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GPS Based Pilot Survey of Freight Movements in the Midwest Region

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16. Abstract

This report explains the methodology and results surrounding a recently completed study of a major grocery trucking firm's travel patterns. The research group used Global Positioning System (GPS) logging devices to trace the temporal and spatial movements of grocery trucks throughout the study period in the spring and summer of 2012. At the end of this survey, the research team successfully recorded 108 logs that represented a full truck-days' worth of GPS data.

GPS data collection is passive and only requires participants to ensure that the GPS devices have sufficient battery power and satellite visibility. In this study, the research team did not require the participant's truck drivers to do anything. Even without driver logs or written surveys, the GPS devices collected a great deal of information that the research team used to make behavioral inferences. Logistical decisions and behavior gleaned from this collected GPS data included destination choice, route choice, time-of-day choice, and trip length. The variables reflecting these behaviors, as well as those of speed and time management, are denoted to illustrate the practicality of modeling freight travel via this methodology.

The information presented here has been collected through the cooperation of a major Illinois based grocery chain with their headquarters and distribution center located in the Chicago region. The research team used the digital log files extracted from GPS tracking devices and the driver logs filled out during distribution tours as part of the analysis. The research team cleaned, processed, analyzed, and summarized this data.

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Executive Summary

Project Summary

This report chronicles the methodology and results behind a recently completed study of a major grocery trucking firm's travel patterns. The research team used Global Positioning System (GPS) logging devices to track the temporal and spatial movements of grocery trucks throughout the study period in the spring and summer of 2012. By analyzing the touring practices of shipping firms, future freight modeling activities can benefit from the insights and patterns extracted from the data.

Background

This project evolved out of the researchers' previous experience conducting a similarly styled survey of non-commercial automobiles. That 2009 study used GPS devices to track the travel movements of private civilian vehicles in the Chicago area, while maintaining a special focus on the travel patterns of the elderly. In carrying over that experience to a study of commercial vehicles, the study team hoped to expedite the data collection process and apply earlier learned lessons.

The study has been carried out by the University of Illinois at Chicago (UIC) with the assistance of the National Center for Freight Infrastructure Research and Education (CFIRE). The region investigated by the study is Northeastern Illinois, focused on the nine counties that make up the Illinois portion of the Chicago metropolitan area. A major grocery chain in the Chicago area volunteered to participate in this pilot study and is the focus of this data collection and analysis. Thus, the major activities tracked include such touring destinations as grocery stores, gas stations, an intermodal facility, and the company distribution center.

Process

From start to finish, the project ran for a duration of 13 months, including the trial runs in 2011. Starting when the GPS devices were delivered to the grocery chain in May 2012, the survey ran for 6 weeks, limited by the number of trucks used for daily runs rather than the number of devices or ability to collect data. By the end of this survey, the research team successfully recorded 108 logs that represented full truck-days' worth of GPS data.

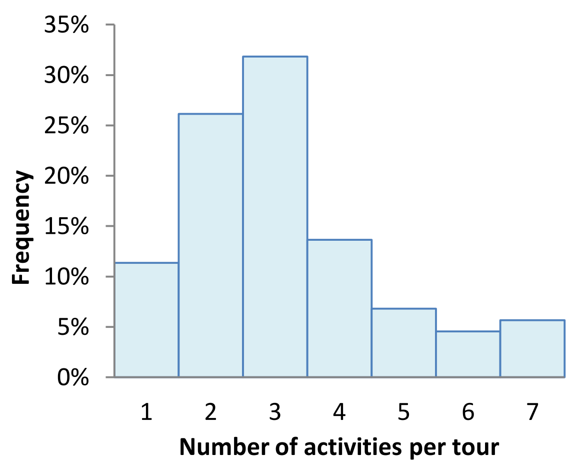
GPS data collection is passive and only requires participants to ensure that the GPS devices have sufficient battery power and satellite visibility. In this study, the research team did not require the participant's truck drivers to participate actively while on their tour. Even without driver logs or written surveys, the GPS devices collected a great deal of information that the research team used to make behavioral inferences. Logistical decisions and behavior gleaned from this collected GPS data included destination choice, route choice, time-of-day choice, and trip length. The variables influencing these behaviors, as well as those of speed and time management, are denoted to illustrate the practicality of modeling freight travel via this methodology.

Written surveys were utilized only in the trial portions of this study. The grocery chain provided the researchers with sufficient logs and background data that relegated written surveys to be unnecessary. The travel logs provided overviewed the basic details of each tour, including odometer readings on the cab, the types and quantities of goods delivered, and the order of delivery locations. Any unscheduled stops could be inferred from the data held within the collection of GPS traces.

Findings and Conclusions

The study served as an efficient demonstrative study and yielded valuable information regarding the operations involved in grocery shipping. Findings extracted from the GPS data and the related driver logs are summarized in greater detail in later sections.

Understanding the trip chaining methodology is of importance to model builders as the order and duration of trips greatly affect travel patterns and route choices. Extracted from the dataset collected in the pilot study, the number of activities on a tour ranged between 1 and 7, most often comprising of 2 or 3 stops. These include main activities, considered pick-up and drop-off activities at stores, warehouses, and distribution centers in the study area, and maintenance activities, those performed in support of the tour. The split between main and maintenance activities can be seen in Figure A.



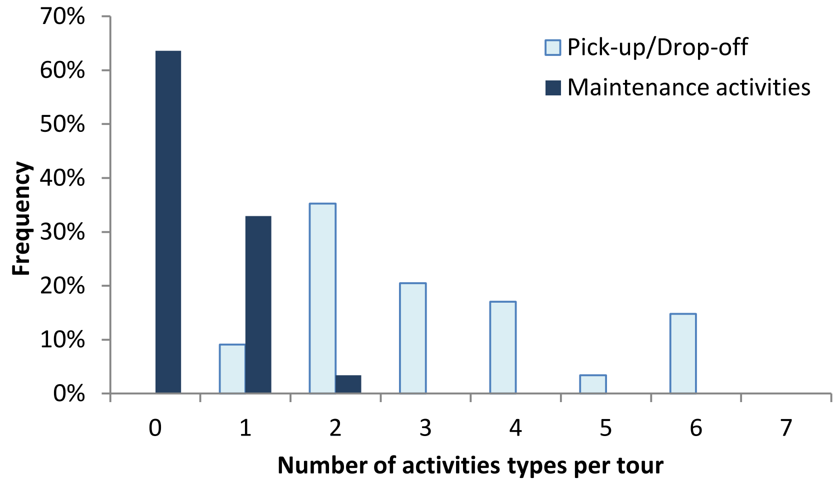


Figure A: Activities per Tour

The duration of trip activities is presented in Figure B. The average activity duration was calculated to be 55.7 minutes with a standard deviation of 28.3 minutes. Main activities were found to last longer however, averaging 66.4 minutes, compared with 45.0 minutes for maintenance activities.

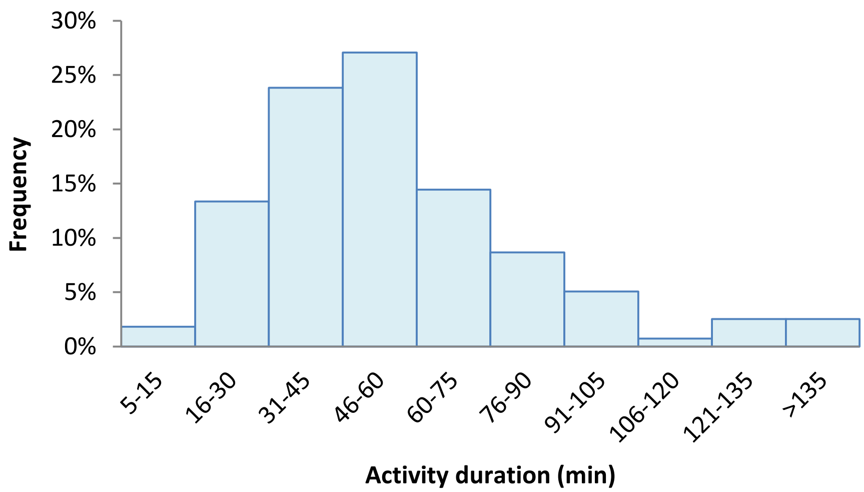


Figure B: Activity Duration

The GPS data was processed utilizing an in-house method that offered for the traits of the Open Street Maps network to be applied to the links of the selected routes. The recorded locations and times were assembled in different ways to offer a multitude of perspectives on the circumstances of urban freight movement, including path shape classification, urban/suburban trip divide, and road classification type. Examples of trace visualizations have also been provided in later sections to demonstrate the ease at which inferences can be drawn from the processed data.

Recommendations for Further Action

The data collected in this study offers a glimpse into an infrequently observed subject matter, urban freight movements in the Midwestern United States with GPS level specificity. The 108 GPS traces collected represent a thorough look at one large grocery chain in Chicago. As an overview of the company and a large chunk of the industry this is satisfactory, however for a robust dataset, the pilot should be expanded, possibly to involve more grocers, but certainly to include freight shippers of other business types.

The methodology tested has coordinated the smooth operation of GPS devices in a company setting, and may be implemented in other settings with few tweaks. Maintaining battery life and extracting the data on a regular basis are important, but obtaining participants across commercial and industrial fields is the prime task and is often difficult due to concerns over privacy. Firms commonly guard their information and trade secrets quite diligently leading to data collection roadblocks, however the name recognition of an organization such as a DOT may be influential.

1. Introduction

Urban society's proper and fluid functioning depends upon expedient and efficient movement of goods within, between, and through urban areas. Trucks overwhelmingly fulfill this growing role for most cities. Unlike their depiction in the four-step transportation forecasting model, trucks commonly make long tours that include multiple chained destinations *(1)*. The patterns and structure of these tours are very important because the distribution of warehouses and destinations, operating hours, and route selections all significantly affect modern cities' travel patterns. Researchers thus need to delve further into this question as well as into how truck tours impact the urban environment and quality-of-life.

With the now widespread use of Global Positioning System (GPS) devices, the implementation of larger and more detailed travel surveys has become significantly easier and less burdensome. While certain trip details are still best learned through written or prompted recall survey forms, the collection of spatial data in this manner offers complete routing information in great detail. Limited only by battery life, GPS devices can record detailed observations that offer more complete information about tour stops and routes taken. This benefit becomes especially significant when considering survey fatigue. In the written surveys that have preceded GPS data collection, participants have regularly noted their displeasure over the amount of data entry requested or have forgotten or neglected to fill out records depicting all activities *(2, 3)*.

The tour information obtained in this data collection effort therefore may be used to analyze urban area freight movements and the relationships between this region and the rest of the country and world. The detailed GPS data also provides insights into route choice, destination choice, and time-of-day choice as they apply to decisions governing goods movement.

2. Background

As they have become cheaper and more common, researchers have more frequently used handheld GPS devices to collect detailed, locational data while minimizing the burden placed on participants.

In 1996, Murakami and Wagner *(4)* oversaw an early trial of GPS surveying in Lexington, Kentucky. Since this study was designed as a proof of concept, it served primarily to supplement the existing household travel survey. The researchers gave a personal digital assistant (PDA) equipped with a GPS device to each participant, who would not only turn the device on and off, but would also enter critical information, such as vehicle occupancy and travel purpose, in real time. This survey was conducted for 100 households over a six day period.

By 2000, an early implementation was conducted in the Netherlands to monitor not just one travel mode but a wide variety of possible travel modes *(5)*. Similar to the Lexington study, the statistical validity was not reported to be high but was considered sufficient enough for early exploratory analysis. This study featured 102 randomly selected participants and 49 volunteers from the engineering department. This study's researchers discovered that the device's size affected trip reporting rates. Cyclists and walkers were less likely to carry along the 2 kg package than the other participants.

Between 1999 and 2001, the Rätt Fart (Right Speed) program collected GPS data in the Swedish town of Borlänge, located approximately 120 miles northwest of Stockholm *(6)*. Their recording devices were installed in approximately 400 private and commercial automobiles. These devices were set up to record when the engines were turned on or off to automatically record trip starting and ending locations.

In 2004, researchers included a GPS component in the Kansas City Household Travel Survey *(7)*, which featured a sizeable survey population, totaling 377 drivers and 2,359 vehicle trips. However, 29% or 108 of these participants neglected to report at least one trip, resulting in 280 unreported GPS trips. The study assembled participants' demographics and traits, which provided insights regarding which groups were more or less likely to report data needed to supplement the GPS information. It was found that males tended to neglect reporting trips more often than females and more educated and employed participants more frequently provided complete information.

A 2008 study at the University of Sydney analyzed GPS trace processing and made a series of recommendations for manual inspection of traces *(8)*. This study found certain records questionable in a recent freight survey in Melbourne and re-analyzed them through visual examination. These questionable records included trips where the direction was reversed, where signal loss occurred, where the trip was very short, and where the engine was turned off between 30 and 120 seconds.

In 2009, the University of Illinois at Chicago conducted a GPS tracking study of Chicago metro area residents *(9)*. This prompted recall study allowed users to upload their GPS traces and verify its accuracy shortly after on a displayed electronic map. Based on the distribution of GPS points in time and space, an algorithm was used to single out locations as potential trip start points, end points, or destinations. Users were able to confirm, add, or remove activities to conform to their recent trip's structure. The setup was designed to be familiar to regular internet users.

The Canadian Vehicle Use Study, known from 1999-2009 as the Canadian Vehicle Survey, is a quarterly study of vehicle movements across Canada *(10)*. Two of the three focus groups consist of medium and heavy trucks. Using vehicle registration files, a random sample of 20,000 vehicles per year were chosen for participation, and owners were contacted by telephone. Beginning in 2012, survey volunteers were able to expedite much of their survey through the use of a provided GPS device in their automobile. In addition to collecting the normal GPS spatial data, a feed into the OBDII data port of the automobile allowed the device to read the engine starts and stops and to turn itself on and off automatically with the vehicle. This input also allowed for the reading of such factors as fuel use, speed, engine information. For more detailed questions, in place of a paper survey, the device's touchscreen interface allowed for the input of basic variables such as passenger count and trip purpose. In eliminating any paper trail in the data collection, data preparation becomes simpler for surveyors and the survey becomes easier and more automated for participants.

To better identify trip destinations in heaps of geographic point data, the University of Toronto developed a method of clustering data points together as a means of eliminating a large source of participant burden when driver records were unavailable *(11)*. This 2011 study determined that a single distance-based threshold for forming clusters of GPS points is unsatisfactory for analysis and instead proposed the following two-step automated clustering procedure.

In the first step, the researchers used Ward's Method of hierarchical cluster analysis to assemble adjacent GPS points into likely clusters using distance thresholds between 400m and 700m. In the second step, they used the GPS point in each cluster that is its geometric median to determine if it is within the same parcel boundaries as any other. These two clusters would then be merged together into one.

The UIC research team will put this data to future use in their disaggregate freight modeling of Northeastern Illinois, but will briefly present similar work in the literature here. The University of Calgary has developed a series of models, which provide significant insights into many aspects of freight movement in the Calgary metropolitan area *(12)*. All types of commercial vehicles are available for modeling, as well as a wide variety of commercial enterprise types. Many policy scenarios may also be studied that incorporate the model's microsimulated representation of freight aspects, such as deadheading vehicles and allocating shipments to vehicles.

Figliozzi has included analysis and disaggregation of tours by tour attributes *(13)*. Different tour varieties are investigated for patterns in vehicle kilometers traveled (VKT) for that trip type. Figliozzi asserted that tours with multiple stops accumulate more VKT than direct tours, when there are equal payloads. Other analysis investigates the relationship between time sensitivity and freight vehicle routing and the shape of trip length distributions.

3. Methodology

The 2011-2012 UIC freight survey relied on the experience and hardware of the previous 2009 GPS travel survey *(14)*, which primarily examined the trip chaining travel behavior of elderly people in Northeastern Illinois. The 2012 survey, meanwhile, focused on freight truck movements in Northeastern Illinois.

The research team used AMOD designed AGL3080 GPS Photo Trackers, which were handheld and operable on rechargeable AAA batteries. These GPS trackers have sufficient storage capacity at 128 MB and have the battery capacity for 15 continuous hours of data collection. This study's full daily duration, however, necessitated that participants recharge the GPS trackers every night.

Cold starts are a problem that affects the accuracy of GPS devices at the beginning of each day. Inaccurate readings may be common for a few seconds to 100 seconds of data collection *(15)*. This occurs as the device establishes connections with nearby satellites and decreases as it makes a sufficient number of connections. This did not affect our freight study as much as other studies on commuter or pedestrian movements. In this study, the GPS devices were turned on in the trucks' cabs when the trucks were cold started. By the time internal company checklists were filled out and the cabs were connected to their trailers, the GPS devices should have been operational while still within the staging ground's confines. Alleviating the truck drivers' survey duties was critical to the research team's successful completion of this study.

The research team requested a series of brief surveys concerning the firm and driver's activities, which the firm primarily completed. Placing the burden more on the firm and not the drivers was important because the firm has a stake in learning more about how to make their logistics functions more efficient. The research team, however, was cognizant about limiting the survey burden to only collect data that would be necessary for the freight model to work well.

The series of surveys consisted of three documents. First, the research team designed a one-time completion, one page long survey to gather data about the firm surveyed, which included its location, fleet size, business type, shipment patterns, and business concerns. Second, the research team composed an additional page for each truck's tour that included questions that the driver needed to answer only once, such as truck type, and evaluation of the day's route. Lastly, a checklist was included for the stops of a tour. This establishes the location, time, and purpose of the stops on the trip.

The GPS device was allowed to remain in continuous operation throughout the duration of the shipping activity. It was only shut off when the journey was complete and a circuit had been made. Other than powering the device on and off, its operation did not require the driver to take any active action. Each day at a scheduled time, a student employee would make the trip to the firm distribution center and trade out drained batteries for recently charged ones. The GPS devices themselves were each assigned to an individual driver, making the trace-drivers log matching process simple.

In addition to the information collected through the survey, the study's main target made the diary logs available. These forms listed the check-in times for the scheduled deliveries, delivery locations, odometer readings, and details of the delivered goods. Unscheduled service stops for needs such as refueling and meals can be inferred from the GPS data in combination with stated survey information. Given the dataset's manageable size, trip and trip stop verification was done by hand after visualizing the traces in Google Earth.

The research team conducted a pilot study of two regional firms to test the GPS devices and refine the data collection procedures. These businesses partook in the study in the summer and fall of 2011, allowing for the investigation of the research team's major client to begin in the spring of 2012. This major client was a major grocery store chain in Chicago with locations throughout the metropolitan area. The resupply of goods for their outlets is necessary on a daily basis, and data was collected on trucks for all days of the week over a period of 44 days in the spring and summer of 2012. In total, 108 truck-day traces were collected over the yearlong exercise after two truck-days were eliminated as erroneous after visual checks were made. Nine different trucks were surveyed in this study. All of these were 50' long tractor-semitrailer trucks most commonly used for touring purposes. Each truck had a capacity of 24 pallets. The details and patterns that the data revealed are detailed in the Descriptive Analysis section.

The grocery stores within the study area are distributed according to the map in Figure 1. The distribution center is located in a central location at the junction of major expressways. Grocery stores extend as far as Gurnee, IL in the North, the Fox River Valley in the West, and US-30 in the South. The mid-distance northern and western suburbs share a common density, but the outer suburbs and those on the South side are more spread out. In the city, the grocery store locations are clustered around the near north and the far north sides. This grocery chain is largely nonexistent on Chicago's West and South sides and does not operate in Indiana. The South side's absence of grocery stores is not limited to one company, but extends across Chicago's chain grocery stores, constituting a well-known and discussed economic pattern known as a 'food desert' *(16).*

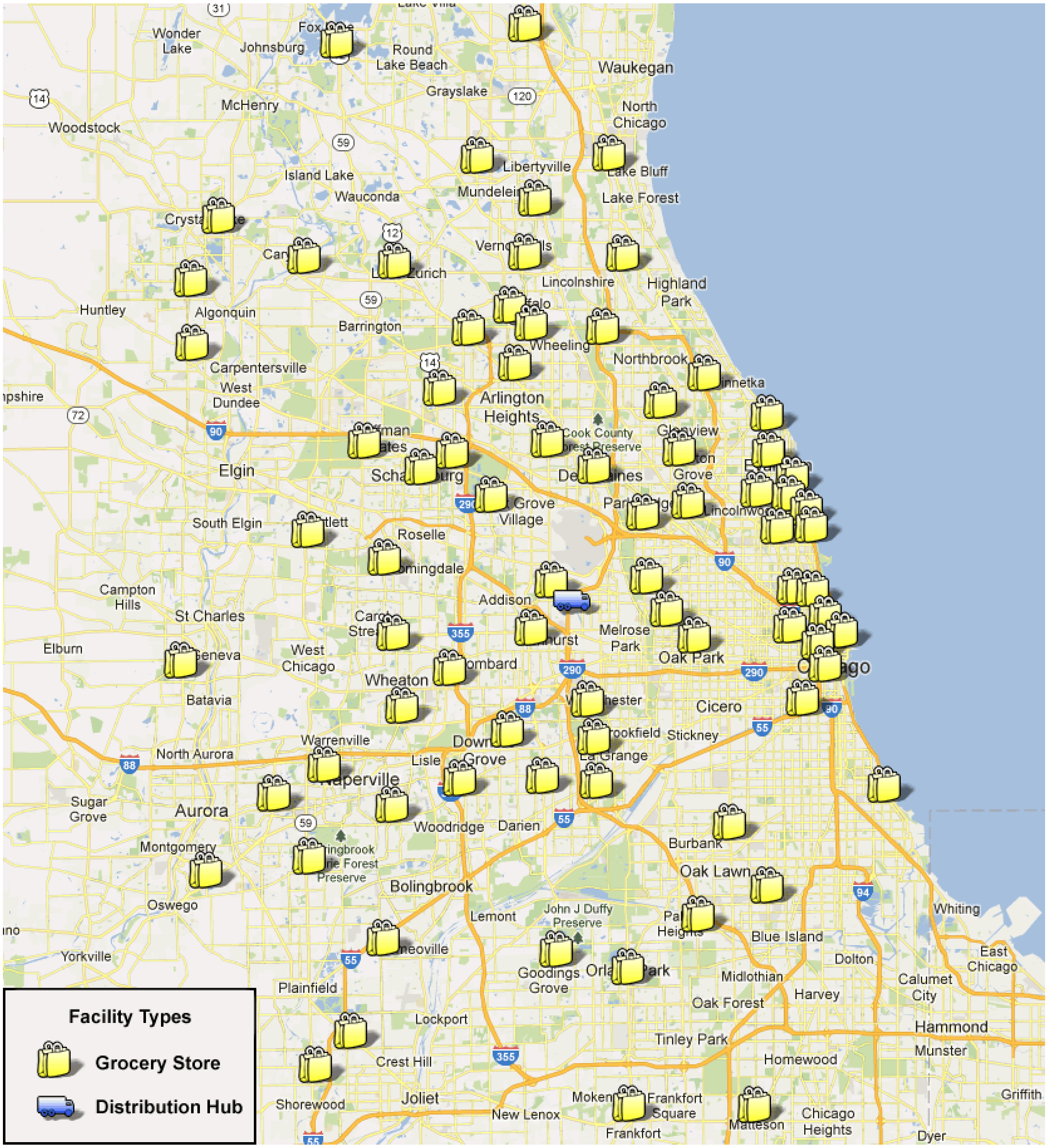


Figure 1: Locations of Stores in Study Area

4. Descriptive Analysis

This section is devoted to analyzing activity and tour characteristics. The research team first analyzed the number of activities per tour and divided the number of performed activities into the following two main categories, main activities and maintenance activities. Main activities are considered pick-up and drop-off activities at stores, warehouses, and distribution centers in the study area. Maintenance activities refer to activities that are performed to make continuation of the tour possible. Stopping at a gas station for fuel and at a restaurant to get food, for example, are considered maintenance activities.

The research team collectively observed commercial vehicles undertaking 312 activities; 89% of these were main activities and 11% were maintenance activities. Figure 2 shows the distribution of total number of activities per tour. The recorded number of activities per tour falls between 1 and 7 with a maximum value of 3. Running a distribution fit analysis, showed that the number of activities per tour follow a Poisson distribution with a parameter value of λ=3.1477 or a Binomial distribution with parameter values of n=13 and p=0.23076 which showed the best and second best fit respectively using Kolmogorov Smirnov and Anderson Darling goodness of fit tests. Also, the number of main activities are compared with the number of maintenance activities per tour. Figure 2 presents the comparison.

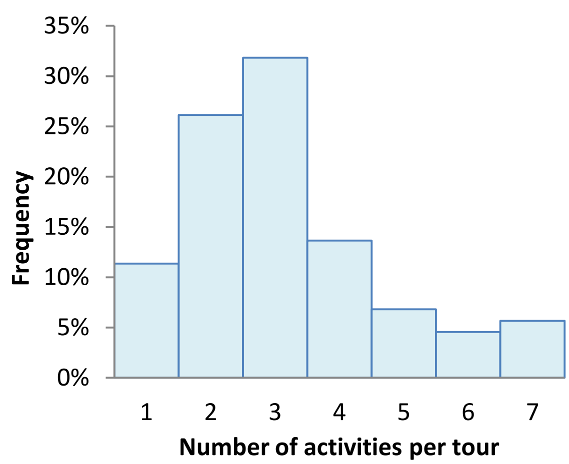


Figure 2: Number of Activities per Tour

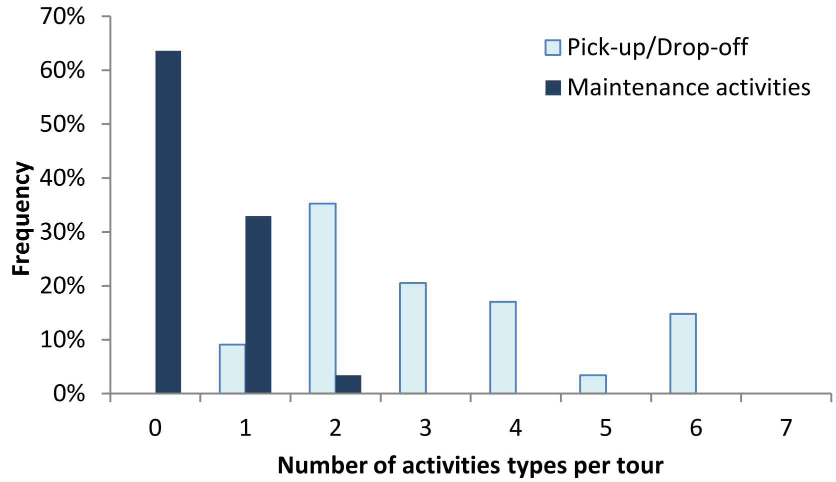


Figure 3: Comparison between Number of Main and Maintenance Activities per Tour

Next analyzed was tour duration. The shortest tour lasted 74 minutes and the longest tour lasted 11 hours and 14 minutes. In general, the average tour duration obtained from our sample is 5 hours, 15 minutes with a standard deviation of 1 hour and 52 minutes. Distribution of tour durations is shown in Figure 4. The maximum density value of tour duration falls between 300 and 360 minutes. Weibull distribution with distribution parameters of α=3.2568 and β=346.78 showed the best fit to the data.

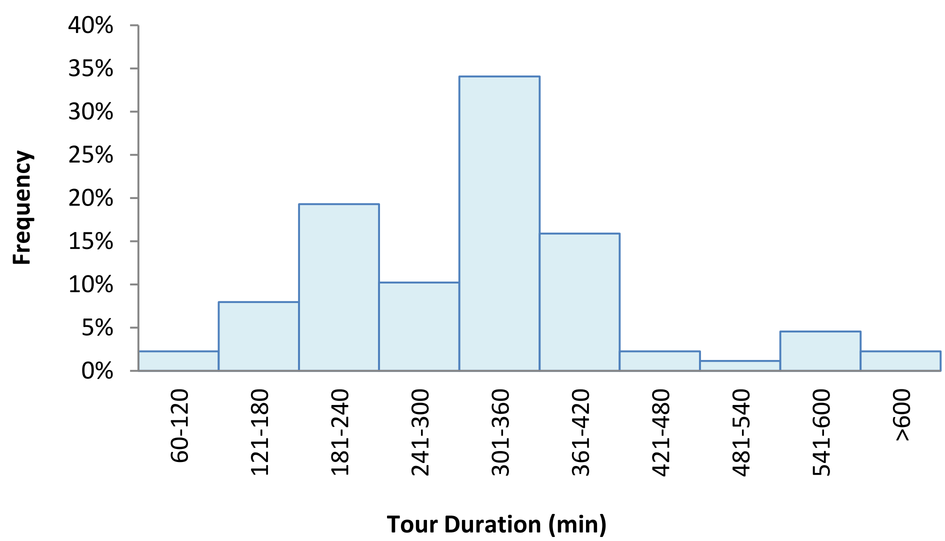


Figure 4: Duration of Activity Tours

The research team also analyzed the activity tour distance in this study. The shortest tour was 13.46 miles and the longest tour was 197.28 miles. Tours had an average distance of 76.46 miles and a standard deviation of 41.02 in the data set. Distribution of the activity tour distance with a maximum density between 31 and 62 miles is shown in Figure 5. Running a distribution fit analysis and performing chi-squared goodness of fit test, showed that the tour length follows a Generalized Extreme Value distribution with distribution parameters of k=0.1878, σ=25.537 and μ=55.952.

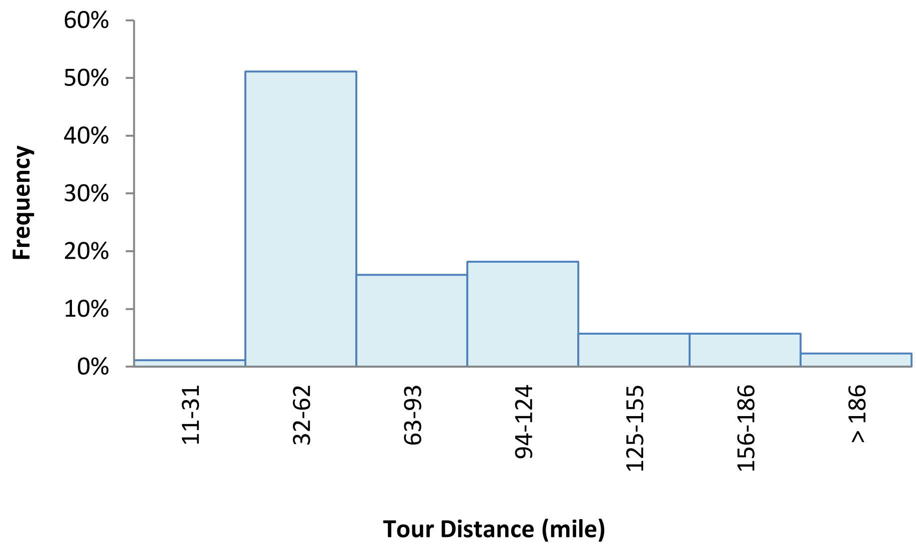


Figure 5: Distribution of Tour Distance

As mentioned earlier, the area covered in this study is the Chicago metropolitan area with an area of 10,857 mi^2. The grocery chain studied in this paper has one distribution center in the study area. Commercial trucks deliver goods from this distribution center to over 70 stores distributed in the study area. These trucks also perform pick-up/drop-off activities at other major warehouse and distribution centers in the study area. Proposed by Joubert and Axhausen *(17),* the measure (metric) of *distance per activity* can be used to determine a company's profitability and compare a region's freight productivity. The *distance per activity* measure is obtained by dividing the total tour distance, obtained in the driver logs, by the total number of activities that the commercial vehicle performs in the study area. As noted in *(17),* the lower values of the *distance per activity* metric are preferred. Fewer traveled miles per activity indicates more limited infrastructure use, which allows decision makers to spend more shares of existing resources on maintaining existing infrastructure and on investing in new infrastructure. This measure can also be used to find the optimal location for building a new distribution center. In the data set, the minimum traveled distance per activity is equal to 7.12 and the maximum traveled distance is 197.28 miles per activity. However, the average traveled distance per activity has a value of 31.43 miles. Figure 6 presents results for the traveled distance per activity of our sample in the study area.

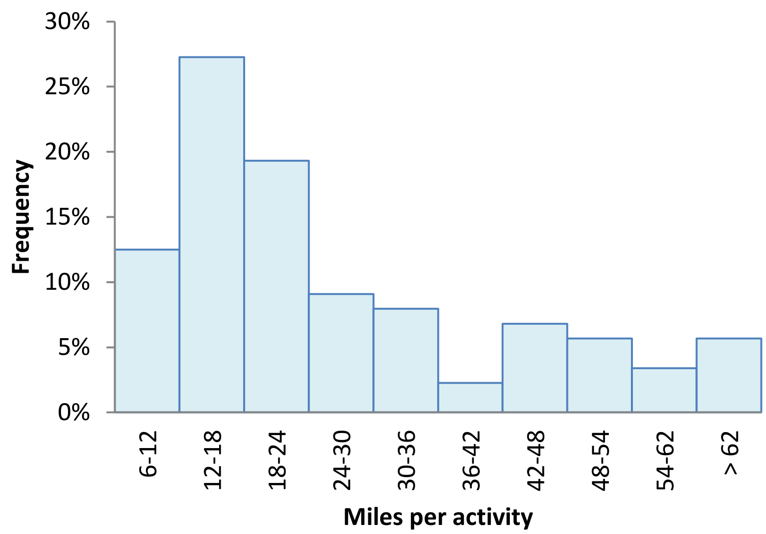


Figure 6: Traveled Distance per Activity

In Figure 7, the research team analyzed the commercial vehicles' activity duration. The sample tours' average activity duration is 55.70 minutes with a standard deviation of 28.33. However, the main activities' average activity duration is greater than that of maintenance activities. The main activities' average activity duration has a value of 66.40 minutes, while the maintenance activities' average activity duration is 45.00 minutes. Figure 6 presents the sample data's activity duration distribution.

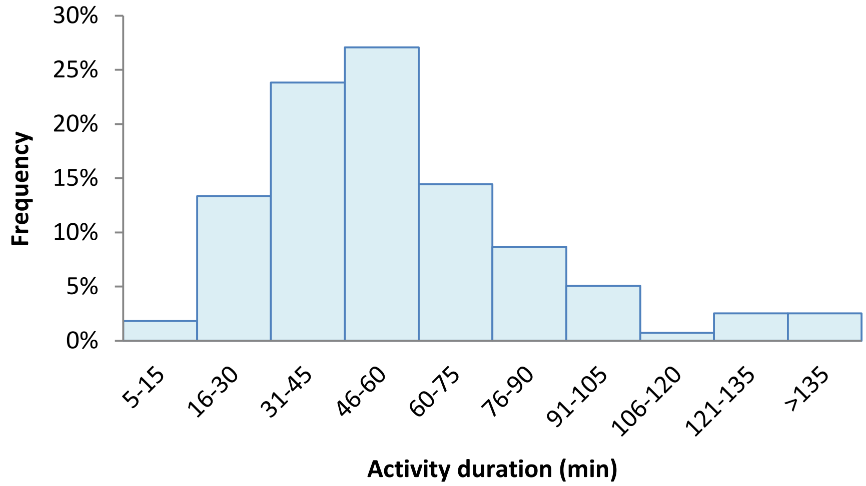


Figure 7: Activity Duration

For efficient delivery operations set in a major urban area, one must consider the size and location of current traffic movements to mitigate their effects. For a distribution center situated in the suburban inner ring, this issue becomes more complicated given the locations of destinations up and down the congested flow. Added to this are the considerations of store hours, the number of drivers, and the logistics of storing goods in a central location. Depicted in Figure 8 is the cumulative distribution function of the grocery truck departure time from the Northlake, IL distribution center for the study's entire duration.

The graph indicates that trucks rarely depart the main distribution facility in the morning hours. Most delivery trucks begin their tours between 12:00 and 15:00 and over 90% of tours begin between 12:00 and 20:00. Much of this traveling overlaps with afternoon rush hour traffic, allowing trucks to enter Chicago during the outbound rush.

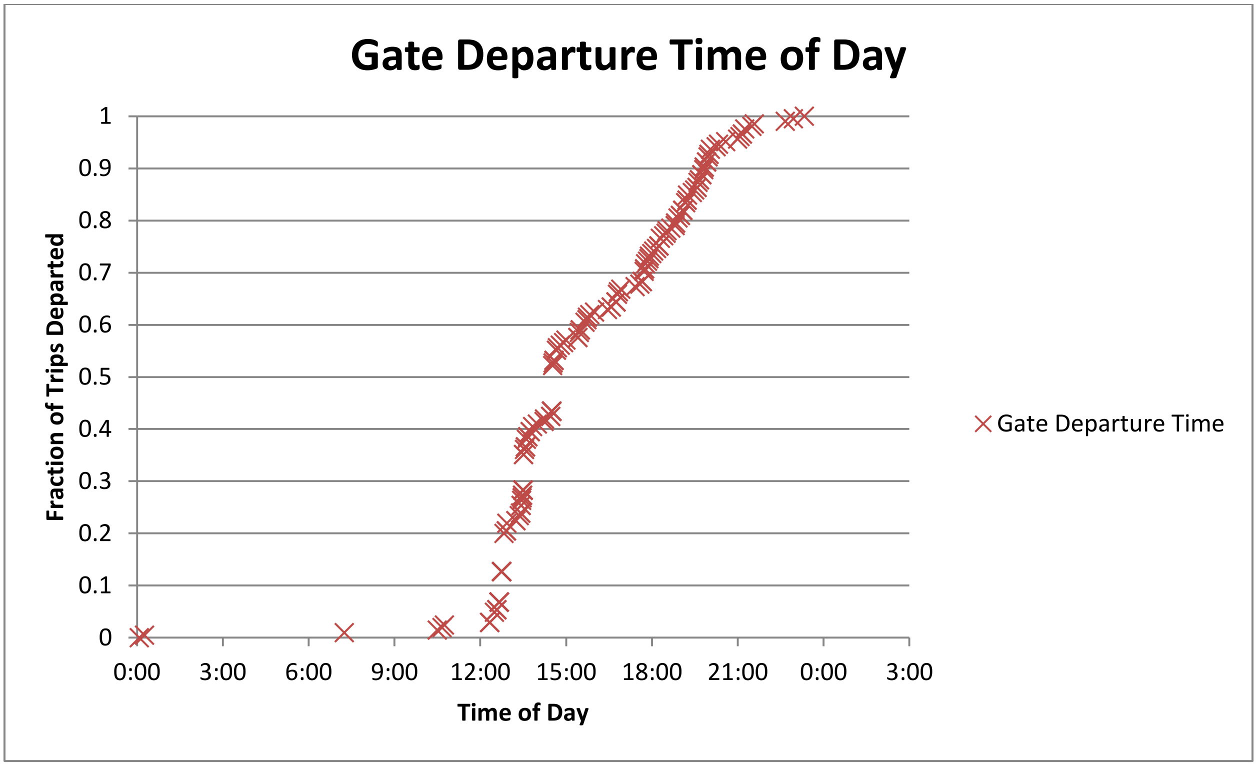


Figure 8: Gate Departure Times

As shown in Figure 4, the surveyed trips encompass a wide range of tour durations. Despite this added irregularity in duration, the arrival times signaling the end of a tour are quite evenly staggered, arrival times being more regularly spaced than the departure times. This is depicted in the cumulative distribution function in Figure 9 below. The graph shares the shape of the departure curve in Figure 8, but features a more consistent, shallower slope, and less of a bulge at the 40% return mark. Tours begin returning to the distribution center at 15:00. They reach 90% returned nine hours later at 24:00. While most of the tours return later in the day, approximately 20% of tours return during afternoon peak hour traffic.

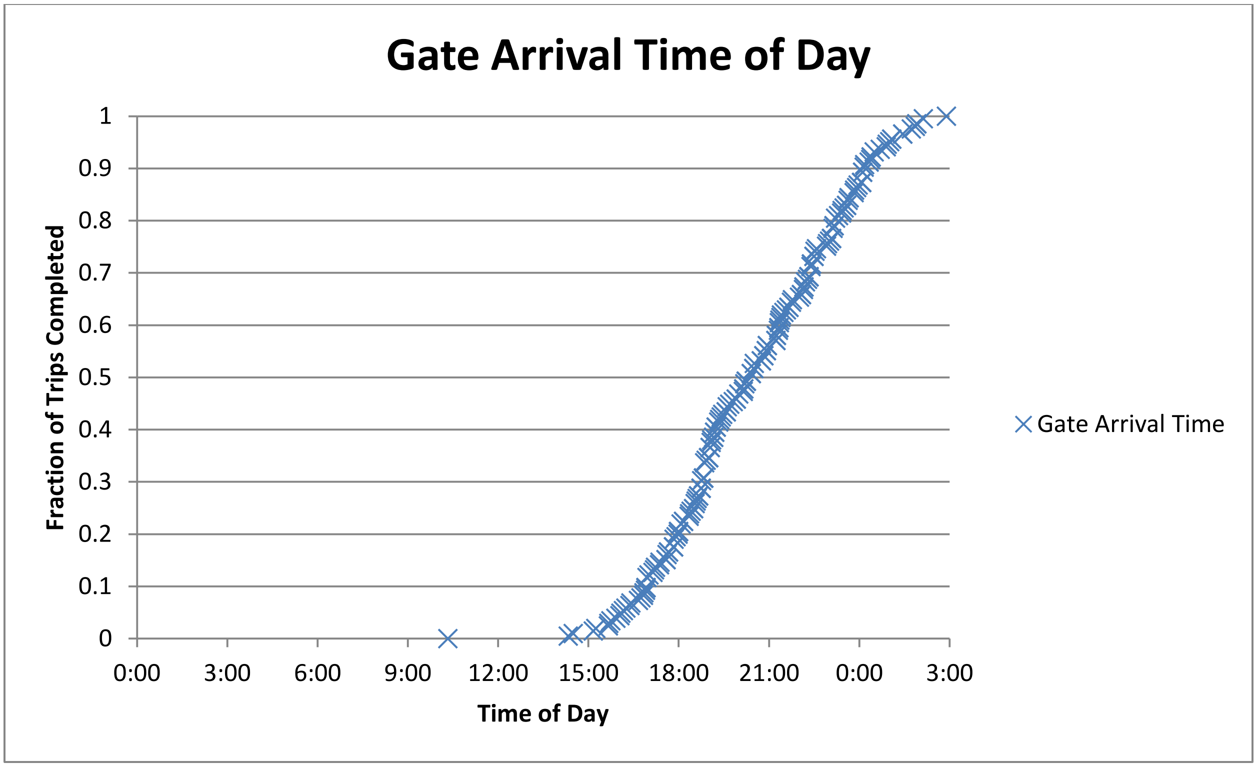


Figure 9: Gate Arrival Times

By numerating the incremental distances between each scheduled stop on a tour, the conventions governing a tour's shape may be identified. Figure 10 depicts the probability distribution functions for the travel distance between each individual numbered stop (first stop, second stop, etc.). For travel between the distribution center and the first destination, 78.16% of travel segments fell between 10 and 30 miles long. Distances of less than 10 miles made up only 16.5%. For trips between the first and second destinations on a tour, the results were much different--44.12% of travel segments fell between 10 and 30 miles, whereas a majority, 52.45%, measured less than 10 miles long. This implies that a sizeable share of the tours formed addressed the needs of grocery stores that are clustered together, rather than those that are simply on a straight line path from the origin.

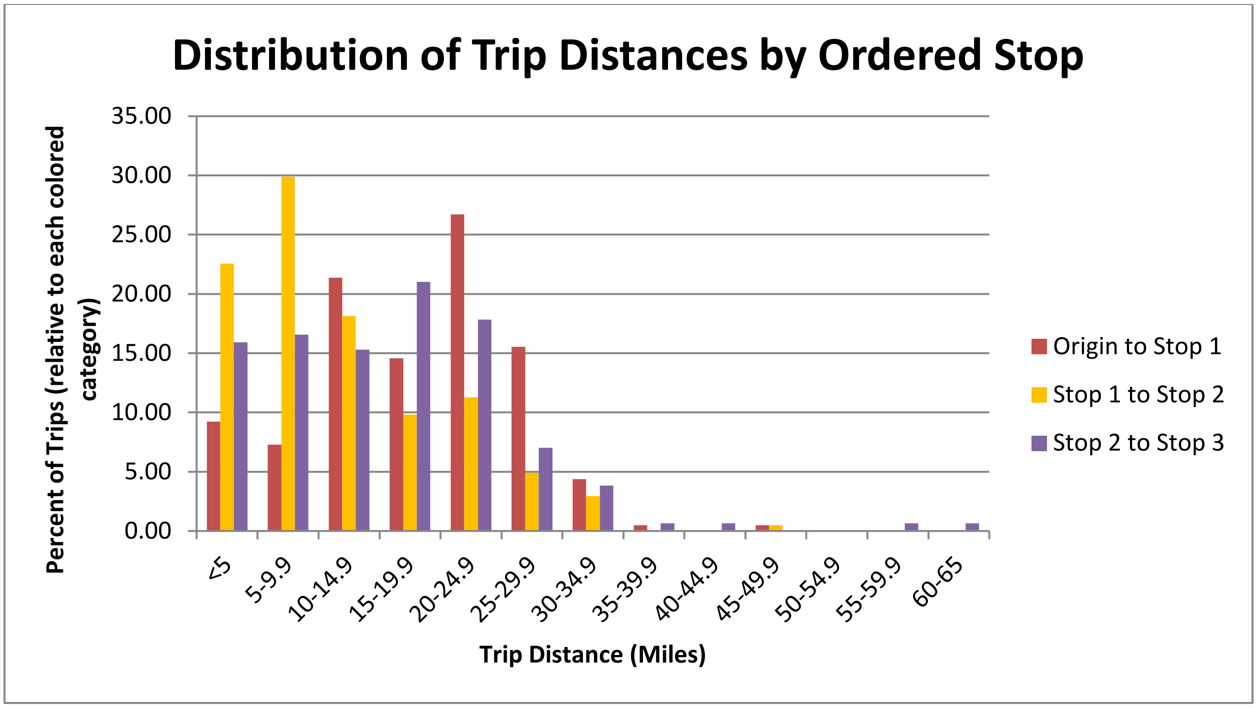


Figure 10: Distribution of Trip Distances by Ordered Stop

For inventory purposes, the research team placed the goods that the grocery chain shipped into one of the following nine categories:

GRO	Grocery
RPK	Repack (Cosmetics, Health Products)
PRO	Produce
DAR	Dairy
DELI	Deli
FRZ	Frozen Foods
MET	Meat
CPS	Special Promotion Items
SAL	Backhaul of Pallets, Boxes

Table 1: Product Abbreviations

These categories encompass an assortment of packaging and temperature needs, which influence truck routing and cargo. To account for this, the grocery chain divided the trucks into two delivery groups, one delivering produce and the one delivering goods classified as ‘grocery.’ Figure 11 below graphs the deliveries made according to product category. ‘Grocery,’ ‘frozen,’ and ‘special promotion items’ are the most often delivered. Deliveries of one of these types are made during 78%, 53%, and 44% of all trips respectively. Only two extra pallet and box shipments were made, indicating that backhauling of these items is not a commonly performed task. Also represented are the average numbers of pallets delivered, both the overall average and the average when any delivery of that type is made.

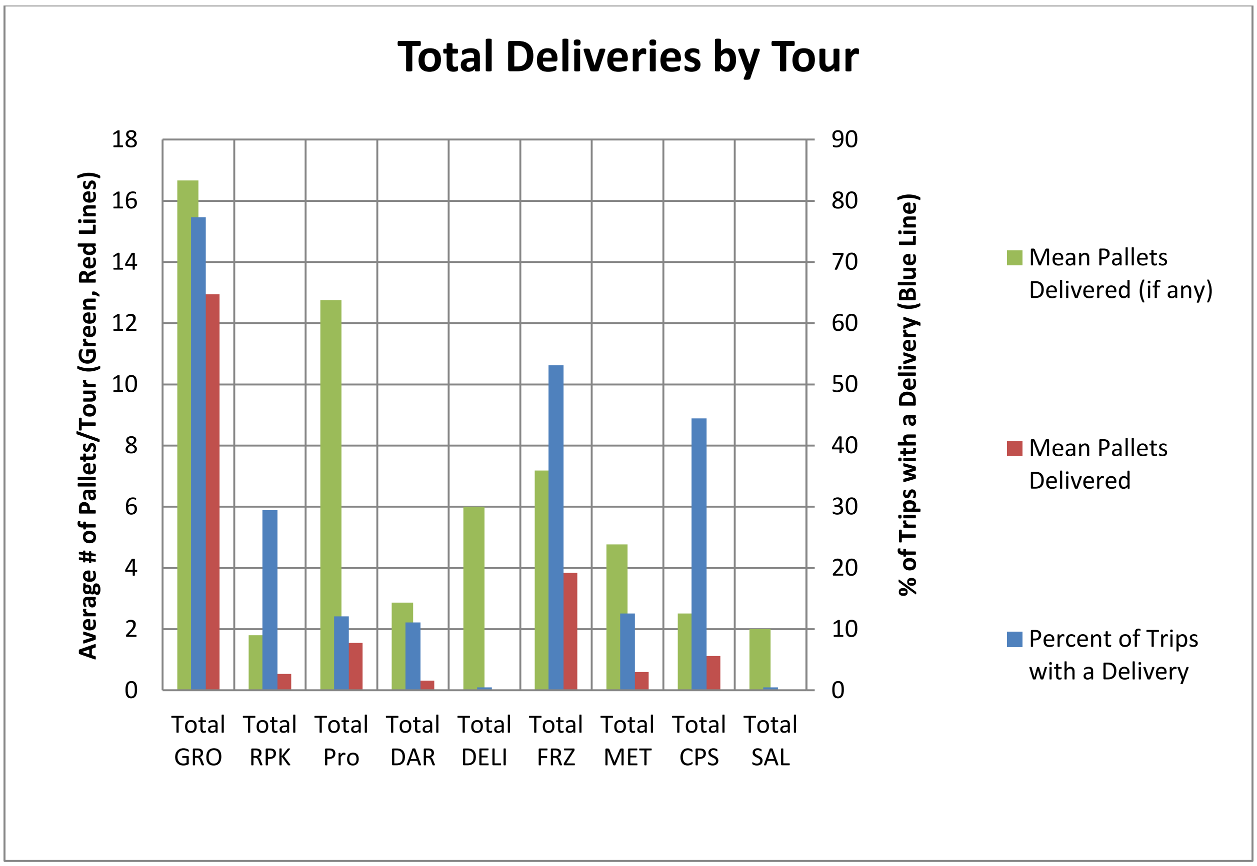


Figure 11: Deliveries Made by Product Type

5. GPS Results

The resultant GPS traces provide a wealth of detailed data related to the routing and temporal patterns that grocery trucks employed on their Chicago metropolitan area tours. The geospatial information obtained is highly accurate under normal settings and is only limitedly affected by the urban canyon effect, a situation where tall structures, natural features or tunnels obstruct satellite-to-GPS device communication *(18)*. With regard to recording routing choices, the GPS tracking approach is ideal. Much of the non-routing information, such as stops and durations, can be inferred from related survey data, however it is non-essential for this study type. This section is intended to demonstrate the GPS data's levels of detail and its capacity for interpretation of the log-type data.

Figure 12 displays the close-up of a truck maneuvering in and around one of the destination grocery stores. In the figure, the truck approaches from the south, turns left into the parking lot, and circles around to the business' rear loading area. During unloading, the GPS device experiences stationary drift, the interference being visible in the bottom of the picture. After delivering its goods, the delivery truck continues on its original heading and turns west. It can be seen that the GPS data points are accurate enough under common driving conditions and that it is possible to identify the side of the road that the truck travels on.

Figure 12: GPS Tracks of Truck Entering and Exiting a Scheduled Stop

To better illustrate the fluidity of travel, the GPS traces were color coded in route visualizations to correspond to the average speed of trucks while making deliveries. The scale ranges through the rainbow spectrum, from blue to red, with red representing the fastest speeds and blue the slowest. This can be seen on the scale of a complete tour in Figure 13. The route direction is counterclockwise. Judging by the color gradation, this tour was performed under entirely free-flow or near free-flow conditions.

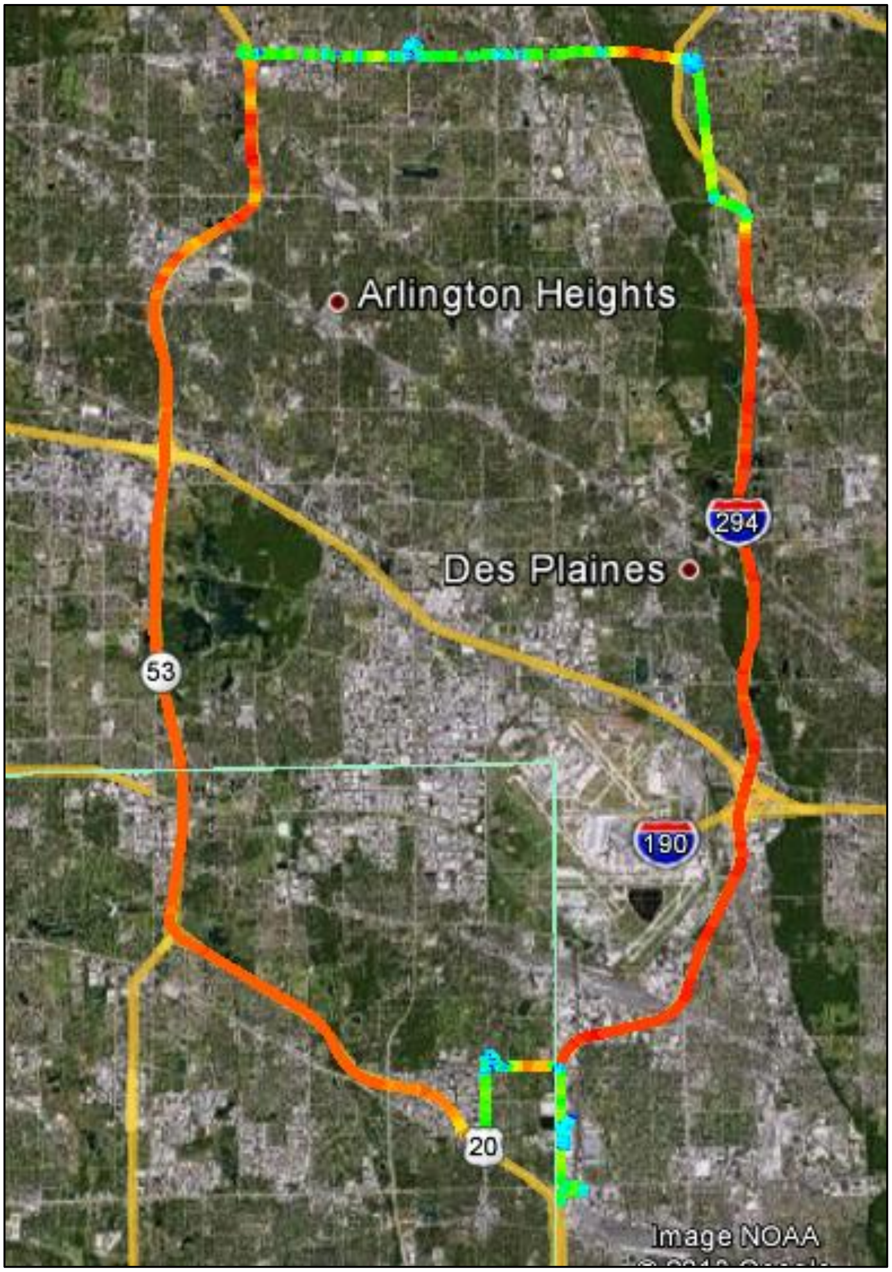


Figure 13: GPS Trace with Color Coded Speed Values

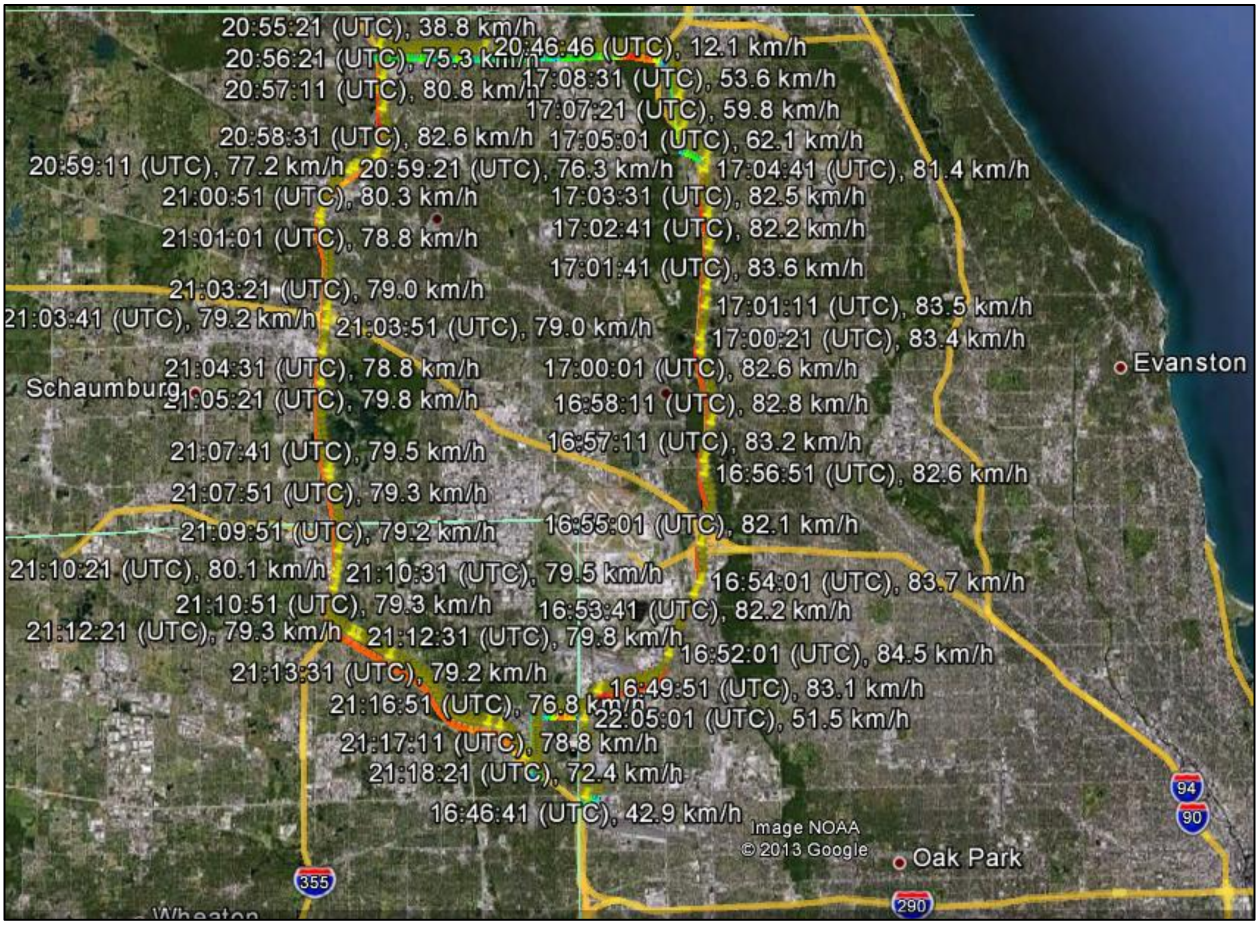
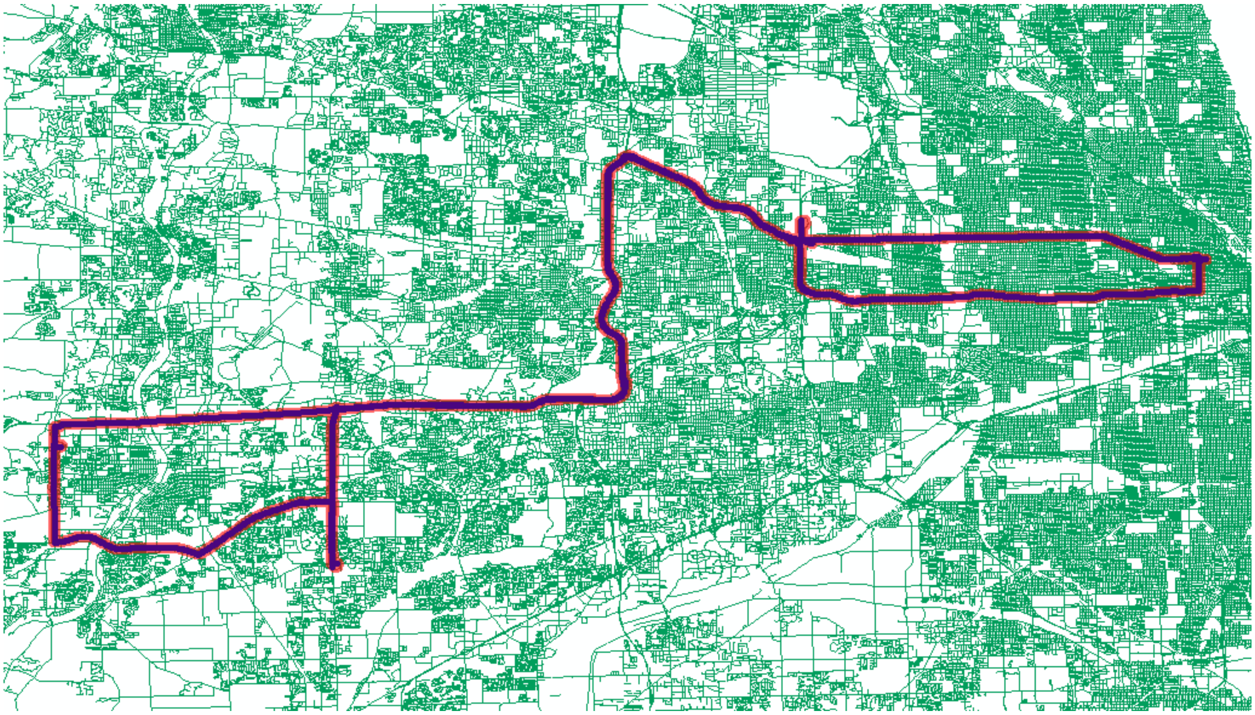


Figure 14: GPS Trace with Labeled Time and Speed Values

In addition to the creation of a colorized speed map, the traces have been fitted with discrete data in visualizations to provide exact values of speed and time for all data points along the route. This can be seen in Figure 14. Speed is measured in kilometers per hour and time is measured in coordinated universal time, a universal standard in timekeeping which is closely related to Greenwich Mean Time. During this study's duration, coordinated universal time was five hours ahead of Central Standard Time.

Through the use of ESRI's Geographic Information System (GIS) software suite, ArcGIS, the collected GPS coordinates have been linked to the local street network, and relevant data such as trip distance, road type, and road permissions has been obtained from their routes. To implement this task, the research team assembled various scripts to automate the linking, routing, and summarizing processes. One such inferred route is shown in Figure 15.



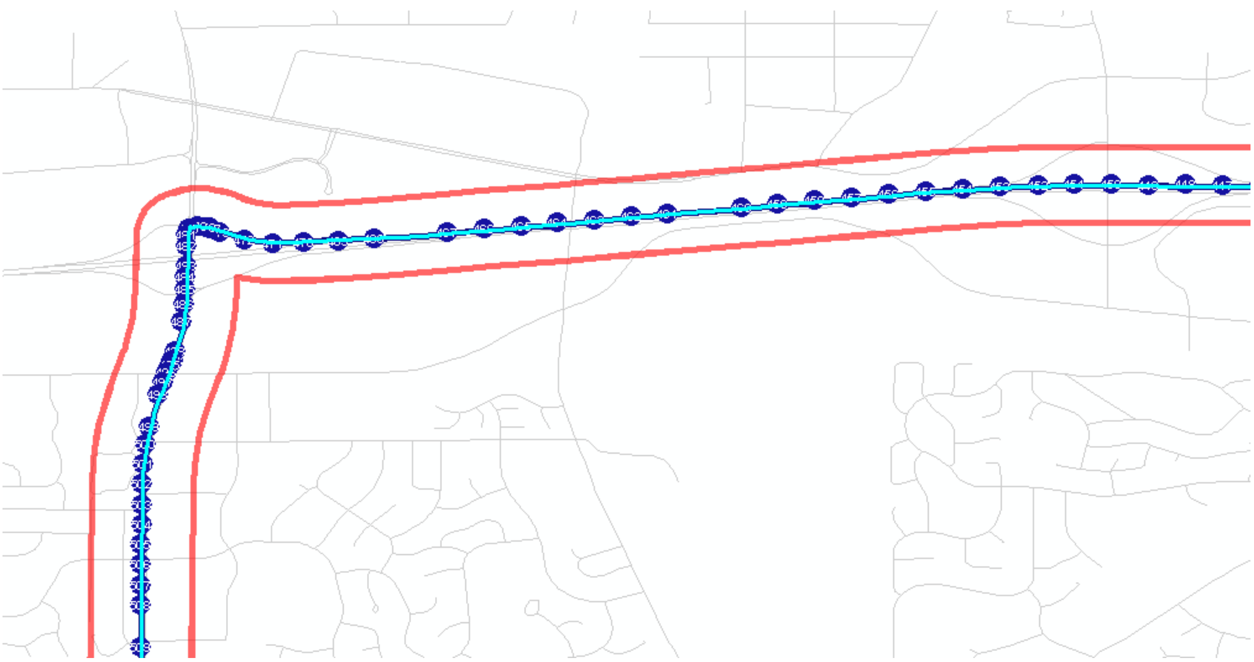


Figure 15: GIS Inferred Route and Route Selection Example

The GPS map-matching process used buffer distances surrounding each trace as non-traversable areas to limit the range of possible routes. By varying the buffer size according to GPS point accuracy, density, and the road type, likely candidate road segments were selected. The research team allowed buffer width values from 50 to 600 feet from centerline to outer extent in, separated by intervals of 50 feet. For this study's purposes, the research team chose an interval of 550', which falls below the average city block width of 660 feet in the city of Chicago, allowing routes nearby to be disallowed while at the same time offering a comfortable margin of error for the data points. However, given the high degree of the points' accuracy, the wide buffer generally allowed the algorithm more leeway to process traces when a truck left the established street network (e.g. to go to parking lots, gas stations, tollway oases, or intermodal facilities).

When a route is plotted, the underlying road segments may be selected, allowing their attributes to be isolated and summated within the street layer's attribute table. Possible attributes include road directionality, vehicle and pedestrian permissions, roadway type, and number of lanes. For example, Table 2 shows the road distribution by a variety of attributes for the 111 mile trace from Figure 15. The type of information gathered here exceeds the variety and detail that can be attained from simpler, written surveys or copied trucking logs.

Motorway	**Motorway Link**	**Primary**	**Secondary**	**Tertiary**	**Residential**
57.96%	2.60%	16.76%	18.19%	1.82%	2.67%

Freeway Lanes (Each Direction)	2	3	4	5
Percent of Route	14.55%	56.27%	29.15%	0.03%

Share of Route with Bike Lanes	
Distance	903m
Percent of Route	0.42%

Table 2: Example Trace Route Distributions: Road Type, Freeway Lanes and Bike Lanes

After the research team processed dozens of GPS traces through the model, a picture of the routing patterns was formed, as depicted in Figure 16. The variety of routes is densest in two locations: near the Northlake distribution center and on the North side of Chicago. The latter occurrence is likely explained by the high number of destinations, density of traversable arterial routes, and the traffic impact on route choice. The South side of Chicago, with only two store locations, is predictably largely void of travelled paths. In the suburbs, travel was more consistently routed over interstate highways, with little to no routing influence attributable to the presence of tolls. The single distant westerly route is a connection to a large multimodal facility in Rochelle, IL where goods are transferred between truck and rail.

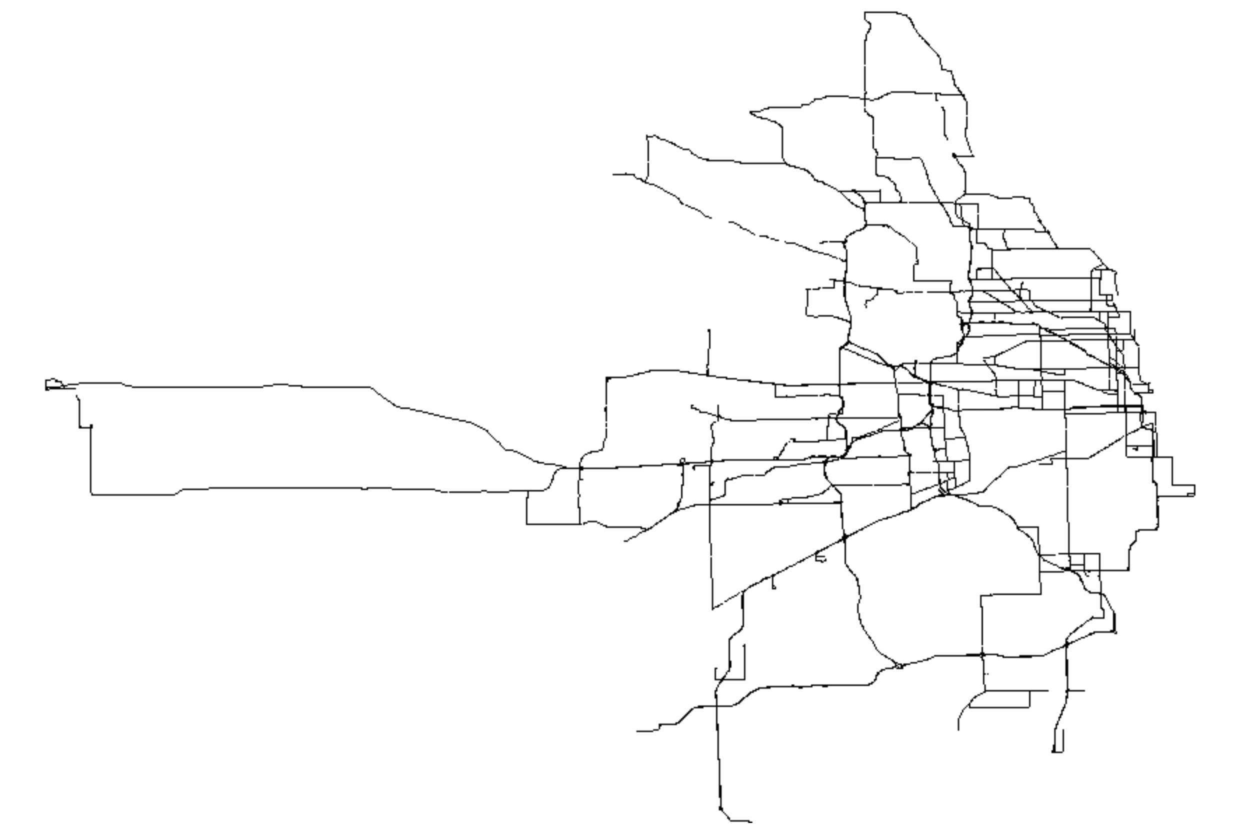


Figure 16: Complete GPS Trace Dataset

Processed traces produced routing paths that were generally very accurate. Among unmatched path segments, most can be attributed to one of two main error sources, both involving the map to which the routes are matched. The first arises when a surveyed truck travels outside the road network's confines before re-entering elsewhere. This can be easily accounted for by either solving each trip chain segment on its own or by a simple manual fix. The other type of scenario occurs when the supplied road network does not align exactly. If two road segments do not end at the exact same coordinates as they should since routes are dependent on the choices available in each junction, the route will not be processed properly or at all. This also may be fixed through manual inspection or through improvement of the base map.

From the bulk set of GPS data, the research team obtained averages and trends of the recorded trips. Most of these recorded trips occurred on controlled access highways (with over 53.8% of all truck miles), followed by primary roads (with over 16.3% of all truck miles), secondary roads (common arterial roads)(with over 15.2% of all truck miles), other roads (at 11.3% of all truck miles), and controlled access highway links (ramps and interchanges)(with 3.4% of all truck miles). The other road category includes trunk (a classification between primary and controlled access), tertiary, and residential roads.

The dataset also provided a look at trip chaining patterns over the study period. Since the traffic patterns differ greatly between the city of Chicago and its outlying cities, the frequency of travel within each area is of interest. Twenty-eight tours were recorded that primarily served the cities of Chicago and Evanston (included with Chicago, given its store pattern density). Forty-six tours were exclusively associated with suburban goods distribution. On a per store basis, given 16 stores in Chicago and Evanston and 59 stores in outlying cities, stores in the cities of Chicago and Evanston received a greater number of tours than their suburban counterparts would have had in equal number, by a factor of 2.25. This greater share could indicate that in densely urbanized areas go through their stock sooner, be it due to greater demand, smaller supply or both.

Three general shapes exist for chained tours, an out and back line tour, a circular closed loop tour, and a figure 8 tour. Since figure 8 tours in practice were generally out, and back line tours that crossed on an express outbound or return run, they were categorized in the line grouping. Of the tours collected, 54% were formed in a circular pattern, 35% were out and back trips, and 11% did not fall into any clear category. Among the circular pattern routes, they were roughly evenly split in direction, 53.3% traversed in a counterclockwise direction and 46.7% traversed in a clockwise direction. However, when urban and suburban stores are split, the results diverge. Urban circular tours used the counterclockwise direction 75% of the time to 25% of the time over clockwise, perhaps indicating a preference for the Eisenhower over the Kennedy

Expressway during the afternoon hours of the day. In suburban circular tours, the clockwise direction was favored 69.0% to 31.0%. Better understanding these touring patterns can benefit the modeling efforts regarding the destination choice and route assignment for chained trips. Circular trips use more perpendicularly directed roads from a trip origin than out and back trips and may influence the general pattern of freight traffic.

As indicated in the above figures and tables, the collected GPS data goes beyond the many relevant temporal log variables traditionally measured to offer a level of detail unavailable in a basic log retrieval and analysis study. By applying the appropriate tools, the basic routing information retrieved in this type of study can produce detailed information on the structure of a tour, from speed values and bottleneck identification to route makeup by type, width, or users.

6. Conclusions

Data scarcity is one of the most critical challenges for understanding the freight decision making process and for developing freight transportation demand models. This study therefore presents a methodology for gathering detailed data on freight vehicle activities in urban areas. The research team used the GPS data collection method to gather disaggregate information on freight vehicle activities in the Chicago metropolitan area. In total, the research team collected 108 usable GPS traces from a major grocery store chain in the study area.

The research team performed a descriptive analysis of tours and activities to identify freight vehicle tour patterns and activity characteristics. Analyses highlight useful characteristics including tour and activity durations, number of activities per tour, tour distance, and traveled distance per activity for the focused industry type.

Approximately 58% of the tours included 2 or 3 executed activities. Seventy-three percent of the tours lasted 360 minutes or less and 68% of tours had a chain distance of 93 miles or less. Approximately 80% of the activities were executed in less than 75 minutes and the average traveled distance per activity was approximately 31 miles.

The GPS data collected contained valuable information regarding each tour's makeup. More than traditional log form surveys, the use of GPS devices can accurately produce highly detailed routing data in a much less intrusive and much more productive manner. Key routing characteristics are easily obtainable using the appropriate toolset, which enables better differentiation between candidate paths in the study's modeling stages.

This study's results can and will be used to better understand the behavioral aspects of freight vehicle activities and to develop disaggregate tour-based freight transportation models in urban areas. This analysis can also be extended to include some other behavioral aspects such as temporal and spatial characteristics of tours and activities that can help find optimal locations for distribution center problems and optimize tour patterns and activity sequences to minimize logistics costs.

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