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Efficient Implementation of Truck Battery Charging and Swapping Stations in Hyperconnected Logistic Networks

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Conference Domain Fitness:

The study will seek to investigate and propose organization for enabling the adoption of Phyical Internet and Hyperconnected supply chains. From this study, we will address the limitations to implementation. Based on these findings, we propose a stakeholder structure and collaboration network to incorporate efficient methodologies to integrate electrified fleets into existing supply chains and hyperconnected logistic networks.

Physical Internet (PI) Roadmap Fitness*:* ☒ *PI Nodes (Customer Interfaces, Logistic Hubs, Deployment Centers, Factories),* ☒ *Transportation Equipment,* ☒ *PI Networks*

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

Research Contribution Abstract

With increasing consumer demand comes increasing transportation costs, costs measured by dollars, miles traveled, and CO_2 emitted. The EPA reported that in 2021 Medium and Heavy Duty trucks emitted about 407.8 million metric tons of just CO_2 [US EPA (2023)] in the United States. To combat such environmentally detrimental outputs, clean energy can replace gas or diesel fuel sources in freight systems. With equally demanding customer bases for rapid deliveries, transportation and commerce networks are being revolutionized. To keep up with innovation and implement clean energy sources, solutions must incorporate modular techniques to prevent additional costs to networks.

In the Physical Internet (PI) template for freight supply chains, electrification limits trucks to be serviced at hubs of optimal route-flow and of electrically feasible charging bays. This combination requirement under battery reenergizing significantly filters capable hubs in the network when constructing charging bays. Doing so at all the facilities in a network pose financial investment challenges. These additional locations may lack electric grid capabilities as well, leading to the route-optimal structure already existing under the Physical Internet infeasible. Since battery charging also requires the electric trucks to be charged at bays in the determined feasible set of hubs, the charging time will often be far greater than estimated dwell time for the facility [Bernard et al. (2022)]. Factors like driver motivation and incurred costs from lag-time minimize the profit achievable through electrification.

An alternative technology, battery swapping eliminates the need for trucks to be charged during hub stops, alleviating long wait times. Known to average around five minutes per swap [Zhu et al. (2023)], the function can be built into existing dwell times for vehicles in the optimized route. However, relying solely on battery swapping poses additional complexity in physical battery inventory management, algorithms on battery swapping optimization policy, and the direct costs of purchasing batteries. Eventually every battery in the system must be reenergized, requiring charging stations similar to battery charging with different specifications. Without fully charged batteries for every time cycle of transportation, the flow will halt.

The combination of two related technologies, battery charging (BC) and battery swapping (BS) can generate more implementable solutions under the Physical Internet framework. The electrification of hyperconnected logistic networks (HLN) will propose less barriers to entry and maximize the marginal utility of electrification. Hyperconnected logistic networks offer resiliency and sequential decision making [Crainic, Gendreau (2020)] by taking in modular container routing to provide optimized policies on which fuel method should be assigned to each arrival [Grover et al. (2023)].

In this paper we seek to highlight the necessary actions by major stakeholders to implement hyperconnected logistic networks integrated with battery charging and battery swapping and a framework for collaborative innovation to reach NetZero goals across industries. Drawing from literature, an outline of incremental steps with associated partners will be introduced for integration of electrification.

Further research on electric grid capabilities, distribution, and integration of electrified freight fleets is necessary to reach the NetZero goal [Revankar, Kalkhambkar (2021)]. Beyond the governmental interests in electrified fleets, large industries have incentives to adopt more clean energy technologies. Innovation policy must provide an incentive for standardized swapping technologies and charging stations to reduce costs to promote seamless integration into Hyperconnected Logistic Networks.

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