TEMPORAL, PHYSICAL, AND SPATIAL DISTRIBUTION CHARACTERISTICS OF URBAN CONTAINER TRUCKS VERSUS OTHER ARTICULATED TRUCKS

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ABSTRACT

Container traffic and the associated interest in developing inland ports to attract this traffic are growing in metropolitan areas. This traffic typically requires drayage trucks to transport containers between intermodal terminals and urban shippers and to hinterlands beyond the urban network, also known as the “last mile.” Container trucks are different than other trucks and their movements are straining the capacity and operation of transportation facilities. Therefore transportation engineers and planners must explicitly consider container trucks in their designs.

This paper quantifies the temporal, physical, and spatial distribution characteristics of container trucks and reveals differences between other urban articulated trucks in Winnipeg, Manitoba, Canada. This research finds that total and articulated truck traffic data are poor surrogates for container truck traffic data and do not represent container truck characteristics. Peak container truck volumes occur during different times of the day than other articulated trucks and total traffic; corridors with high truck volumes do not necessarily have high container truck volumes, and vice versa; and about 80 percent of container trucks have tridem axles with the remaining having tandem axles whereas about 20 percent of articulated trucks have tridem axles with the remaining having tandem axles.

1. INTRODUCTION

This paper quantifies temporal, physical, and spatial distribution characteristics of urban container truck traffic based on research conducted in the Canadian Prairie Region. The research develops and validates the first urban container truck traffic model in North America. The model is applied in Winnipeg, Manitoba to estimate the container truck traffic volumes of this Canadian prairie city as a case study. Winnipeg has a population of 650,000, a land area of 465 square kilometres, and a 650 centre-line kilometre truck route network. The mainline of Canada’s only two Class 1 railroads, Canadian Pacific (CP) and CN, converge in Winnipeg. Both CP and CN operate an intermodal terminal in this city with capacities of 35,000 and 85,000 container lifts per year, respectively. Figure 1 shows Winnipeg within the Canadian Prairie Region along with the CN and CP mainlines.

Estimating urban truck traffic is difficult for many reasons including absence of data, complex road networks, insufficient data analysis tools, and limited personnel and financial resources. Consequently there is relatively little understanding about urban truck activity. Estimating traffic volumes for specific truck types, such as container trucks, increases the degree of difficulty; therefore the level of understanding about these trucks is much less than the general truck population. This research and its results are intended to improve knowledge about urban container trucking using Winnipeg as an example and provide other jurisdictions with a reference to begin understanding their situation.

Figure 1 – Canadian Prairie Region, CN and CP mainlines, and the City of Winnipeg

2. NEED FOR UNDERSTANDING CONTAINER TRUCKS

The demand for fast, reliable, and on-time delivery of containers is exerting pressure on the transportation system to become increasingly efficient while imposing expectations on it to adapt harmoniously with fluctuating, uncertain, unpredictable, and competitive global market trends. The pressure is particularly acute in urban areas where containers are transported by truck (known as drayage) along "last mile" intermodal connectors.

Major government transportation infrastructure investment programs such as Transportation Investment Generating Economic Recovery (TIGER) grants in the U.S. and the Building Canada Program contain specific provisions for urban intermodal connectors. Despite the magnitude of these multi-billion dollar initiatives, the absence of container truck data [1] and lack of methods to obtain this data [2] hinder the ability to make evidence-based investment decisions. This impedes the development of strategic infrastructure to maintain and enhance the efficiency, safety, and productivity of the transportation system necessary to compete globally [3]. Technological advancements to address this data shortage are converging and show promise but are currently insufficient for estimating container truck traffic on individual urban road segments [4]; subsequently the tools for quantitatively analyzing container trucking are also insufficient [5].

Understanding urban container truck traffic volumes and their operational characteristics is necessary to rationally approach transportation engineering and planning issues such as:

- identifying Intermodal Connectors which are eligible for federal funding,
- relating container truck traffic flow to rail intermodal terminal hours of operation,
- quantifying impacts of container trucks on pavements, bridges, and traffic operations,
- investigating freight modal shift effects on intra-city truck routing, and
- predicting changes in drayage patterns resulting from intermodal terminal relocation.

The objective of this paper is to demonstrate that urban container truck traffic characteristics can be quite different than other urban truck traffic and quantify these differences to help make better transportation system improvements. Understanding the temporal, physical, and spatial distribution characteristics of container trucks is essential for identifying and prioritizing areas of need for these trucks. Subsequently, funding dedicated to improve international freight transportation can be effectively and efficiently allocated to these areas to maximize return on investment.

3. THE URBAN CONTAINER TRUCK TRAFFIC MODEL

The research develops a vehicle-based container truck traffic model consisting of three steps: (1) defining the container truck network, (2) acquiring container truck traffic data, and (3) estimating and validating container truck traffic volumes on this network. Traffic models are commonly dichotomized as vehicle-based and commodity-based. Vehicle-based models use traffic data to estimate traffic volumes whereas commodity-based models convert economic data (e.g., commodity flows) to truck trips and assign these trips to the network using some derivation of a shortest path algorithm. Vehicle-based models are advantageous for urban container truck flows because economic variables influencing container freight volumes are often more difficult to predict than container truck traffic volumes [6]. Other advantages are greater availability of truck data compared to commodity data, conversion of commodity shipment volumes to truck trips is avoided, empty container movements are captured, and truck trips can be readily integrated with passenger car trips for route assignment [6]. However, it has been argued that these models lack information about commodities transported between analysis zones, do not provide any basis for estimating trip ends, are ill-suited for addressing trip chain patterns, and have limited capability for analyzing policy options [7].

3.1 Defining the Container Truck Network

The Winnipeg container truck network is defined by rationalizing the truck network in consultation with municipal government officials and trucking industry representatives, applying local knowledge of the transportation system, and identifying major container generators through a shipper survey. Figure 2 shows this network, land use zones generating container freight, intermodal terminal locations, CN and CP mainlines, and container truck traffic data collection stations used for this research. The container network comprises 285 of the 650 centre-line truck route network.

3.2 Acquiring Container Truck Traffic Data

Truck traffic data is commonly unavailable in urban areas. Cities that do have truck traffic data collection programs do not collect container-specific data. Furthermore, while current traffic measurement and monitoring technologies can classify trucks by length, weight, axle configuration and spacing, they generally cannot provide relevant body style information which is critical for identifying container trucks. Global positioning systems (GPS), radio frequency identification (RFID), Untethered Trailer Tracking (UTT) systems, optical detection, and inductive loop sensor-detector combinations are technologies with the potential to automate container truck data collection on road segments. Merging these technologies provides opportunity to automatically obtain container truck data but is still in the conceptual stages.

Readily-available data sources are insufficient for estimating urban container truck traffic. Statistical databases (e.g., U.S. Bureau of Transportation Statistics, Statistics Canada), transportation agency databases (e.g., Freight Analysis Framework, Canadian National

Roadside Survey), and transportation association databases (e.g., Intermodal Association of North America, Association of American Railroads) are unable, either individually or collectively, to capture vehicle-based data with the spatial, temporal, and physical specificity necessary to understand urban container truck traffic volumes.

This research uses two existing data sources and creates two new databases to estimate container truck traffic in Winnipeg. Existing data sources are average daily articulated truck volumes on the Winnipeg truck network provided by the City of Winnipeg and rail intermodal data from Statistics Canada. Databases created by this research are a shipper survey to identify container freight generators in Winnipeg and manual intersection truck classification turning movement counts. Following are descriptions of each.

3.2.1 Shipper Survey

Semi-structured telephone interviews guided by a series of discussion points are conducted to determine if a company uses containers for transporting freight, the magnitude of container generation, which rail intermodal terminal the company uses, and truck routes used for transportation. Fifty-seven of 70 potential companies participated in the survey (81 percent response rate) with 27 confirming their involvement in container freight transportation. Results are normalized to estimate annual container generation by land use zone.

3.2.2 Turning Movement Counts

The research designs a turning movement count program (hereby referred to as the Container Count program) to collect truck traffic data required to quantify temporal, physical, and spatial distribution characteristics of container trucks. The following data are collected for articulated trucks: body style, axle configuration, container owner, truck carrier name, and container length. Non-articulated trucks are excluded from the program. The program follows recommendations from the Federal Highway Administration (FHWA) Traffic Monitoring Guide [8] and incorporates qualitatively understood and assumed operational characteristics of container trucks (e.g., container trucks originate from, or are destined to, intermodal terminals).

The Container Count program consists of four tiers of count stations: Terminal, Primary, Secondary, and Tertiary. Establishing these tiers provide structure to the count program and facilitate a systematic method to prioritize count locations. Each tier is defined by the temporal and geographic characteristics of the count. Terminal count stations are located at the intermodal terminal entrances and involve collecting 48 hours of data at each location representing each hour of the day and day of the week. The other station tiers are distributed throughout the container truck network to obtain sample container truck data. The number of count hours assigned to each Primary, Secondary, and Tertiary station is 24, 12, and 8, respectively. A total of 90 counts are conducted at 17 locations and cover 138 of the 285 kilometres of the container truck network. The program collected 316 hours of data; 96 hours at two Terminal stations, 96 hours at four Primary stations, 108 at nine Secondary stations, and 16 hours at two Tertiary stations. The program counted 28,876 articulated trucks, including 3,854 container trucks.

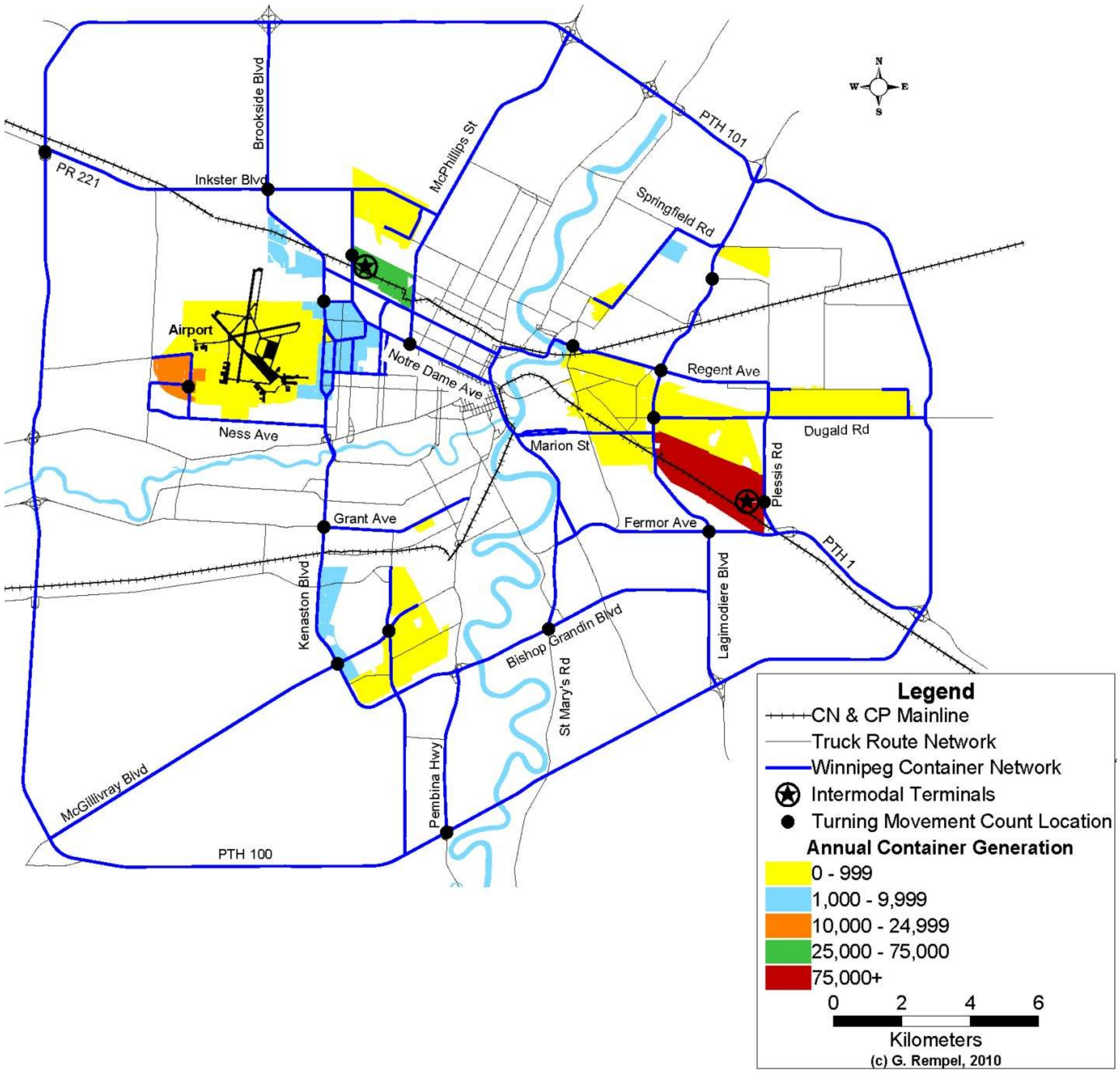


Figure 2 – Winnipeg road network, container demand, and data collection locations

3.2.3 Rail Intermodal Data from Statistics Canada

Statistics Canada collects monthly rail intermodal data using the mandatory Railway Carloadings Survey. Approximately 40 rail carriers report their monthly intermodal traffic in terms of the number of intermodal units and tonnage. Commodity data is not provided for intermodal freight and data is aggregated at the national level. Data is archived and available from 1999 to 2009, inclusive, and provides a high-quality source for estimating the monthly distribution of rail intermodal freight. The research uses this distribution as a surrogate for urban container truck traffic monthly distributions.

3.2.4 Average Daily Articulated Truck Traffic Volumes from the City of Winnipeg

The City of Winnipeg produces average daily articulated truck traffic volumes for each road segment on the Truck Route Network. Truck data is derived from pneumatic road tube count data, intersection turning movement counts (TMCs), and video traffic counts. Pneumatic road tube count data is used to calculate average daily traffic volumes expressed as passenger car equivalents (PCEs). This data is collected on the Truck Route Network each year between September and December. Each count is a minimum of 48 hours (although the City has defined 95 control stations that collect data for seven consecutive days). City of Winnipeg intersection TMCs collect turning movement data by vehicle class on the Truck Route Network. Vehicle classes are cars, single unit trucks, semi trailers, and semi combinations. Data is aggregated into 15-minute bins and body type data is not collected. These counts occur between 07:00 and 22:00 on all days except Sunday. In 2010, 24-hour video traffic counts were conducted at four locations on the Truck Route Network which classified vehicles as passenger, single unit truck, semi trailer, semi combination, and bus. Hourly factors were created for each vehicle class and assigned to the Truck Route Network to estimate average daily traffic volumes for these vehicle classes [9]. These estimates include vehicle-kilometres travelled (VKT) by truck type, by hour, and by speed, but do not disaggregate truck volumes by body type or axle configuration.

3.3 Estimating and Validating Container Truck Traffic Volumes

Average daily container truck traffic volumes are estimated separately for road segments with and without Container Count data. For segments with Container Count data, hour-of-day and day-of-week temporal expansion factors are calculated from Terminal count data. These factors are applied to the sample data collected at Primary, Secondary, and Tertiary stations to expand these short-duration counts into daily volume estimates. For segments without Container Count data, container truck volumes are estimated by transferring volumes from adjacent segments with data, conducting intersection flow balancing, or applying a default value. The default value is the average percent of container trucks to articulated trucks; this is calculated using data from all segments with container truck volumes. This percentage is then applied to the daily articulated volume on road segments without Container Count data and where volumes cannot be transferred. Completing this process produces daily container truck volumes on the entire container truck network and provides information about the spatial distribution of these trucks.

As with all models, a population of data is unavailable and assumptions are made in this research. Therefore, applying an industry-accepted model validation test is necessary to instil confidence in the model and demonstrate the accuracy of the results. Validation quantitatively tests the ability of the model to predict future behaviour by comparing model predictions with information from data sources not used to develop the model [10]. Validation tests can range from simple reasonableness checks of model outputs to sophisticated statistical techniques.

The validation test in this research compares container truck traffic volume estimates produced by the model at intermodal terminals to loaded containers generated by intermodal terminals provided by Statistics Canada. Modelled container truck volumes are deemed valid if they differ from Statistics Canada data by less than 10 percent [11]. However, modelled volumes include empty containers whereas Statistics Canada provides loaded container data only. Therefore the sensitivity of the validation test also considers empty containers. The validation test reveals that the modelled container truck traffic volumes are valid if between one-third and two-thirds of Statistics Canada containers are empty. The literature, industry statistics, and data collected by this research support this as a reasonable range of empty containers; therefore this model passes the validation test.

4. URBAN CONTAINER TRUCK TRAFFIC CHARACTERISTICS

The hour-of-day and day-of-week temporal expansion factors produced from Terminal counts, sample count data collected at the other Container Count stations, and rail intermodal data from Statistics Canada provide information about the temporal characteristics of container truck traffic. Container length and axle configuration data provide information about the physical characteristics of container trucks. This section quantifies these characteristics and demonstrates that container trucks differ from other articulated trucks in nearly all these aspects.

4.1 Spatial Distribution Characteristics

Spatial distribution differences are evident between container trucks and all articulated trucks. These differences are important to understand since improvements made to routes that carry high truck volumes may not translate into benefits for container trucks. For projects targeted at enhancing container freight movement, such as the Canadian Government's Asia-Pacific Gateway and Corridor Initiative, these differences can result in resources being incorrectly allocated. The model developed by this research produces average daily traffic volumes on the container truck route network for container and articulated trucks to demonstrate these differences.

Figure 3 and Figure 4 show average daily container and articulated truck traffic volumes, respectively. The purpose of these figures is to illustrate the differences in spatial distribution between container trucks and articulated trucks and not to compare volumes. Therefore, the scales of the figures are different to increase the clarity of the traffic volumes. These figures illustrate that segments carrying high volumes of truck traffic do not necessarily carry high volumes of container truck traffic.

The research uses the spatial distribution of container trucks and the magnitude of their daily volume on each segment to define a container truck route network. Applying the model developed by this research reveals the following important characteristics about the container truck route network:

- The length of the container truck route network is about 45 percent of the truck route network and about five percent of the total street network.
- The container truck route network is under-represented in terms of average daily traffic but over-represented in terms of average daily articulated truck traffic. The container truck route network carries about one-third of the average daily traffic volume on the truck route network but two-thirds of the average daily articulated truck traffic volume.
- The container truck route network supports nearly 90 percent of the truck vehicle-kilometres travelled (VKT) on the truck network.
- Container truck volumes on the container truck route network are 13.3 percent of articulated truck traffic volumes.

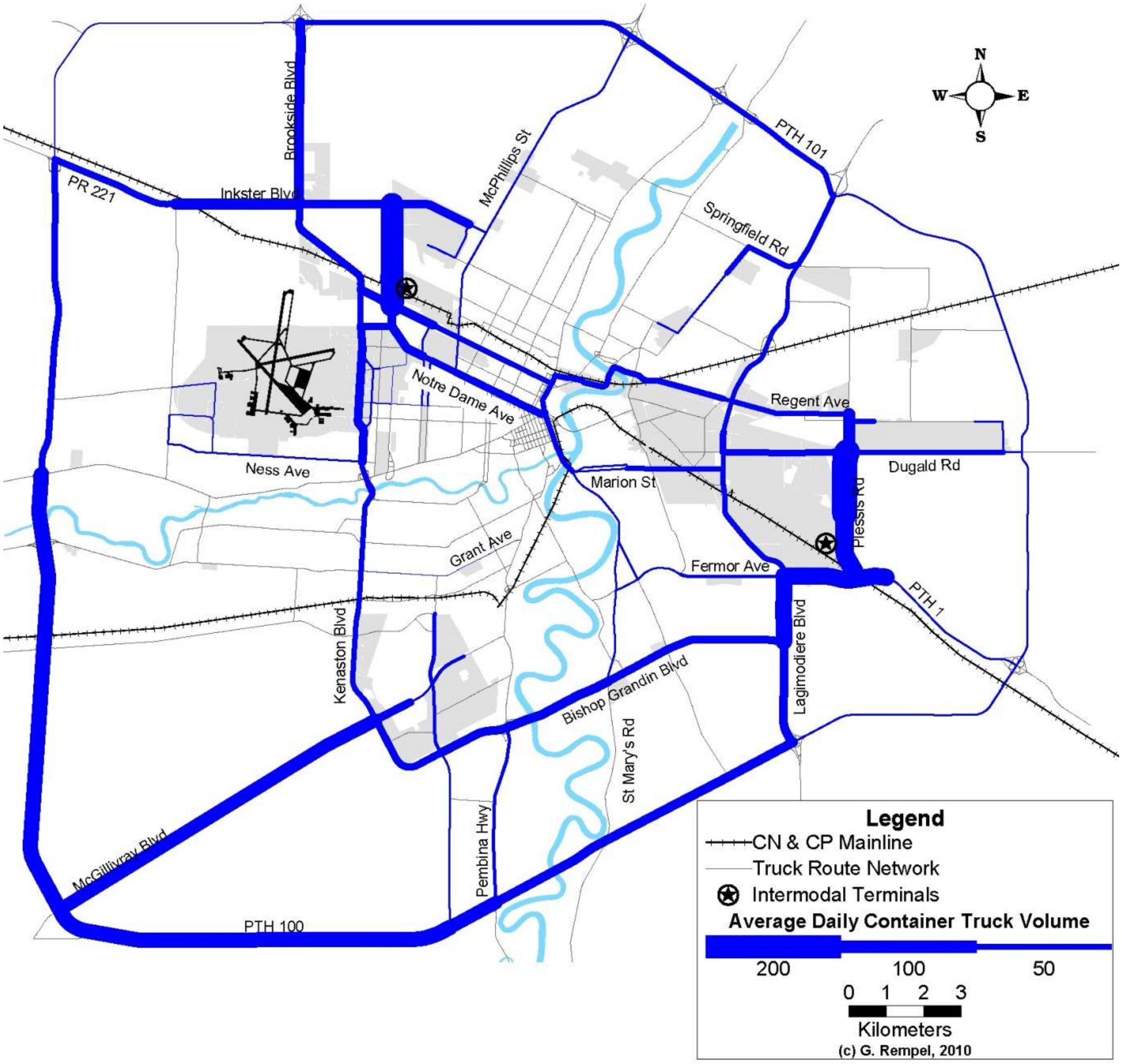


Figure 3 - Average daily container truck volume

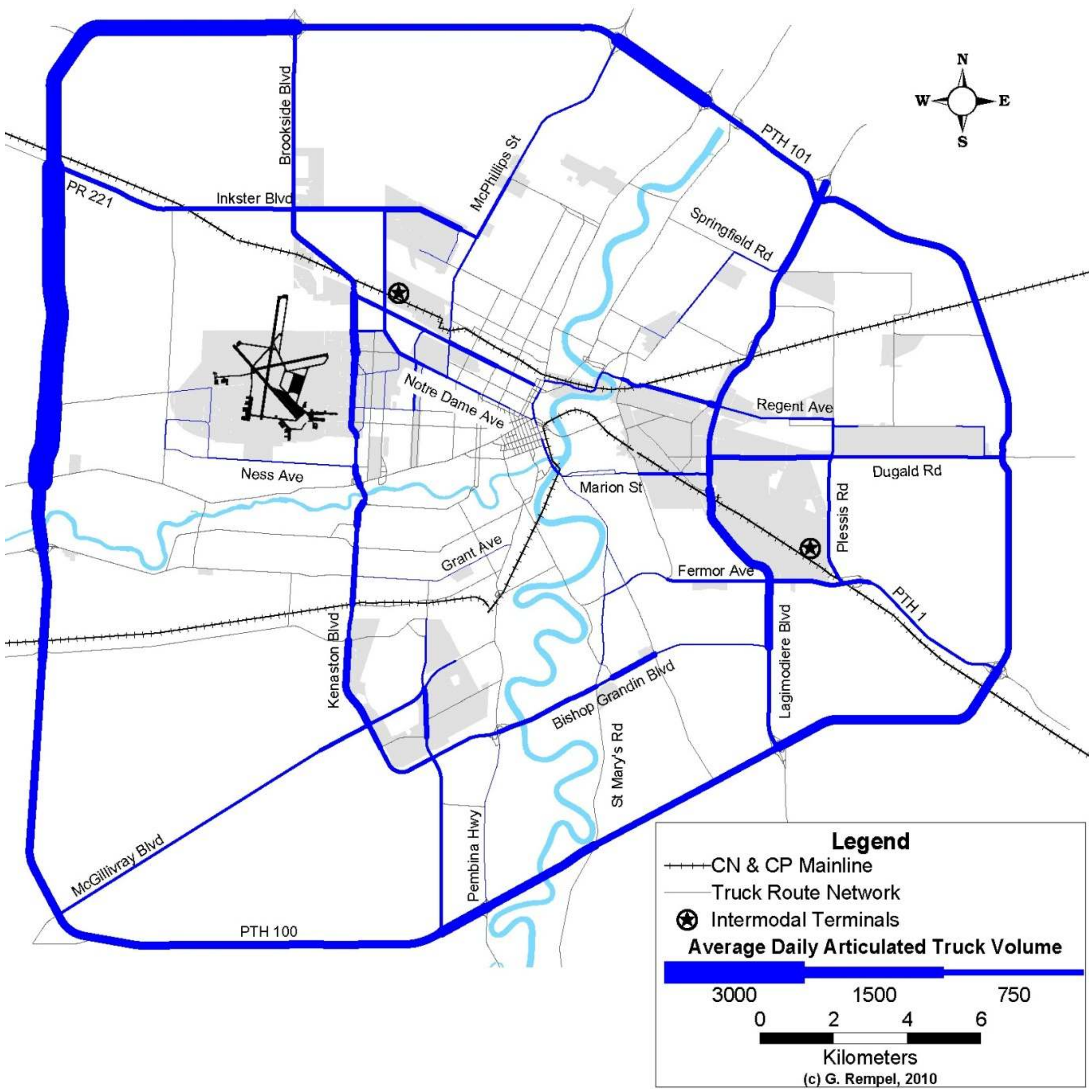


Figure 4 - Average daily articulated truck volume

4.2 Physical Characteristics

The physical differences between container trucks and articulated trucks are important to understand for bridge and pavement design and traffic operations analysis. Physical characteristic data provided by this model are axle configuration, container length, and trailer configuration of container trucks. The following three observations are made based on model results:

1. More than 95 percent of container trucks are single-trailers. The remaining are double-trailers and there are no triple-trailer container configurations observed.

2. There is about a 20/80 split between tandem and tridem axle configurations for container trucks. Conversely, there is an 80/20 split for articulated trucks. This observation is likely influenced by chassis manufacturers as opposed to the types of commodities being carried. This is because chassis are required to carry a fully loaded container at any time, thus requiring a tridem axle configuration. By manufacturing all chassis with tridem axles, the equipment fleet balancing task becomes simplified at the expense of having extra axles for low density commodities.

3. Nearly all containers are 20-, 40-, or 53-feet long (>95 percent). In total, approximately 10 percent are 20-feet, 30 percent are 40-feet, and 60 percent are 53-feet.

4.3 Temporal Characteristics

Container truck traffic differs temporally from other articulated truck traffic in terms of hour-of-day, day-of-week, and month. Figure 5 and Figure 6 show the hour-of-day and day-of-week characteristics of container trucks and articulated trucks on the container truck route network and at the intermodal terminals. These figures reveal the following temporal characteristics:

- Container truck traffic peak periods occur during typical off-peak hours of other traffic.
- The hour-of-day, day-of-week, weekday, and weekend container truck traffic distributions at intermodal terminals is a reasonable representation of these distributions on the rest of the container truck route network.
- The day time and night time distribution of container trucks and articulated trucks are nearly identical.
- Container truck volumes are above the average daily container truck volume between Sunday and Thursday, and decrease to about 50 percent of the average between Friday and Saturday.
- Articulated truck volumes on the container truck route network are above the average articulated truck daily volume between Monday and Friday and between 30 to 40 percent of the average on the weekend.

These findings indicate that the temporal characteristics of container trucks at intermodal terminals extend to the entire network. There is a strong correlation between the hour-of-day and day-of-week distribution and therefore container truck traffic at intermodal terminals may be an appropriate predictor of container truck traffic on the network. The research applies a linear regression model to quantify this correlation. For hour-of-day distribution, the R^2 value is 0.79 and for the day-of-week distribution it is 0.98.

These findings also show that peak container truck traffic volumes occur during non-peak hours of other traffic, including articulated trucks. Furthermore, container truck volumes are highest between Sunday and Thursday whereas articulated truck traffic volumes are highest during weekdays. Therefore, while traffic operation improvements specific to peak-hour traffic and weekday conditions may address critical issues for articulated trucks, these improvements may not translate into benefits for most container trucks. The only temporal similarity between container truck and articulated truck volumes is their proportionality between day and night; about 70 percent of daily truck traffic occurs during day time hours (defined as 07:00 to 19:00).

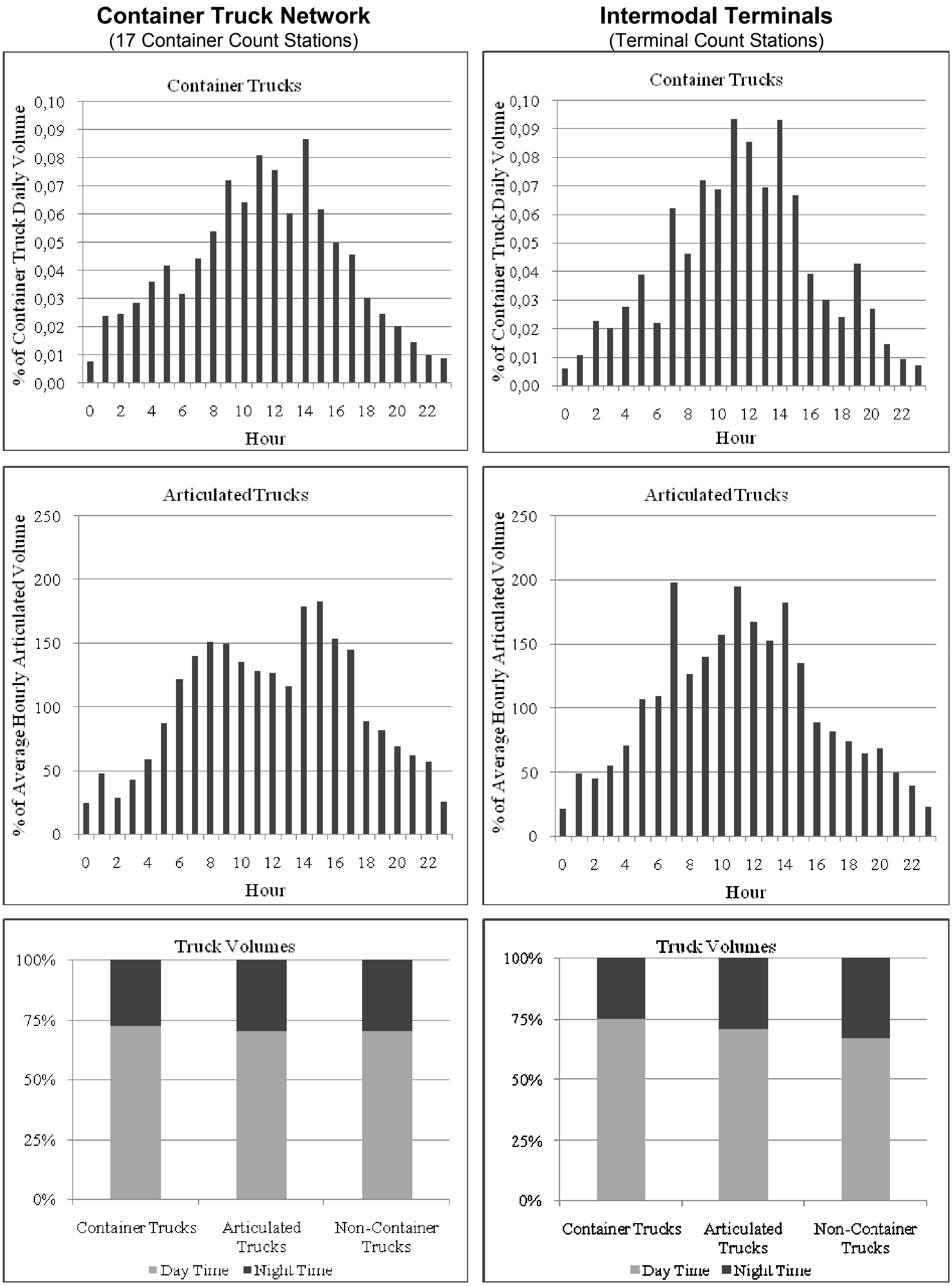


Figure 5 - Hourly temporal differences between container and articulated trucks

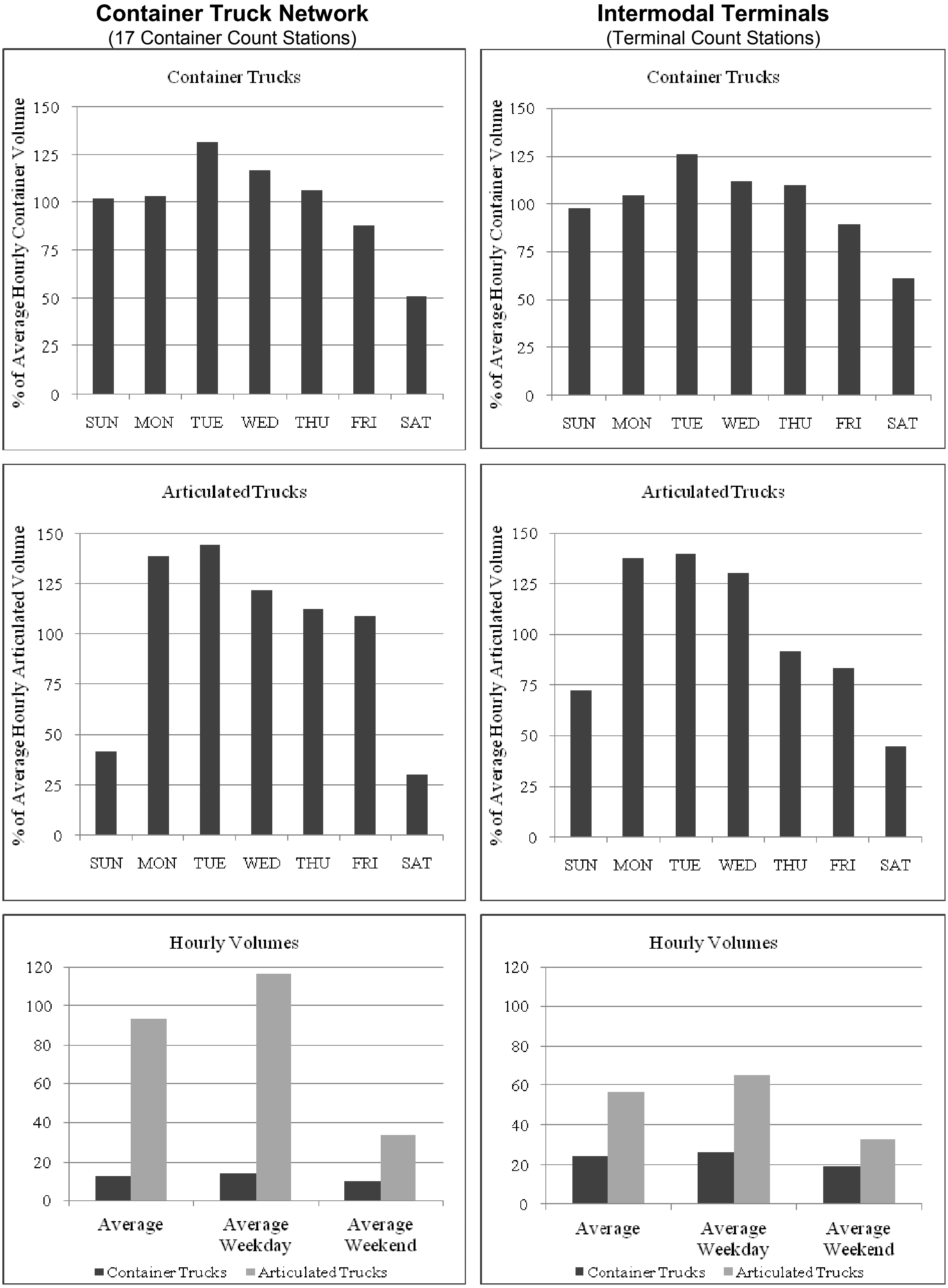


Figure 6 - Daily temporal differences between container and articulated trucks

Figure 7 shows the monthly distribution of articulated trucks increasing between January and August (about 10 percent per month) and decreasing from August to December (about 10 percent per month, with a 25 percent drop from November to December). Articulated trucks exhibit seasonality, with volumes ranging from 75 percent of the average in January and December to 125 percent in August. Container truck traffic is stable between January and November with about a 10 percent drop from November to December and does not exhibit strong seasonal trends. This is an indication that containers carry a diverse commodity mix that results in balanced seasonality demands.

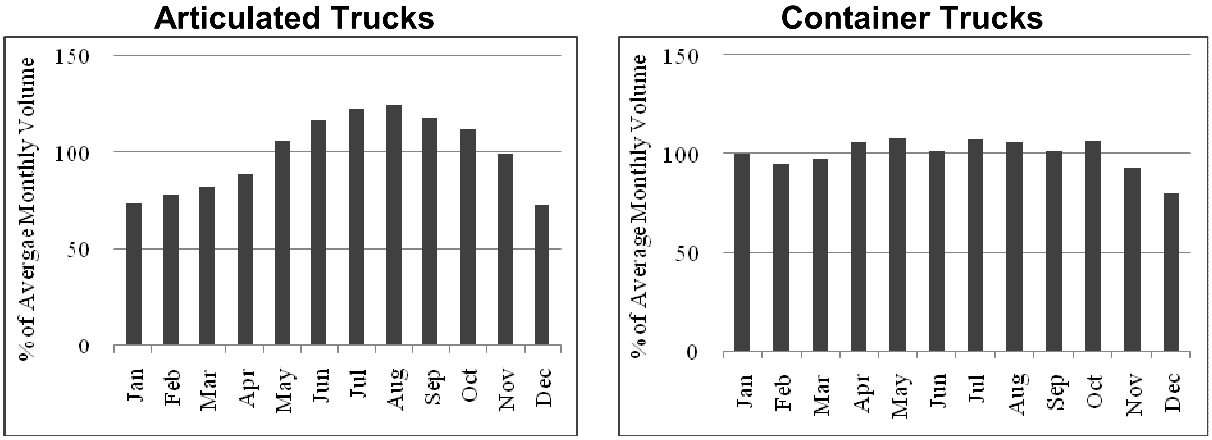


Figure 7 - Monthly temporal differences between container and articulated trucks

Figure 8 shows the hourly distribution of container and articulated trucks on the container truck route network. This figure illustrates that container truck volumes follow a different hourly distribution than articulated trucks. Articulated trucks exhibit distinct peaking periods, particularly between 13:00 and 18:00; however, hourly changes in container truck volumes are less apparent. This figure also illustrates the proportion of container trucks to articulated trucks on the network. On average, container trucks comprise 13.3 percent of articulated truck traffic. This is not an insignificant component of the truck population and thus requires specific attention from transportation engineers and planners.

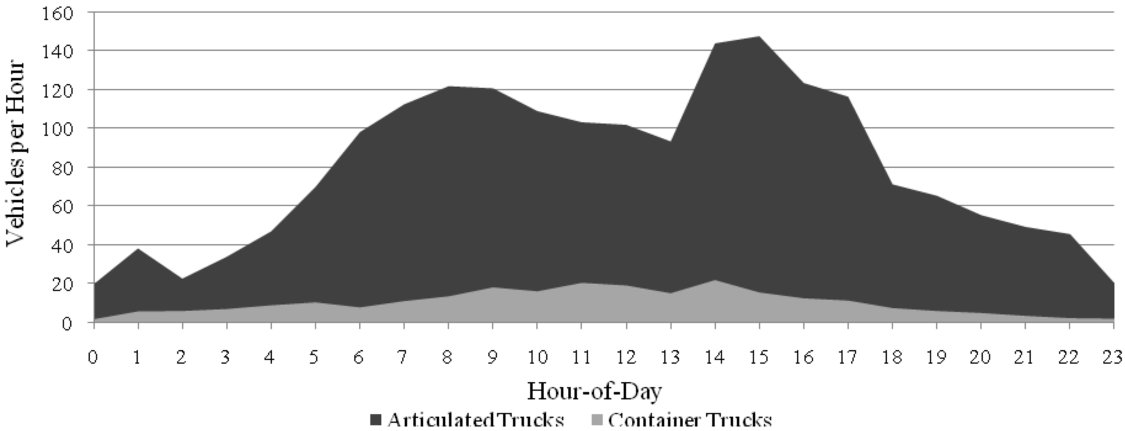
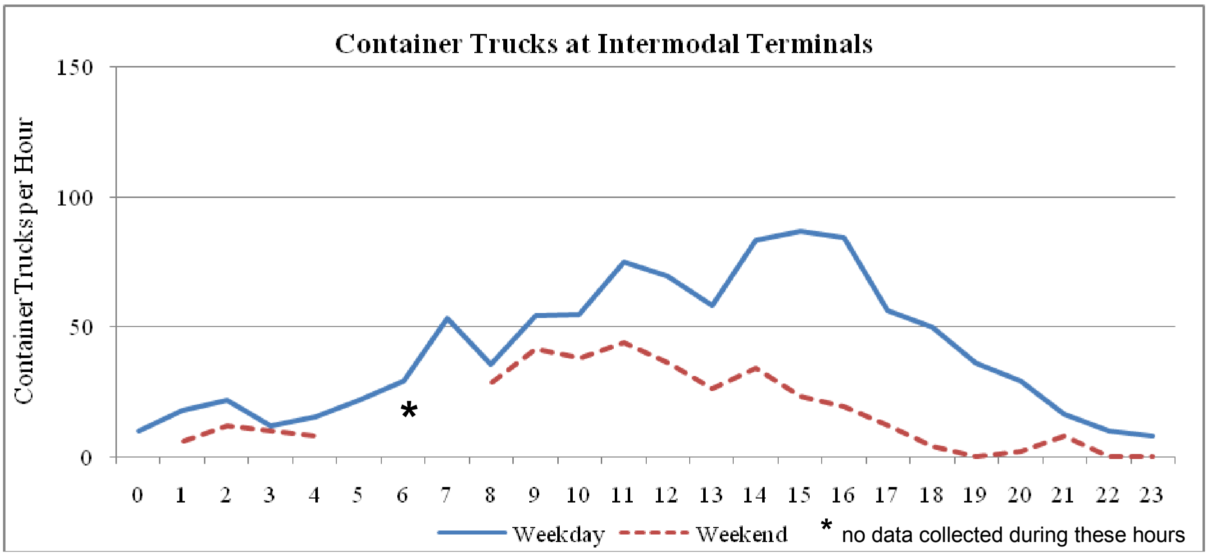


Figure 8 - Hourly container and articulated truck traffic on the container network

Weekday and weekend traffic volumes are another difference between container trucks and articulated trucks. Figure 9 shows container truck volumes at intermodal terminals and articulated truck volumes on the container truck route network for weekdays and weekends. This figure indicates that weekend articulated truck volumes on the container truck route network are substantially less than during weekdays. In terms of average hourly volumes, weekend articulated truck volumes are about one-quarter of weekday volumes. Furthermore, the hourly distribution on weekends does not have the same peaking characteristics as during weekdays. For container trucks at intermodal terminals, the figure indicates that weekend container truck volumes do not experience the type of decrease as articulated trucks. The average hourly container truck volume at intermodal terminals on weekends is approximately three-quarters of weekday volumes with similar hourly distributions on weekends as weekdays. These differences reveal that container trucks operating during the weekend may require special accommodation, particularly at intermodal terminal entrances.



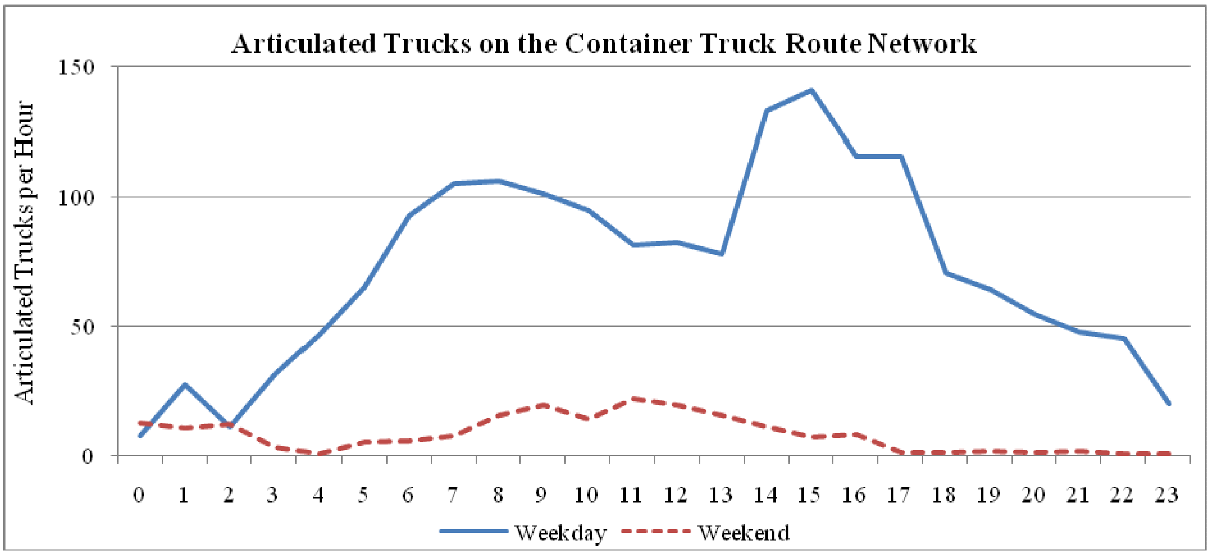


Figure 9 - Hourly weekday and weekend container and articulated truck traffic

CONCLUSIONS

This research concludes that total truck traffic and articulated truck traffic data are poor surrogates for container truck traffic data and do not represent the temporal, physical, and spatial distribution characteristics of container trucks. Cities do not have the data required to understand container truck traffic on their road networks and technologies are not yet available to automatically obtain this data. Therefore, there is little understanding about urban container truck traffic at a time of intense global competition and increasing international freight demand. This research produces the first urban container truck model to bring new data and knowledge on this subject.

Peak container truck volumes occur during different times of the day than other articulated trucks and total traffic. Container truck volumes decrease by 28 percent on weekends compared to a 70 percent decrease by articulated trucks. The monthly distribution of container trucks remains consistent whereas articulated truck traffic exhibits seasonal variations. Prior to using Terminal data for expanding short-term counts, temporal container truck distributions on the network are compared to distributions at intermodal terminal entrances. This comparison reveals that the hour-of-day and day-of-week distributions of container trucks at intermodal terminals is a reasonable representation of the distributions on the rest of the container truck route network.

The model finds that corridors with high truck volumes do not necessarily have high container truck volumes, and vice versa. Container trucks were found to use only a portion (45 percent) of the truck route network. The daily container truck volume estimates produced by this model are capable of identifying routes that qualify as candidates as Intermodal Connectors and inclusion in the National Highway System.

The difference in axle configurations is the most important physical difference between container trucks and articulated trucks in terms of pavement design and the difference in trailer configurations is the most important physical difference in terms of geometric design. About 80 percent of container trucks have tridem axles with the remaining having tandem axles whereas about 20 percent of articulated trucks have tridem axles with the remaining having tandem axles. More than 95 percent of container trucks are single-trailer units with the rest in a double-trailer configuration. The proportion of 20, 40, and 53 foot containers is 10, 30, and 60 percent, respectively.

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