berths, and revenue tons throughput as independent variables to calculate trip rates. Trip rates were calculated for an average weekday because of insufficient data. This study uses an automatic vehicle classification system to collect detailed data on travel demand patterns for the container port. The demand patterns have been related to land use characteristics used in previous trip generation studies, and a new land use characteristic has been included in the calculation of trip rates: TEUs.

DATA COLLECTION

This study focused on the Port of Houston's Barbours Cut container facility. Field traffic volume counts were performed at the site, and data were also collected on the independent variables of the site. Then actual trip generation rates were calculated for average weekday, a.m. and p.m. peak hour of the generator.

Site Configuration

Barbours Cut has three access roadways leading into the terminal. Trucks and other vehicles used these roads. The main road is a public road and is the main access to the terminal. It has two 12-ft lanes in each direction divided by a median. The other access is a private, two-directional road, which is mainly used for carrying containers that are taken to the railhead, from where it is distributed to the final destination.

Initial visits to the site were made to observe the traffic flow and select the most suitable spot for installation of the automatic vehicle classification equipment. The system was set up at the site so that all entering and exiting vehicles were counted and classified. Each system consisted of photoelectric sensors and reflectors mounted on steel posts on either side of the road. Two such systems were set up on the public road for each direction to count and classify entering and exiting vehicles. It was observed that vehicles on the two-lane entry and exit roads seldom passed each other, and therefore very rarely did two vehicles cross the sensor beams at the same time. Hence, the error of counting two vehicles as one was negligible. The third system was set up on the private road. That system counted vehicles irrespective of their direction. Manual counts were made during the data collection period to adjust the directional distribution on this road. Data were collected using this methodology and then were input into the trip rate calculations.

Automatic Vehicle Classification System Arrangement

At Barbours Cut Terminal an effort was made to collect data on traffic volumes and vehicle classification by using photoelectric sensors. The procedure included designing the needed hardware and software and installing the systems at selected field sites so that the desirable data could be collected. Commercially available photoelectric sensors were used to acquire traffic data for a period of 7 consecutive days, 24 hr per day, or 168 hr of data. These sensors, along with microprocessors, made up the data collection system.

The sensors were arranged at the sites to allow all vehicles to be counted and classified. The classification data required for this study and from the data collection system were (*a*) number of axles (six or more, five, four, three, or two) and (*b*) container length (20 or 40 ft).

As previously stated, photoelectric sensors were installed on the roadside at the site. The sensors and the reflectors were mounted by using steel posts and other diagonal support. The sensor and the reflector arrangements S1, S2, S3, S4, and S5 and R1, R2, R3, R4, and R5, respectively, of each system are shown in Figures 3 and 4. These sensors can be used to collect different types of data, such as

- Vehicle counts,
- Vehicle classification,
- Vehicle speed,
- Spacing between successive axles,
- Approximate size of the tire/pavement contact area, and
- Overall dimension of the vehicle body (*9*).

Batteries were used to provide power to the sensors. The sensors used an infrared light beam to detect the presence of vehicles. The beam was focused on a reflector located across the roadway from which it was reflected and sent back to the

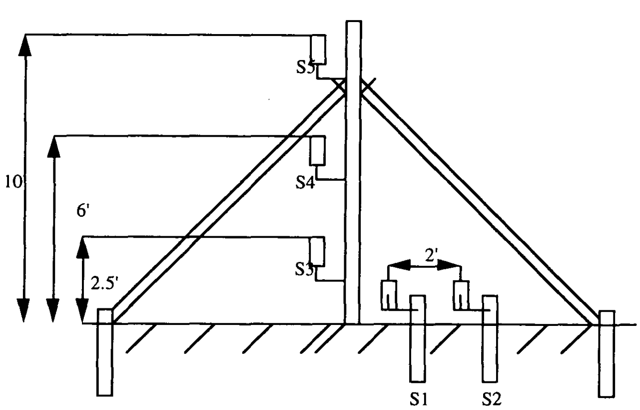

FIGURE 3 Sensor arrangements: front elevation.

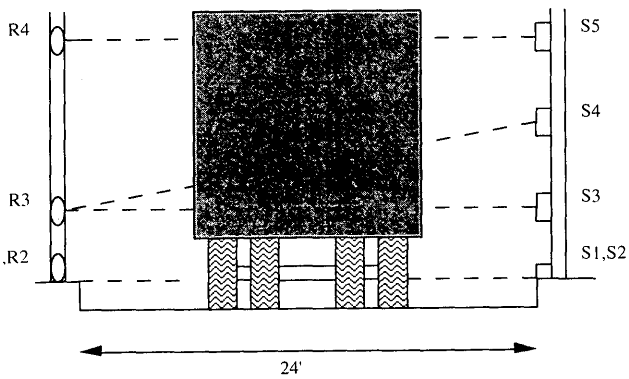

FIGURE 4 Photoelectric sensor system to count and classify vehicles.

receiver and transmitter located in the sensor head. The beam, when interrupted, generated a signal to detect the presence of the vehicle body.

Two pavement-level sensors (S1 and S2), which were spaced 2 ft apart, were used to count the number of axles per vehicle. This also enabled calculation of the speed of the vehicles by dividing the distance between sensors by the time between successive beam interruptions. The speed data were then used to find the length of the containers. To determine the overall vehicle length, two sensors (S3 and S4) were mounted about 2.5 and 6 ft above the road level and placed at such an angle that all of the vehicle presence time was detected. To differentiate trucks from passenger cars and pickups, a sensor (S5) was mounted approximately 10 ft above the roadway at the roadside. This also provided information pertinent to determining the length of the containers.

Traffic Volume Counts

A detailed trip generation study was conducted at the Barbours Cut facility to estimate the vehicle trips generated at or attracted to the site. Automatic counters (photoelectric sensors) as described in the previous section were used to collect traffic data. The equipment was designed and deployed at the site in such a way that vehicles passing the sensors were divided into those entering and those exiting the port. The data were collected for 15-min intervals over 7 days. Manual counts were conducted at the site during the peak hours to test the accuracy of the sensor equipment. Table 1 summarizes the vehicle trip ends, which are the sum of entering and exiting vehicles for weekdays and peak hours of the generator as collected at the site.

Independent Variables

Another part of the data collection phase of trip generation calculations involved compiling data on independent variables of the site. For this study, information was gathered on total acreage of the site, revenue-tons of cargo throughput, number of ship berths, and container throughput (TEUs). These data were provided by the terminal manager. Land area in acres, revenue-tons, and number of ship berths were chosen for this analysis because these variables have been used previously as input into trip generation calculation *(14)*. In actual practice, data for all these variables may not be readily available; therefore, it is helpful to have the ability to estimate vehicle trips based on more than one variable. Most container terminals have TEUs instead of revenue-tons of cargo as their productivity unit. Therefore, the TEU was established as another independent variable for use in calculating trip rates. Table 2 is a compilation of the land use characteristics.

Vehicle Classification

In trip generation studies, information about the types of vehicles that constitute the total traffic is valuable. Because of increases in container traffic, there has been an increase in the number of trucks to and from these facilities. The typical vehicular unit is a five-axle truck with a 20- or 40-ft container. There are also four-, six-, seven-, and occasionally eight-axle trucks. Other than these trucks, two- and three-axle vehicles enter and exit the port for a variety of purposes. The two-axle vehicles are usually service vehicles, employees' personal vehicles, or other purpose vehicles and are typically pickups, single-unit trucks, or passenger cars. The three-axle traffic is mainly bobtails (a truck without a trailer). The variety of vehicle types entering and exiting a container port suggested that it was important to consider all traffic related to the facility. Data were collected at the site to document the types of vehicles that entered and exited the facility.

TABLE 2 Independent Variables

Independent Variables	Barbours Cut Facility
LandArea(acre)	230
Revenue-Tons(per week)	83333
Twenty Foot Equivalents(per week)	4413
Ship Berths	4

TABLE 1 Total Vehicle Trip Ends at Site

DAYS	24 hour vehicle trip ends			A.M. peak hour vehicle trip ends			P.M. peak hour vehicle trip ends		
	IN	OUT	TOTAL	IN	OUT	TOTAL	IN	OUT	TOTAL
MONDAY	1453	1776	3229	160	180	340	170	200	370
TUESDAY	1734	2071	3805	170	192	362	178	168	346
WEDNESDAY	1864	2325	4189	166	246	412	176	215	391
THURSDAY	1785	2367	4152	166	273	439	180	222	402
FRIDAY	1703	2122	3825	155	252	407	156	182	338
SATURDAY	499	555	1054	31	35	66	43	53	96
SUNDAY	672	792	1464	33	34	67	90	72	162

DATA EVALUATION

Trip Generation Analysis

Actual trip generation rates of the sites were computed by developing mathematical relationships between measured traffic volumes and the independent variables. Trip rates are expressed in terms of independent variables. Depending on the duration of the data collected, trip rates are calculated for average weekday trip ends, a.m. and p.m. peak hour of generator trips.

After collecting the data, trip generation rates were calculated. With the above data, average weekday trip rates were calculated for the site with respect to land area (per acre), ship berth (per berth), and revenue-ton throughput (per ton). In the calculation of average weekday trip rates, an average of the trip ends over a period of 5 days was calculated and then divided by the independent variable unit. Since data were collected over a period of 7 days and information about the independent variable TEU was also available for this period, weighted average weekday trip rates were calculated by summing all trip ends and all independent variables and then dividing the sum of trip ends by the sum of the independent variable units for Monday through Friday. Tables 3 and 4 present examples of the procedures performed to calculate average weekday trip rates and weighted average weekday trip rates, respectively. Data were collected for 15-min intervals and were tabulated to determine the peak-hour traffic volume for each day at the site. After identifying the peak hours of operation, a.m. and p.m. rates were calculated. Peak hour of the generator rates for a.m. and p.m. and weighted average weekday trip rates are summarized in Tables 5 and 6, respectively.

TABLE 3 Peak Hour of Generator Trip Rates per Berth (Sample Calculation)

TOTAL TRIPS:

PEAK HOUR OF GENERATOR (11:00 A.M.-12:00 P.M.)

	TOTAL
Vehicles Entering:	166
Vehicles Exiting:	273
	439
Percent of Vehicles Entering:	166/439 = 38%
Percent of Vehicles Exiting:	273/439 = 62%
Trip Rate:	439/4 = 109.75 Trips per Berth

TABLE 4 Average Weekday Trip Rate per TEU (Sample Calculation)

TOTAL TRIPS

Trip Ends:	19200
Total TEU's:	4413
Percent of Vehicles Entering	48%
Percent of Vehicles Exiting	52%
Average Weekday Trip Rate:	19200/4413 = 4.35 Trips per TEU

Vehicle Classification

Considerable effort was made to record the vehicular volume and class for the study site. The data were collected over a period of 7 days and checked for accuracy before being used in the analysis. After the equipment was installed, 15-min manual counts were made to validate the automatic counts.

During a validation check it was observed that the equipment was recording more vehicles with six or more axles and too few five-axle vehicles, although the total number of vehicles was correctly recorded. It was found that some trucks had mud flaps behind the front and rear wheels that were hanging so low that they were almost touching the surface of the road and would on some passes be registered as another axle. The sensors were placed as low as possible to eliminate the error, but without complete success. To adjust for this error, manual classification counts were performed to get a percentage distribution of five-axle vehicles that were erroneously registered by the equipment as having six or more axles. It was found that about 73 percent of those vehicles placed in the class of six or more axles were actually five-axle vehicles. This facilitated a calibration of the classification distribution.

TABLE 5 Peak Hour of the Generator Trip Rates

DAYS	Average Trip Rate for Peak Hour of the Generator							
	Per Acre		Per Berth		Per Revenue-Ton		Per TEU	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
MONDAY	1.47	1.6	85	92.5	0.02	0.02	0.34	0.37
TUESDAY	1.57	1.5	90.5	86.5	0.02	0.02	0.44	0.42
WEDNESDAY	1.79	1.7	103	97.75	0.02	0.02	0.51	0.48
THURSDAY	1.9	1.74	109.8	100.5	0.02	0.02	0.45	0.42
FRIDAY	1.74	1.46	100.5	84.5	0.02	0.02	0.47	0.39
SATURDAY	0.28	0.41	16.5	24	0	0	0	0
SUNDAY	0.29	0.7	16.75	40.5	0	0	7.44	18

TABLE 6 Weighted Average Weekday Trip Rates

Average Week Day Trip Rate			
Per Acre	Per Berth	Per Revenue-Ton	Per TEU
16.69	960	0.23	4.35

The results of the field survey indicated that 30 percent of total traffic was container truck traffic. The rest consisted of passenger cars, pickup trucks, and truck-tractors (bobtails). Table 7 presents the percentage variation of each vehicle class for each day. As expected, vehicles with five or six or more axles were negligible on weekend days because of the closure of the terminal on those days.

SUMMARY AND CONCLUSION

This paper presents the results of a case study of a single container port, the Barbours Cut Terminal in the Port of Houston. The case study focused on obtaining primary data in an effort to characterize the trip production and attraction associated with the container facility and its operation.

It is recognized that the observations may not be transferable to other container ports; however, the methodology and data collection techniques may lead to other efforts that will enrich our appreciation of landside traffic characteristics. A search of the published literature and reference material suggested that limited data are available for similar efforts. However, the growth in containerization and forecasts for increasing activity suggested that landside access will in all likelihood become a much higher priority issue among state and local transportation and port management officials. To appreciate the relative impact of container port operation on landside traffic conditions, more complete information must be available to guide investment decision and evaluate alternative recommendations.

It is recognized that there are seasonal variation in commodity flow, variance in vessel calls at respective ports, changes in intermodal transshipments, and directional splits that represent only some of the traits affecting container ports. This effort begins the documentation of such activities.

FINDINGS

Trip generation rates for the peak hour and for average weekday were calculated from the data collected for the Barbours Cut Terminal in the Port of Houston. These rates, using a set of newly defined independent variables, are total values that include automobile trips. Although the rates may vary by season and other factors affecting port operations, the TEU was found to be a significant variable in explaining trips for the container port facility and may be important in studies of other container facilities.

Average weekday trip rates for total vehicles (trucks and automobiles) as calculated in the analysis section were 16.69 trips/acre, 960 trips/berth, 4.35 trips/TEU, and 0.23 trips/ton. An effort was made to calculate peak hour of generator trip rates, both morning and evening. The directional distribution of traffic entering and exiting the site was measured. The average weekday directional percentages entering and exiting were 53 and 47 percent, respectively. The peak hour differed for each day, as did the directional splits.

Vehicle classification represented a significant effort in this case study. Container terminals do not document the actual percentage of types of vehicles that use the port. This case study provides information on the classes of vehicles that make up port traffic, measured in 15-min intervals over a period of 7 days and grouped by number of axles. The analysis indicated that only 30 percent were trucks, 60 percent were automobiles (cars, pickups, and two-axle trucks), and the remaining 10 percent were three-axle trucks (bobtails).

Similar studies of different container facilities in the United States are needed to develop a more comprehensive understanding of container port characteristics. Because of steady increases and anticipated growth in container tonnage through U.S. ports, further studies are needed to guide future investments to improve landside access. Studies should also focus on negative consequences of container growth, such as the contribution of truck traffic to traffic congestion and related air quality issues. This case study represents a limited initiative in this larger vision.

ACKNOWLEDGMENTS

The authors thank Tom Kornegay of the Port of Houston, who supported our efforts in collecting data within the Barbours Cut Terminal. Clyde E. Lee, Liren Huang, and Libby Jones of the University of Texas at Austin deserve special recognition for their guidance and assistance in the data collection effort.

TABLE 7 Percent Variation of Vehicle Classes (Monday–Sunday)

DAYS	2 AXLE	3 AXLE	4 AXLE	5 AXLE	6/MORE AXLE
MONDAY	58	11	5	16	10
TUESDAY	58	11	4	19	8
WEDNESDAY	63	10	5	15	7
THURSDAY	63	10	4	16	7
FRIDAY	60	10	5	18	7
SATURDAY	82	10	4	3	1
SUNDAY	80	11	6	2	1

REFERENCES

1. G. Muller. *Intermodal Freight Transportation* (2nd ed.). Eno Foundation for Transportation, Inc., Westport, Conn., 1989.
2. U. S. Ports Upgrade: Container Facilities. *Global Trade,* Vol. 106, No. 5, May 1987, pp. 25–28.
3. R. M. Katims. Keynote Address: Terminal of the Future. In *State of the Art Report 4: Facing the Challenge: The Intermodal Terminal of the Future,* TRB, National Research Council, Washington, D. C., 1986.
4. *U.S./Canadian Port Container Traffic in TEUs.* American Association of Port Authorities.
5. U.S. Ports Vie for Load Center Status. *Marine Log,* Vol. 93, July/Aug. 1988.
6. C. E. Shaw, C. H. Banks, W. W. Delaney, and D. J. Shuman. Container Competitive Strategies of Two Atlantic Ports, Freight Transportation. In *Transportation Research Record 1061,* TRB, National Research Council, Washington, D. C., 1986.
7. *The Port of New Orleans: Strategic Rail Plan, Phase 1—Situation Analysis.* Draft report. Ernst and Young, June 1990.
8. R. A. Nordahl. *Waterborne Commerce Trends and Port Ground Access Provision: San Francisco Bay Ports Access Study.* U.S. Department of Transportation, May 1985.
9. H. S. Marcus. Improving Port Productivity: Research Trends and Issues. *Transportation Research Forum,* Vol. 25, No. 1, Oct. 1984.
10. T. Guha. *Traffic Impact of Container Ports in the Southwest Region: A Case Study.* Master's thesis. The University of Texas at Austin, Austin, Dec. 1992.
11. *An Introduction to Urban Development Models and Guidelines for Their Use in Urban Transportation Planning.* Federal Highway Administration, U.S. Department of Transportation, 1975.
12. *NCHRP Report 187: Quick Response Urban Travel Estimation Techniques and Transferable Parameters.* TRB, National Research Council, Washington, D.C., 1978.
13. S. B. King. *Trip Generation Rates: A Case Study.* Master's thesis. The University of Texas at Austin, Austin, May 1990.
14. *Trip Generation* (5th ed.). Institute of Transportation Engineers, Washington, D.C., 1991.

Publication of this paper sponsored by Committee on Intermodal Freight Terminal Design and Operations.