Reducing Transport Miles Through the Use of Mobile Hubs:
A Case Study in Local Food Supply Chains

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Abstract

Though environmentally friendly in many regards, local supply chains are often inefficient due to lack of proper infrastructure. This paper explores the use and placement of mobile hubs for consolidation and distribution of goods in local supply chains. Specifically, we look at local food supply chains where food typically travels from rural farms to suburban and urban restaurants. Currently, consolidation is minimal and not optimized in these supply chains. This paper computes suitability and location analysis through a novel multi-criterion scoring methodology utilizing kernel density and network analysis. The effectiveness of these mobile hubs is assessed through strategic routing, where the routes are optimized for time and distance. Results indicate that on average mobile hubs do in fact reduce mileage and number of stops, lessening emissions in addition to saving time and money. The proposed methodology can be implemented in other local supply chains to better consolidate and distribute goods.

1. Introduction

Food supply chains have gained traction moving towards sustainability and transparency. Consumers are demanding more information from restaurants. Where did the food come from? Are the products genetically modified? What is the carbon footprint of my food [1]? In turn, restaurants have increased responsibility for the raw supplies they purchase [2]. One way to shift towards sustainability is through local food supply chains. They are generally known to be sustainable, notably helping to reduce emissions by eliminating long-distance transport and minimizing "food miles" [3]. Local food supply chains also bring more money into rural communities, helping producers and disrupting the large-scale supply chains controlled by giant food distributors [4].

Local food supply chains have not gone unnoticed by the business world. There has been an increased presence of marketplace and logistics platforms enabling direct connection between farms and restaurants. However, these startups often do not have the time or capital to invest in logistics infrastructure and leading to nonoptimized routing.

A lack of logistics infrastructure is not unique to local food supply chains. It is present in many supply chain and logistics systems. For example, infrastructure can be destroyed by disaster [5]. In other cases, a lack of infrastructure investment and planning can threaten supply chain efficiency [6]. Local community interest and involvement in neighborhood logistics has blossomed. Government and industry have begun to consider local needs in resource allocation and decision-making processes [7]. This interest has pushed companies to consider ventures within local supply chains.

Also, in the current case of COVID-19, infrastructure was broken down for large-scale food supply chains. It has become harder to source food globally due to health and safety restrictions. The World Economic Forum advised consumers for the "post-COVID need" to support "local food systems with shorter fairer and cleaner supply chains that address local priorities." [8]

Logistics are essential to these supply chains and directly affect supply chain performance [9]. The use of logistics centers as intermodal distribution hubs have become increasingly popular. These logistics centers often serve multiple purposes including but not limited to distribution, consolidation, storage, infrastructure nodes, materials handling and customs checkpoints [10].

Particularly in food supply chains, food hubs have grown in prominence. As defined by the USDA, a food hub is "a business or organization that actively manages the aggregation, distribution and marketing of source-identified food products, primarily from local and regional producers to strengthen their ability to satisfy wholesale, retail and institutional demand" [11]. These hubs serve as a meeting points and points of sale for both producers and consumers.

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Local food supply chains stand to benefit from the use of a hub that is made up of characteristics drawn from both logistics and food hubs. However, local food supply chain hubs do not need as many features as traditional logistics and food hubs. Simplicity is key. This study aims to identify the important attributes needed for a local food supply hub.

Unlike large food distribution systems, in local food supply chains, customer deliveries are not on a regular schedule and vary by day/week/month. Due to the fluctuating nature of the daily customers, this study aims to test the feasibility of mobile food consolidation hubs. These hubs serve as consolidation and distribution points for delivery drivers that can change location based on daily demand.

In order to ensure success of such a mobile hub, location is of the utmost importance. The hubs must be placed strategically for accessibility, transportation efficiency and service coverage. The objective of this paper is to identify potential mobile hub locations using a combination of GIS and optimization techniques for location intelligence. Suitability and location analysis are done through a novel multi-criterion scoring methodology utilizing kernel density and network analysis.

The paper is structured as follows: Section 2 reviews literature in logistics hub location, food hub location and route planning. Section 3 presents the case study context. Section 4 introduces the methodology for hub location selection. Section 5 summarizes the results. Section 6 discusses the results. Section 7 presents conclusions of the study and presents areas for future research.

2. Literature Review

The objective of a Logistics Hub Location Problem (LHLP) is to choose a location that allows for the smallest transportation costs and largest customer coverage [12]. The LHLP is relatively new, with most multi-method approaches developed in the last two decades. The majority of papers use a Mixed Integer Program (MIP) Formulation to provide solutions for the LHLP [13, 14, 15]. Alumur et al. uses a MIP to select locations of airport and ground hubs. They show a detailed trade off analysis between cost and service quality [13]. As one would expect, and as is present in many LHLP papers, the more hubs that are utilized, the higher the CPU time. The LHLP is innately a spatial problem. It involves the use and interpretation of large geographic datasets that must be broken down into trends in order to place hubs.

Despite being a natively spatial problem, GIS is not commonly used in the LHLP. However, innovative papers that use GIS have shown promise [7, 16, 17].

Shahparvari combines GIS embedded multi-criteria decision tools, a k-means based heuristic approach and a multi-criteria decision-making tool [7]. Mahini & Gholamalifard combine GIS and Weighted Linear Combination (WLC) to select landfill locations [16]. GIS methodology provides a degree of accuracy that can't be captured in a MIP model [17]. Historical routes with actual road-traveled distances can be used, rather than rough approximations. Albino states the relevance for of the use of spatial aspects in supply chains, particularly at the local level due to an emphasis on the relationship between energy and environmental aspects with economic aspects [18]. We use spatial and GIS methods in our model in order to capture the relationship between distance and time traveled which are directly correlated to energy use & emissions (environmental) and cost savings (economic). Particularly, we use a combination of kernel density and network analysis. Kernel density has been used to build effective hotspot maps, most notably in analyzing crime density for the purpose of community planning [19]. We use kernel density in a similar manner in order to identify hotspots of delivery orders to help determine hub location.

The work that has been done in the LHLP has focused on large scale supply chains often with large geographical areas, thousands of customers, and thousands of suppliers. These papers must consider several hubs to cover the intended customer coverage area. They often must make several assumptions and estimations for simplicity of calculation due to the size of the system. However, in local supply chains customer coverage much smaller. Local supply chains are often defined by consumers and policy makers to only cover a radius of 100 - 400 miles [20]. Due to the small number of suppliers and customers, we are able to consider exact road distance in most circumstances whereas most LHLP solutions use some sort of route length estimation like the technique proposed by [21]. However, it is important to note that we do use an estimation to capture multiple vehicles, and this is necessary due to the computation complexity of the Vehicle Routing Problem (VRP) [22]. Thus, overall, we are able to provide a more accurate calculation of distance and time savings. We propose a methodology that is tailored to local supply chains and provides a degree of accuracy that is not present in current literature. We acknowledge the fact that our strategy is not likely computationally feasible for large scale supply chains, and our methodology is tailored for use in local supply chains, particularly local fresh food supply chains.

Local supply chains are encased by a relatively small geographical area with a limited number of suppliers and customers. Particularly, in local food

supply chains, size and volume of the system is relatively small. For example, the Local Food Hub in Charlottesville, VA serves a 100-mile radius and has 60 suppliers, The Oklahoma Food Cooperative (OFC) serves a 160-mile radius around Oklahoma City and started with 20 producers and 60 customers, and the High Plains Food Cooperative serves a 300-mile radius in Northeastern Colorado with 40 producers and 154 consumers [20]. Keep in mind that not all producers and consumers participate on a daily basis, therefore, daily product volume would be able to fit in a single mobile hub (see Figure 2). For this reason, we chose to examine the LHLP case of p = 1, where we consider only one mobile hub.

Tang et al. use a multi-objective optimization model to select a sustainable logistics facility location and demonstrate that increased facilities can decrease emissions and improve service level [23]. The increased facilities can be drawn in parallel to moving a facility throughout the workweek, potentially increasing service area. While they consider distance between each customer and the candidate facility location, they do not consider the distances between customers. Their paper focuses on independent customer deliveries directly from the logistics facility without consideration for consolidation.

In Food Hub location analysis, GIS is commonly used. For example, Hamilton et al. consider thirteen different factors such as Population Density, Transportation Routes, and Fruit & Vegetable processing. They are able to provide direction to food hub founders on potential locations [24].

Each of these studies focus on stagnant brick and mortar hubs. A stationary hub has different needs than a mobile hub. For example, historical models consider five main Spatio-structural criteria as outlined and used by Shahparvari et al.: Transportation Infrastructures, Geophysical Conditions, Socio-Economic Infrastructures, Environmental Limits and Geo-political Conditions [7]. Transportation Infrastructures is defined as access to a transportation network, in our case, interstates and roads. Geophysical Conditions are defined as areas that have suitable land surface and landform. Socio-Economic Infrastructures focus on the ability to access skilled manpower. Environmental limits encompass vegetation cover, soil types, and temperature. Geo-Political Conditions consider proximity to political boundaries [7]. Some of these criteria do not apply to mobile hubs (Environmental Limits, Geo-Political Conditions, and Socio-economic Infrastructures), but some may prove useful and should be considered (Transportation Infrastructures and Geophysical Conditions) as seen in the following paragraphs.

Local food is defined as food purchased within 275 miles or the same State where it was produced by the Food Safety Modernization Act, enacted in January 2011 [20]. Geo-political conditions, or the proximity to political boundaries, are negligible here as a small geographic area is highly likely to have uniform conditions. Environmental limits, such as vegetation cover, and soil types are also insignificant as mobile hubs do not need to be built and will remain on asphalt. As a mobile hub is a one-man operation and there is not a need for a large number of skilled workers, Socio-economic infrastructures such as access to skilled workers, are also inconsequential.

The last two criteria, Geophysical Conditions and Transportation Infrastructures are important to a mobile hub. The mobile hub's main goal follows the same goal as the LHLP: to pick a site that offers the greatest customer coverage while offering the lowest possible transportation cost [12]. Access to transportation infrastructure, in this case, highways and interstates, are especially important, thus showing the importance of Transportation Infrastructures [10, 25]. Geophysical conditions usually pertain to topography and disaster risk [26]. However, for this case, it concerns the availability of a flat parking space for the mobile hub. This is not a given commodity at every location since many restaurants are located in extremely urban areas without nearby parking. In our study, we focus on transportation infrastructure as it is the most pertinent to mobile hubs and the hardest to capture. Geophysical conditions are considered at a base level briefly in the model.

There has been limited work done studying the effectiveness of mobile hubs and with this work we add to the literature. Faugere et al. show that mobile hubs are valuable when demand is consistent and are even more valuable when demand is variable [27]. The flexibility offered by mobile hubs allow for network adjustments based on variations in demand patterns. Faugere et al. also show the positive impact of mobile hubs on environmental sustainability of the systems [27]. We expand on this work by applying a mobile hub to a local supply chain system.

For this study, we pull aspects of different studies in combination with new variables to create a novel methodology. There has been a burgeoning body of literature that deploys ensemble methods, highlighting GIS [28]. We add to this literature by combining spatial analytical methods with spatial optimization to solve location-routing problems. Most previous work focuses on large-scale supply chains and local supply chains are not addressed. There is a lack of literature on LHLP for local supply chains. This paper contributes a hub-location methodology that is built for local supply chains. The model uses GIS and real

routing data to achieve degree of detail in a smaller scoped problem that has not been achieved in previous literature. We also introduce the novel use of a mobile hub in a local supply chain.

3. Case Study Context

We explore the location analysis of a mobile hub within a hyperconnected logistics system for a startup Farm-to-Table (F2T) platform that enables local food supply chains. We particularly look at an Atlanta based F2T platform that connect suppliers directly to customers surpassing middlemen. The F2T secures the services of drivers to deliver between suppliers and customers on a contract basis. This platform induces logistics that must consider both the downstream side of markets, such as urban agglomerations with restaurants, institutions, and households demanding fresh and local food, and their upstream side consisting of farms producing and selling fresh and local food. The restaurants and farms are all located in the state of Georgia, since this is a local food supply chain. A map of the restaurants and farms can be seen in Figure 1.

We utilize Hyperconnectivity which stems from the Physical Internet (PI) and aims to improve the economic, environmental, & societal efficiency and sustainability of the way physical objects are moved, deployed, realized, supplied, designed and used. PI is a global hyperconnected logistics system that enables asset sharing and consolidation across numerous parties and modes. Hyperconnectivity allows for efficient and seamless information, transaction and material flow across stakeholders throughout the supply chain [29]. In this particular case, we are looking at a system where the platform has no physical assets and secures the services of drivers who own vehicles. The drivers are paid via a daily salary, which is formulated considering the number of stops, volume of goods, and are paid a bonus if they are able to deliver all their goods on time. Roughly, each hired driver is given the same number of stops per day. Since the drivers own their vehicles, they are self-incentivized to take the most efficient routes because they are responsible for their own gas, mileage to their vehicle and the time of their end of the workday. The combination of these factors imply that the drivers are motivated to maintain efficiency and timeliness for their routes. They are therefore aligned with the overall goal of using mobile hubs to reduce the time and length of routes.

We explore integrating mobile hubs into the model. A mobile hub in this case, is a movable, refrigerated trailer cooled at a food safe temperature that can be picked up by a pickup truck and moved on command. The mobile hub will be manned by one driver for security. Examples of mobile hubs can be seen in Figure 2.

In this problem there is a large pool of on-demand carriers, each with potentially limited capacity, with

Figure 1: F2T farms & restaurants.

Figure 2: Mobile hubs of different sizes

time windows for both pickups at farms and for deliveries at restaurants. Each restaurant order can contain multiple products from multiple farms, with potential transport incompatibilities between purchased products. We explore the use of a mobile hub that can thus be relocated as necessary from day to day or within a day to fit these constraints.

Through strategic routing, we want to optimize the routes of the carriers for time and distance. There are four main types of orders in the system: subscription type (where orders are known well in advance), orders with a week advance notice, orders with one-day advance notice, and same-day orders. The majority of orders are not same-day orders, so routes can be planned daily and in advance. Unlike large food distributors, the customer list is not the same each day/week/month. Due to the fluctuating nature of the daily customers, we examine the feasibility of mobile consolidation hubs.

These hubs serve as consolidation points for the delivery drivers that can change location based on daily demand. Most customers order products from multiple farms. Without consolidation at hubs, it is extremely likely that clients are visited multiple times in one day which is not ideal for restaurants. We test consolidation to minimize the number of drops per client (restaurant) while meeting delivery time expectations. The hubs also potentially save time and "food miles" as the farms are usually far from the customer demand clusters. Specifically, we test hub feasibility with an Atlanta based F2T platform that currently does not use any hubs and serves as a perfect test subject for analysis.

4. Methodology

Due to the size of the dataset, which is in the 10's to 100's of orders per day, we simplify the problem to one hub per day as is discussed in the literature review. There is simply not enough product to warrant more than one hub in most local food supply chains. We first identify hub locations and then use a combination of heuristics to generate the daily routes of on-demand carriers. Then, using historical data we are able to simulate historical routes to compare to the newly generated hub routes.

4.1 Methodology Summary

Step 1: Use Kernel Density to identify customer "hot spots" where customer density is expected to be high.

Step 2: Identify customers that fit certain delivery frequency criteria and fall in a "hot spot."

Step 3: Use Network Analysis on the customers identified in Step 2 to narrow down the list of possible restaurant hub locations to the 10 that were most central to the entire customer base.

Step 4: Further narrow this list of 10 by eliminating potential hub locations far from a major roadway.

Step 5: Further narrow the list by eliminating the 3 hubs located in the most population dense areas.

Step 6: Based on historical data estimate the routes (and their distances) that would be required for the remaining hubs on one randomly selected week.

Step 7: Select a hub for every day of the week based on the least distance traveled.

Step 8: Compare actual historical route data with estimated route with hub data to determine if there is a reduction in mileage and/or stops.

4.2 Kernel Density Map

The first step was to identify potential hub locations. ArcMap version 10.7.1 (ESRI) was used to geocode destinations that received deliveries over a span of time. These destinations were geocoded based on their latitude and longitude coordinates from the data retrieved from Tookan, the F2T's assignment software, and include restaurants, cafes, hotels, and markets. Each of these locations were visited a certain number of times over the 14-month period. The Kernel Density function of ArcMap was used to visualize the areal density of delivery destinations recorded over the 14-month period. The Kernel Density function estimates the "density by counting the number events in a region, or kernel, centered at the location where the estimate is to be made." [30] We use Kernel Density to estimate the expected number of deliveries in an area, effectively identifying customer "hot spots," to help pick an appropriate hub location.

4.2.1 Kernel Density Function. By using ArcMap, we used the following algorithm where, SR is Search Radius, SD is the standard distance, D_m is the median distance, n is the number of points if no population field is used, or if a population field is supplied, n is the sum of the population field values. We apply the following formula to calculate the bandwidth [31]:

$$SR = 0.9 * \min\left(SD, \sqrt{\frac{1}{\ln(2)}} * D_m\right) * n^{-0.2}$$

ArcMap Kernel Density analysis was performed using cell size $(2 * 10^{-4})$ and density radius $(5 * 10^{-2})$ decimal degrees. We predict location density

with a quartic kernel through the equation below [31], where $i = 1,...,n$ are the input points, pop_i is the population field value of point i, and $dist_i$ is the distance between point i and the new location:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} \left[\frac{3}{\pi} \cdot pop_i \left(1 - \left(\frac{dist_i}{radius} \right)^2 \right)^2 \right]$$

$$\text{For } dist_i < radius$$

The kernel density map was colored according to the Jenks natural breaks classification, as is the standard setting in ArcMap. Jenks natural breaks is a heuristic method which classifies the data in choropleth maps. We acknowledge that Jenks natural breaks may not be the ideal way to classify the data and other methods could be used. However, we choose the default on ArcMap for simplicity. The distribution and density of destinations were mapped for the full set of data obtained, as well as each of the distinct weekdays for a singular week during the year.

Furthermore, ArcMap's "Extract Values to Points," spatial analysis was carried out using the data points for each day of the week and the Kernel Density results. Candidate hub sites were then selected based on the following criteria: where the immediate area of had more than 52 deliveries a year (at least once a week) and where the raster cell kernel density values were greater than 240,000 (represents locations where there is a high density of restaurant deliveries).

4.3 Network Analysis

A network data set was then created in ArcMap using the roads data set. Using the Network Analyst extension, the closest facility function was run on the Network Dataset. This function takes the earlier identified hub locations and determines the 10 hubs that are most central to the restaurants via street distance. The purpose of this process was to form the largest cluster of restaurants that would be best served by each hub.

These 10 hubs were then mapped against daily orders over a week. The hub location for each day was chosen by selecting the hub based on several different criteria. First, there was weed out criteria. We used buffer analysis which is a GIS function that identifies candidates which fall in areas of a particular width from a vector feature or raster grid cells. In this case, we create a 3-mile buffer around interstates within Georgia and remove any hub candidates that do not fall within the buffer. This is for ease of access of the drivers.

Next, we divided Georgia into its 1,969 census tracts as identified by the 2010 Census of U.S. Census Bureau. For each census tract, we identified the population density. High population density means less parking and well-trafficked areas which are less desirable for a mobile hub. We removed the bottom 3 candidates that were found within the census tracts with the highest population densities.

For the purpose of the study, it was assumed that hub to delivery location is covered by one driver for all the buyers of the day. This is a generalization to simplify the problem. Without the generalization, we would have to solve for multiple vehicles. This problem is known as the vehicle routing problem (VRP) and much harder problem than the Traveling Salesman Problem (TSP) which involves one car [22]. With our generalization, we solve for the TSP, and add a small 5-mile buffer for each driver that would've been assigned that day. This buffer is to account for the small distance from the hub to the driver's first stop (hub – restaurant).

The New Route Analysis function within Arc Map was used to generate hub-to-restaurant routes for the remaining candidate hubs, for a randomly selected week of historical data. To efficiently execute this, the stops were allowed to reorder with hub location preserved as the starting point. In the next step, farm-to-hub distances were calculated using closest facility analysis for each day of the week. Here, it is assumed that farm-to-hub distances for each day are being covered by a separate driver (from each farm) to the hub. The distances for the final candidate hubs can be seen in the Results section.

The final hub selections were made by selecting the daily hub that resulted in the least distance traveled. Using this technique, one hub (roaming) was selected for each day of the week for the final selection. In order to calculate the efficiency of these hubs, we compare the distance traveled by drivers with and without hubs by using historical Tookan data.

5. Results

ArcMap version 10.7.1 (ESRI) was used to geocode 123,556 destinations that received deliveries between Oct 15, 2018 and Nov 18, 2019. Using a Kernel Density Based Heuristic (Steps 1 & 2 of the Methodology Summary), we were able to identify 41 feasible hub locations. The 41 candidate hubs were plotted on top of the kernel density map for each weekday of a singular week. The results from the kernel density analysis indicated that for every day of the week, the estimated concentration of the restaurants that required deliveries were in the central region of Atlanta.
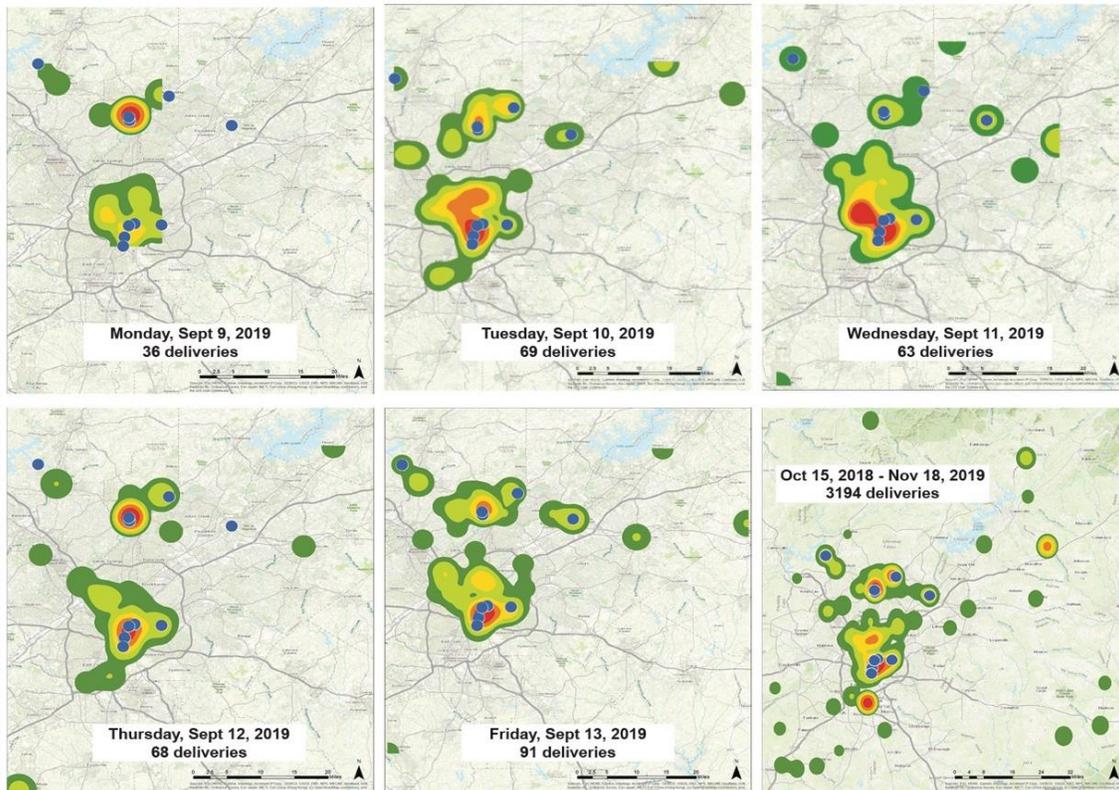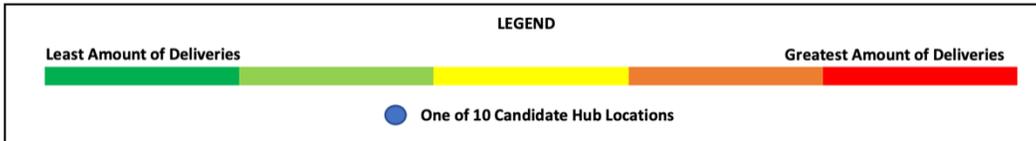
Figure 3: Dynamic demand heat mapping of ten candidate hubs

Next, using Network Analysis, we were able to reduce the 41 candidates to 10 (Step 3). Figure 3 depicts the 10 candidate hubs overlaid on the Kernel Density Map. Most hubs are located in Downtown and Midtown Atlanta with some in restaurant heavy suburbs such as Roswell. The ten candidate consolidation hubs are illustrated as blue circles on kernel density maps which estimate density of deliveries for each day of the week between Monday, September 9, 2019 & Friday, September 13, 2019, and for all deliveries recorded between Oct 15, 2018 & Nov 18, 2019. Locations with the highest estimated density are in highlighted in red, and areas with lowest estimated density are Dark Green.

Table 1: Estimated Mileage for different hub locations.

	Estimated Delivery Distance in Miles				
	Monday	Tuesday	Wednesday	Thursday	Friday
Hub 1	540	912	1297	962	703
Hub 2	*491*	905	1340	*945*	716
Hub 3	523	899	*1153*	951	688
Hub 4	567	*871*	*1248*	957	*669*

Next, we were able to eliminate 3 hub locations due to the lack of transportation infrastructure near those locations (Step 4). They were eliminated because the restaurants were not within a 3-mile buffer of an interstate. After this, we eliminated the three

Figure 4: An estimated route for one of the hubs on the on the sample week.
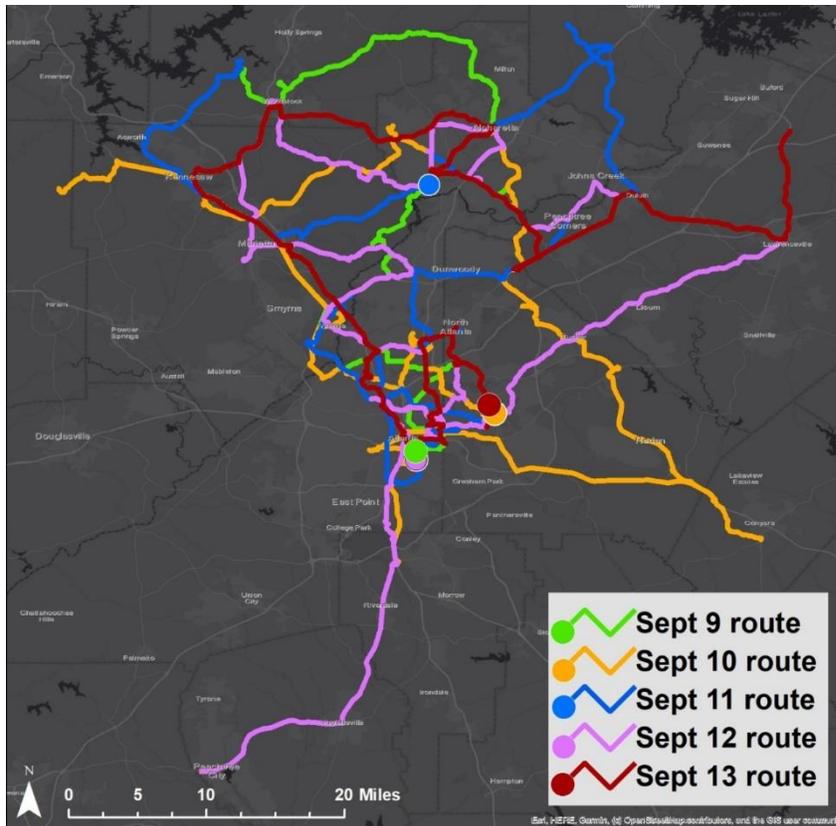
Figure 5: Selected hub locations and their routes for the sample week.

candidates that were in the three most population dense areas (Step 5). This was done in order to provide for more parking as is a necessary Geophysical factor for a mobile hub.

Next, we took the remaining 4 hubs and estimated the total distance traveled for the sample week of September 9th- 13th, using the historical customer location data for each of those days. In this case, we ignore the driver-to-hub buffer that we added to approximate the VRP because this would be the same for every hub. These results can be seen in Table 1. Hubs 2 and 4 were chosen twice, Hub 3 once and Hub 1 zero times. A route for one hub location on Wednesday can be seen in Figure 4. This hub did end up being chosen for the final selection. The final daily hub location was picked based on the location that resulted in the least mileage for the day as bolded and italicized in Table 1 (Step 7). In all cases except for one, the hub was able to decrease the amount of total mileage traveled per day.

In Figure 5, the optimal hub for each day of the week is shown by a colored dot. This shows that two candidate hubs were able to serve as hubs on multiple days. Deliveries on Mon, Sept 9 & Thurs, Sept 12 and Tues, Sept 10 & Fri, Sept 13 share the same hubs.

Next, we were able to compare these estimated routes to historical mileage traveled, which can be seen in Table 2. First, it displays historical information: the number of drivers needed, the number of restaurants served, the number of farm pickups, volume of orders, and historical distance. Next, it shows the estimated distances for deliveries using the mobile hub. In order to calculate the total distance, we add together the total distance traveled from the individual farms-to-hub, the distance traveled from the

Table 2: Comparison of Historical Routes to Estimated Routes

Day	Drivers	# of Rest.	# of Farms	# of Orders	Historical Farm-Direct-to-Restaurant Distance (miles)	Estimated Distances for Deliveries Using Consolidation Hubs (miles)			
						Hub-to-Restaurant	Farm-to-Hub	Farm-to-Hub-to-Restaurant	Driver-to-Hub
MON	5	23	6	31	576	86.84	404.2	491.04	25
TUES	6	48	7	67	917	158.44	712.4	870.84	30
WED	7	41	10	58	1354	209.13	943.8	1152.93	35
THUR	7	59	9	75	959	190.03	755.3	945.33	35
FRI	10	42	7	115	743	132.53	536.9	669.43	50

Table 3: Change in number of stop and distance traveled between historical routes & estimated routes.

Day	Change in Stops	Percentage Difference in Stops	Change in Distance (Miles)	Percentage Difference in Distance
MON	-3	-9.7%	-59.96	-10.4%
TUES	-14	-20.9%	-16.16	-1.8%
WED	-8	-13.8%	-236.07	-17.4%
THURS	-7	-8.8%	+21.33	+2.2%
FRI	-4	-3.5%	-73.57	-9.9%

hub-to-restaurants, and the driver-to-hub distance (which we added to the TSP value in order to estimate the VRP value). This chart shows the demand variability from day to day, as well as comparison of miles traveled, which can vary greatly.

Table 3 depicts the change in the number of stops and the change in distance from the historical distance traveled to the calculated estimated distance traveled with the use of a hub. Every day a hub is used, there is a reduction in the number of stops. In all but one day, Thursday, there is a reduction in the amount of distance traveled with an average reduction of 7.46% and a range from -17.4% to +2.2%.

6. Discussion of Results

When selecting one hub location from the final four options for each of the five days, both Monday and Thursday had the same location for a hub (Client 1) and Tuesday and Friday had the same ideal location for a hub (Client 2). This may indicate that since a lot of the restaurants are clustered near each other, there is a very likely chance that the same hubs will be utilized on a frequent basis. This is ideal for drivers when they pick up products from the hub location because they would essentially be alternating between a few locations regularly, although the days may change. Demand varies on different days of the week and the routes become more efficient when the hubs can move based on demand.

This can be seen in the different distances traveled for all hubs in Table 1. This indicates that consolidation was not the only factor in reducing the mileage. Each hub provides consolidation, but the location of each hub is different, indicating that there is importance to the location of the hub, demonstrating the added value of having a mobile rather than stagnant hub.

Table 3 indicates that there is a reduction in stops in all cases since we are consolidating orders such that no restaurant receives more than one shipment a day. This drastically reduces the time drivers spend unloading as a single drop off, which typically takes between 5-10 minutes. This also helps cut down on the distance traveled. We notice that in almost all cases distance is reduced when adding the hub. In the case

where distance is not reduced, we hypothesize this is due to wide farm-spread for that day.

These preliminary results indicate hub use could serve as a valid way reduce mileage and stops. They are also more sustainable system as emissions are directly related to distance traveled. A reduction in mileage will result in a reduction in emissions. The hub system is also more cost-effective as the overall number of stops is reduced reducing the number of drivers needed to be hired.

7. Conclusion

Though we used a small sample size for testing, we believe our results are important for small local supply chains. We have shown that using a mobile hub reduces food miles and number of stops on a route. This is not only good for the F2T company, but also for the environment; transportation accounts for 28.9% of the US's Greenhouse gas emissions [32]. Any reduction in transportation helps reduce such emissions. We have also shown how to incorporate the use of real routing data into hub location analysis.

We have demonstrated how to use a hybrid methodology for hub location selection, in the case of a local supply chain that may not have the manpower to conduct other more elaborate location analysis. We are also able to build a model that focuses on real distance traveled and makes fewer estimations and assumptions than is usually done in literature for larger supply chains. We understand that there are limitations to this study. We do make assumptions in the estimation of hub routes. Future research could study the feasibility of creating a VRP heuristic for such routing. The kernel density analysis and network analysis were limited to functions available in ArcMap could be expanded to use other programs which may be more detailed and/or accurate.

In further research we hope to show the statistical significance of these reductions through t-testing on a larger set of days with a cost analysis of the hubs used. Mobile hubs could change the way local supply chains operate. Instead of warehouses with large footprints, mobile hubs only take up a spot in a parking lot. They are especially useful in supply chains where demand is not constant and OD pairs are variable. The number and location of mobile hubs are flexible, such that they can be assigned on the day of delivery and could even move throughout the day based on changing demand. Additional research could also investigate the impact of time sensitivity, such as accounting for preferred and detrimental delivery times at client locations, as well as synchronicity impacts of arrival and departure times at hub on overall performance.

This work can also be expanded beyond local food supply chains. Mobile hubs could also be used in local disaster relief. Relief supplies often come from many different areas and need to be distributed to various locations daily. In this example there is also a fluctuating nature in the customers and their locations, which makes it a candidate for mobile hub use. Our research shows that there is potential in this area of study, and we hope more work is done in the future.

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9. References

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