Meta-Heuristic Optimization of Last Mile Deliveries by Electric Vehicles in Rural Areas Using Synchronized Routing and Resupply Strategies – Project 12

Deliverables and Reporting Requirements for UTC Grants Awarded in 2023 (June 2023)

Exhibit D

Recipient/Grant (Contract) Number: The University of Tennessee; North Carolina A&T, Grant No. 69-A3552348338

Center Name: Center for Freight Transportation for Efficient and Resilient Supply Chain (FERSC)

Research Priority: Improving Mobility of People and Goods

Principal Investigator(s): Steven Jiang (NCAT), Om Yadav (NCAT), Hieu Nguyen (NCAT)

Project Partners: NCDOT

Research Project Funding: $100,000 Federal and $50,000 non-Federal funding

Project Start and End Date: 07/01/2024 – 06/30/2025

Project Description: The adoption of clean energy vehicles such as Electric Vehicles (EV) for the last mile logistics have shown the economic and environmental benefits, and studies have highlighted the importance of more research into the area of sustainable and efficient rural last mile logistics. For example, implementing electric drones for rural last-mile delivery was shown to reduce emissions compared to traditional diesel trucks in addition to also being economically cost-effective. Last mile rural delivery networks can vary depending on the location, and multiple case studies have shown that EV bicycles can lead to increased savings in certain last mile rural delivery networks. Many states have considered the adoption of EVs and studied the impact of such adoption. The United States Department of Transportation (US DOT) has proposed multiple plans in the coming decades to improve the efficiency and economic opportunity of the transportation sector. North Carolina Department of Transportation (NCDOT) has a strategic goal to transform the existing infrastructure to accommodate and accelerate the adoption of electric vehicles.

The primary objective of this project is to develop a synchronized routing solution for an electric vehicle based last mile delivery system in rural areas that incorporates synchronized refilling of goods and battery swapping. The proposed project aims at mitigating the challenges associated with adoption of electric vehicles in rural areas, directly addressing the lack of infrastructure available and range anxiety among other challenges [5-8]. We believe this project will facilitate the adoption of EV's into rural road networks, and simultaneously optimize the cost, reliability, and delivery times of the network by implementing special constraints. These special constraints will synchronize the movements of the vehicle fleet with a single resupply vehicle for resupplying goods and batteries. This research provides a solution to accelerate the adoption of EV vehicles into rural vehicle networks with minimal changes to the existing infrastructure, which often ends up as a significant limiting factor.

The justification for implementing synchronization constraints to solve this problem is multifold. The versatile nature of synchronization constraints specifically with respect to vehicle routing domain has been investigated and found to be able to model the real-world complexities of routing problems to a higher degree of accuracy compared to non-synchronized vehicle routing problem [9]. The last-mile delivery problem in rural areas utilizing electric vehicles is an excellent candidate that can be approached and optimized using the synchronization constraints. Meta heuristics have been shown to generate good solutions to such complex combinatorial problems [10-11].

The data used for the model will be based on the rural area of Greensboro (where North Carolina A&T State University (NCA&T) is located) and will also be evaluated on benchmark instances that will be developed with NCDOT and other stakeholders. Examples of data that will be collected include existing EV charging infrastructure, EV ownership data, last mile delivery locations, demand data, and operation metrics, traffic analysis zones, land parcel data, and road network data. These can be retrieved from sources such as the US Department of Energy's alternative fuels data center, NCDOT, US Census Bureau, logistic companies operating in the area, and NC OneMap.

US DOT Priorities: Improving Mobility of People and Goods; Sustainability, Transformation, Organizational Excellence. FERSC's research priority directly aligns with the strategic goals of the DOT by placing a focus on optimizing the first and last mile deliveries, rural transportation, and improving the infrastructure.

Outputs: The technology transferred for this project proposal would involve multiple phases. The initial phase involves case studies and simulations followed by small scale and large-scale implementations. Research team will simulate the model on benchmark instances and present the quantitative assessment with stakeholders, followed by the model being directly shared with stakeholders including NCDOT, logistics companies and the data analytics firms so that it can be simulated on the existing data that they have. Any new findings regarding the performance of the model or the meta heuristic method will also be shared with these stakeholders at every phase of the project. Once the simulations and case studies are completed and verified, the small- and large-scale implementations of the model will be made possible through the collaboration between the research team and the stakeholders.

The proposed research and its findings will be incorporated into a graduate/senior elective special topic course at the ISE department at NCA&T to prepare the next generation engineers, especially African American engineers (NCA&T is a HBCU) that are ready to address challenges in freight transportation supply chain. Students in the team will also develop games/tool kits based on this research and utilize the close ties between NCA&T and local high schools and middle schools to educate students (especially underrepresented students) and to broaden the participation in STEM.

Outcomes/Impacts: This research provides a solution to accelerate the adoption of EV vehicles into rural vehicle networks with minimal changes to the existing infrastructure, which often ends up as a significant limiting factor. The primary stakeholders in this research include the logistics companies, rural communities (i.e., rural area in Greensboro, North Carolina), EV manufacturers, regulatory agencies and local government bodies that are responsible for infrastructure development.

REFERENCES

1. Patella SM, Grazieschi G, Gatta V, Marcucci E, Carrese S. The Adoption of Green Vehicles in Last Mile Logistics: A Systematic Review. Sustainability. 2021; 13(1):6. https://doi.org/10.3390/su13010006
2. Jiang X, Wang H, Guo X. Analyzing Service Quality Evaluation Indexes of Rural Last Mile Delivery Using FCE and ISM Approach. Information. 2020; 11(6):327. https://doi.org/10.3390/info11060327
3. Raghunatha, A., Lindkvist, E., Thollander, P. et al. Critical assessment of emissions, costs, and time for last-mile goods delivery by drones versus trucks. Sci Rep 13, 11814 (2023). https://doi.org/10.1038/s41598-023-38922-z
4. Innovation Concept Review E-cargo bikes and rural green logistics. (n.d.). Retrieved March 30, 2024, from https://nicre.co.uk/media/kp1pjwa5/nicre-icr-no-1-march-2023-e-cargo-bikes-and-rural-green-logistics.pdf
5. Raeesi, R., & Zografos, K. G. (2020). The electric vehicle routing problem with time windows and synchronized mobile battery swapping. Transportation Research Part B: Methodological, 140, 101-129.
6. Ren, X. X., Fan, H. M., Bao, M. X., & Fan, H. (2023). The time-dependent electric vehicle routing problem with drone and synchronized mobile battery swapping. Advanced Engineering Informatics, 57, 102071.
7. Siragusa, C., Tumino, A., Mangiaracina, R., & Perego, A. (2022). Electric vehicles performing last-mile delivery in B2C e-commerce: An economic and environmental assessment. International Journal of Sustainable Transportation, 16(1), 22-33.
8. Stamadianos, T., Kyriakakis, N. A., Marinaki, M., & Marinakis, Y. (2023). Routing Problems with Electric and Autonomous Vehicles: Review and Potential for Future Research. Operations Research Forum, 4(2), 46. Springer International Publishing.
9. Soares, R., Marques, A., Amorim, P., & Parragh, S. N. (2024). Synchronisation in vehicle routing: classification schema, modelling framework and literature review. European Journal of Operational Research, 313(3), 817-840.
10. Fink, M. (2016). The Vehicle Routing Problem with Worker and Vehicle Synchronization: Metaheuristic and Branch-and-Price Approaches (Doctoral dissertation, Technische Universität München).
11. Simoni, M. D., Kutanoglu, E., & Claudel, C. G. (2020). Optimization and analysis of a robot-assisted last mile delivery system. Transportation Research Part E: Logistics and Transportation Review, 142, 102049.