CMU Tepper School of Business MS in Business Analytics Capstone Project

412 Food Rescue:

Optimizing Route Delivery Pathways to Enhance Home Delivery

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ABSTRACT

This capstone project is a joint, collaborative effort between Carnegie Mellon University Tepper School of Business & 412 Food Rescue with a focus on optimizing food delivery routes and logistics. Home deliveries, which are essential for food access in households throughout Pittsburgh, currently struggle with inefficient routes due to a technical process that is heavily reliant on manual adjustments to a software-generated delivery route system, which often results in unclaimed and/or canceled food orders.

Our main objective is to boost food distribution efficiency by identifying optimal geographic locations for the strategic placement of mobile food storage and distribution hubs/delivery trucks through the employment of k-means clustering. We performed an extensive analysis of 412 Food Rescue's food delivery data to determine optimal locations that were situated in high-demand areas to establish more centralized distribution hubs in an effort to reduce route planning complexity and overall delivery times. This streamlined, data-driven approach to food delivery and route optimization aims to significantly enhance route reliability, as well as attract more volunteers, to ensure more timely and complete food deliveries to households in need.

INTRODUCTION

The primary challenge we addressed is that volunteers are not delivering the distributed food packages to their respective household assignments even after rescuing (claiming) them from donor locations. We identified two major causes that contributed to this problem: improper assignment of households to each of the volunteers and lack of convenience for the volunteers, who were delivering food without getting incentivized for their efforts.

After careful deliberation with the Food Rescue team, we designed a creative and innovative solution: mobile food storage and distribution hubs, which would be placed in optimal geographic locations that were in close proximity to clusters of households using k-means clustering. Then, the next step was to determine where we should store the food. To solve this, we implemented machine learning algorithms and optimization techniques to address this challenge. We also generated a Tableau dashboard to help the Food Rescue team visually comprehend our solution, as our result was generated in the form of latitude and longitude coordinates.

After successful implementation of our solution, we predict that the average delivery time taken for a volunteer to deliver rescued food packages from mobile food hubs to each of the determined subset of households within a given cluster will decrease significantly by approx. 30%. In addition, the probability of a volunteer missing, or canceling, a home delivery is predicted to go down by a matter of 13%, thus maximizing the total number of households being fed and served every week by 412 Food Rescue.

METHODS & MATERIALS

Model Development – Benchmark Setting: Using k-means clustering, we establish benchmarks to identify strategic hub locations for mobile delivery trucks, optimizing the k-value for precise grouping. This method incorporates constraints like donor-household affiliations, ensuring hubs serve high-frequency donor locations effectively. We begin by leveraging the Haversine formula to calculate the shortest distances between each household and donor location, accommodating the curvature of the Earth's surface. These distances are stored systematically for subsequent analysis.

Anomaly Detection and Constraint Integration: We apply anomaly detection to refine the delivery network, identifying irregularities in delivery patterns and standardizing them based on geographic and delivery frequency variables. This process also accounts for capacity and demand constraints due to donor-household affiliations. Using linear programming, we optimize the assignment of donors to households, aiming to minimize the total distance traveled while ensuring efficient resource allocation. Decision variables and constraints are set to manage the relationships and capacities effectively.

Model Training and Validation: Data Segmentation and Toolset: We segment delivery data to include all relevant variables for accurate representation of donor-affiliated households. Development tools like Jupyter Notebooks support complex modeling, with Tableau providing visualization to optimize distribution efficiency within these constraints. Further, we utilize clustering algorithms to group 9990 households into 8 clusters based on geographic proximity, optimizing resource allocation and delivery processes.

Dashboard Development and Geospatial Analysis: Engineered interactive Tableau dashboards to visualize and interpret complex datasets, enabling more intuitive insights into donor and household geographic correlations. Leveraged Tableau's advanced geospatial tools to map delivery routes, identify high-demand areas, and display donor-household relationships. We measure the total distance traveled by all donors, before and after optimization, to evaluate the effectiveness of these strategies in reducing travel distances and improving resource utilization.

RESULTS

The data comprised 30 donor locations and over 885 households, served weekly by 451 volunteers. There were a total of 9990 deliveries over the 3 year time period. Since volunteers choose deliveries on a first-come, first-served basis, they have the flexibility to select their preferred food rescue spots. However, delivering to multiple distant homes presents a challenge. To address this, we propose the establishment of centralized drop-off points.

After applying our clustering model, we identified 8 strategic mobile hub locations across Pittsburgh, two of which are showcased in the graph below. These hubs will be equipped with refrigerated storage, enabling volunteers to efficiently collect and distribute food.

This approach addresses several key issues:

1. It reduces the number of pick-up points and strategically locates them closer to delivery areas.
2. It offers volunteers convenience in selecting locations and households.
3. It significantly cuts delivery times, enhancing the efficiency of the overall food rescue operation.

DISCUSSION

Challenges: More than 70% of donations came from the top 3 donors as can be seen in the above graph. While deciding the optimized locations of food storage we might also have to structure the capacity of storages accordingly. The recommendation is operation-heavy, and Food Rescue will have to make significant changes in the current system, including adding infrastructure.

Alternatives: We initially built a model that restructured the route allocations to the volunteers. While that could have been one way forward, it did not impact our KPIs significantly as much as the current solution does.

Expanding the Scope: Additional Perspectives on Delivery Challenges*:* Based on feedback from long-term Pittsburgh residents and discussions from a Reddit thread, we identified several factors that complicate delivery in Pittsburgh, such as narrow streets and complex intersections (Reddit, 2022). The city's narrow streets, complex intersections, and historic urban layout contribute to these difficulties, often leading to delivery delays and increased cancellation rates.

1. Enhance Navigation and Delivery Instructions: Expand this strategy to integrate the parking database directly into the navigation systems used by volunteers. Provide not only route guidance but also real-time parking updates that help volunteers plan their parking strategies before they arrive at their destination. This could reduce time spent searching for parking, thereby improving overall delivery efficiency.
2. Engagement with City Planners: In addition to discussing temporary delivery zones, use the data collected to advocate for longer-term changes in urban planning that support delivery and parking needs. Presenting concrete data to city planners could help make a stronger case for the necessity of these changes, potentially leading to more supportive infrastructure developments like designated delivery spots or adjusted parking regulations.
3. Volunteer Training and Support: Update training programs for volunteers to include how to effectively use the new parking database and navigation tools. Educate them on interpreting real-time data and adjusting delivery plans on the fly. This could enhance their ability to handle the dynamic challenges of delivery, reducing stress and increasing delivery success rates.

Future Directions: Looking further, assuming the probable continuation of this capstone project in coming years, we have identified an area of interest to better enhance route delivery between subsections of donor and household locations. We predict that the results of our k-means clustering geospatial model, specifically the optimal geographic placement of centroids OR mobile food storage & distribution hubs, will be converted into a readable, route-optimization file, which will contain a list of shortest paths between 3-5 households, that can be utilized as an input for modern, cutting-edge, industry-standard route optimization softwares, such as MapBox, HGS-CVRP, or Google OR-Tools, to seamlessly revolutionize the route planning system used by 412 Food Rescue. These actionable results and insights can be leveraged to greatly reduce the overall distance covered by volunteers as well as the time taken by volunteers to deliver to certain households. Our goal would be to have this new route optimization software run in parallel with 412 Food Rescue's current route planning system, Routific, and conduct real-time analysis of key performance indicators (KPIs) to determine which route planning system to adopt going forward, whether it be ours or theirs.

CONCLUSION

By employing k-means clustering to optimize the placement of mobile food storage & distribution hubs, we have generated a creative solution that has led to a transformative improvement in food delivery logistics by effectively streamlining the routing process for home deliveries.

The implementation of machine learning algorithms and optimization techniques, as well as advanced data analytics, has allowed for the systematic identification of optimal hub locations that align closely with the geographical distribution of donor and household affiliations.

The predicted reduction in food delivery times and a decrease in missed/incomplete deliveries highlights the project's potential to significantly increase the number of households served by 412 Food Rescue each week.

REFERENCES

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