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Battery Swapping and Charging Station System Design in Logistic Hubs for Electric Trucks

Guanlin Chen[1,2], Yujia Xu[1,2], Benoit Montreuil[1,2], Valerie Thomas[1]

1. H. Milton Stewart School of Industrial & Systems Engineering, Georgia Institute of Technology, Atlanta, United States
2. Physical Internet Center, Supply Chain Innovation & Logistics Institute, Atlanta, United States

Corresponding author: guanlin.chen@gatech.edu

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Conference Domain Fitness: *Enhancing the societal, economic, and environmental efficiency, resilience, and sustainability of freight transportation by utilizing clean energy to reduce greenhouse gas emissions.*

Physical Internet (PI) Roadmap Fitness*: Select the most relevant area(s) for your paper according to the PI roadmaps adopted in Europe and Japan:* ☒ *PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories),* ☐ *Transportation Equipment,* ☒ *PI Networks,* ☐ *System of Logistics Networks,* ☐ *Vertical Supply Consolidation,* ☐ *Horizontal Supply Chain Alignment,* ☐ *Logistics/Commercial Data Platform,* ☒ *Access and Adoption,* ☐ *Governance.*

Targeted Delivery Mode-s*:* ☒ *Paper,* ☐ *Poster,* ☐ *Flash Video,* ☐ *In-Person presentation*

Research Contribution Abstract

On December 12, 2015, world leaders at the UN Climate Change Conference in Paris reached the Paris Agreement. This sparks the transition towards a net-zero emissions world. World targets are for emissions to be reduced by 45% by 2030 and reach net zero by 2050 [1]. Freight transportation is responsible for 8% of the global greenhouse gas (GHG) emissions, with 65% of these coming from road vehicles such as trucks and vans [2]. Thus, transitioning from conventional to electric trucks could reduce the GHG emission, contributing to the achievement of the net-zero goal.

To integrate electric trucks into the freight transportation systems, battery charging stations and battery swapping stations are the two main methods for recharging the batteries on trucks. Compared to conventional trucks with combustion engines that only need around 5 minutes to refuel the gasoline tank, electric trucks encounter the challenge of significantly longer recharge times (6-8 hours using low DC power to recharge and 30-45 minutes using megawatt charging to recharge [3]) and the need for specific yet expensive infrastructure [4].

Due to the high battery capacity and extensive energy consumption of electric trucks, Megawatt Battery Charging Stations can be deployed to ensure the trucks finish charging batteries within 3045 minutes and do not spend hours at the station. However, the substantial energy output of several

Megawatt Battery Charging Stations handling charging for multiple trucks at the same time could significantly impact their local power grid. Battery Swapping Stations could further reduce the time needed at the station since they could replace the depleted batteries with charged batteries within 5 to 10 minutes. The depleted batteries can then be either recharged locally at the station or managed centrally. Since Battery Swapping Stations allow strategic management of the battery charging schedule, the peak power output at each swapping station could be reduced. As a result, they have lower impact on their local power grid compared to Megawatt Battery Charging Stations.

In this paper, our goal is to reduce the battery inventory level at the Battery Swapping Stations, while keeping the extra dwell time caused by electrifying the trucks. We will be using a queueing network model and simulation to analyze how the average truck dwell time and maximum truck queue length would change in response to the change of battery inventory level. With the computational result from our analysis, we would be able to determine the optimal battery inventory level for each hub in the hub networks so that the freight system could maintain high efficiency with reasonable cost while adapting to the electric trucks to achieve the net-zero goal.

To leverage the existing hyperconnected hub networks, Megawatt Battery Charging Stations and Battery Swapping Stations will be deployed at the hubs within the networks. This paper will focus on intra-day planning of a single hub within the hub network that is selected to be Battery Swapping Station where depleted batteries can be charged locally.

We consider the Battery Swapping Station as a queueing network with an open queue of trucks and a closed queue of batteries. Upon truck arrival, if there exists an available battery swapping server and a fully charged battery, the fully charged battery will be swapped to the truck and the depleted battery on the truck will enter the battery queue. Previously [5] has shown the steady state distribution of the system based on the assumption that the arrival of truck has a fixed Poisson arrival rate. Within the hyperconnected hub network, information sharing allows us to model the system more accurately to real-world scenarios using a time-dependent Poisson arrival rate. A day is then divided into 8 different time regimes; each regime is 3 hours long and has a fixed Poisson arrival rate. As a steady state is not guaranteed within 3-hour time frame, we use an agent-based simulator to better capture the behavior of the system and calculate the empirical results.

Our simulation result provides the relationship of the battery inventory level versus the maximum parking space needed and the truck waiting times, which would facilitate in determining the best configuration of battery inventory level for each hub in the network. And the result can be further utilized in the network planning process.

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