A methodology to evaluate the performance of urban transshipment networks with electric freight vehicles in low emission zones

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Problem definition: Over the past decade, increased emissions from logistics activities are forcing municipalities to introduce low emission zones (LEZ) that limit access to diesel-powered cargo vehicles in high-density urban areas. LEZs pose a significant challenge to logistics service providers (LSP) engaged in last-mile delivery services as they conventionally use diesel vehicles to deliver customers located within these areas. A potential solution involves changing the existing logistics network to an urban transshipment network with light electric freight vehicles (LEFV). These new networks utilize a set of micro transshipment hubs located in the urban areas to deconsolidate and transfer shipments from high capacity vehicles to lighter electric freight vehicles that meet the entry requirements of LEZs. Albeit showing potential, logistics service providers must assess, ex-ante, the performance of these new networks in achieving their business objectives. However, this ex-ante assessment is somewhat complicated because the configuration of logistics networks, affecting the entire distribution process, is not known in advance and usually designed for an application. In the case of an urban transshipment network, these configurations are characterized by the size, location, number of micro hubs, and fleet sizes of the cargo vehicle fleets. Moreover, an LSP would consider adopting only that particular network configuration, which minimizes the costs to the firm. Therefore, network design optimization models play an essential role in ex-ante performance evaluation of networks, as they can reproduce analytically the cost-optimal configuration that is likely to be adopted by LSP and the corresponding distribution activities.

Several location routing problem models (LRP) have been developed in the past to determine cost-optimal configurations of the logistics network with transshipment points. These models, indeed, can be used to determine the cost-optimal configurations of urban transshipment networks. However, these LRP models are computationally complex as they combine two NP-hard problems, facility location problems, and capacitated vehicle routing problems (CVRP). Solving these models require sophisticated heuristic approaches, which impedes the understanding of logistics practitioners and application to real problem contexts. Parsimonious techniques like continuous approximation (CA) have shown to alleviate the complexity of these models, especially at routing levels, by approximating the route lengths of the vehicles. Thus, indicating the need for developing new continuous approximation-based models to assist LSPs in evaluating the performance of urban transshipment networks with LEFVs.

Approach: This research presents a novel continuous approximation-based model that reduces the computational complexity by decomposing a traditional LRP into two interconnected simpler optimization subproblems. The model analytically aggregates the distance traveled by LEFVs fleets instead of finding their distinct routes from the micro hub. The proposed model is applied to multiple distinct scenarios, which are synthetically generated with varying customer densities, vehicular technologies, micro hub specifications, and LEZ regulations. The validity of the CA approach is tested by comparing approximated distance traveled by LEFV with the exact estimates obtained from the CVRP model. Based on the obtained cost-optimal configurations of urban transshipment networks and the corresponding distribution activities costs, a range of key performance indicators (KPI) aligned with the overall business objectives of a typical LSP are measured. Economic KPIs involves the *total logistics cost* and the *average cost per parcel*, whereas, the environmental performance of networks is measured through the *total* CO_2 *emissions* from the transportation of packages.

Results: The results of validation revealed that the number of LEFV trips obtained from the CVRP model and the proposed model was the same, but the total distance traveled by the LEFVs was excess by an average of 5%. Secondly, the proposed model could generate a near-global cost-optimal configuration of urban transshipment networks for all the demand scenarios considered. Finally, the KPI analysis indicates that the customer density in the scenario affected the overall performance of urban transshipment networks. Table 1 shows that the performance of the urban transshipment network increases significantly as the customer density increases while keeping the values of the remaining parameters the same across the scenarios. Furthermore, the results also show that locating the micro hubs inside the LEZ helps in further enhancing the overall performance of urban transshipment networks for higher customer densities.

Table 1: KPI results for demand scenarios with increasing customer density

Key performance indicators	**Demand scenario 1 (customer density 2.5/ sq. km)**		**Demand scenario 2 (customer density 5 / sq. km)**		**Demand scenario 2 (customer density 9.5 / sq. km)**	
	Micro hubs at periphery of LEZ	**Micro hubs inside LEZ**	**Micro hubs at periphery of LEZ**	**Micro hubs inside LEZ**	**Micro hubs at periphery of LEZ**	**Micro hubs inside LEZ**
Total logistics cost (€)	793.1	817.8	1275.9	1225.8	1918.6	1823.9
Average cost per parcel (€)	3.01	3.2	2.5	2.4	2.1	1.9
Total CO_2 emissions (kg)	60.7	38.4	77.8	57.5	156.4	88.1