Green Urban Freight Distribution Network Design under Demand Uncertainty

Mengtong Wang[1,2,*]; Michael G.H. Bell[1]

[1]The University of Sydney Business School, [2]Tsinghua University

Abstract

We investigate a green location-routing problem under demand uncertainty (R-G-LRP) where **the location of depots to install chargers** and **the delivery plan of electric vehicles (EVs)** are optimized simultaneously from the perspective of logistics companies.

The **variation of demand** is customer specific, does not assume any probability distribution of demand, and may be estimated using historical demand data.

Based on the numerical results, **the benefit of a robust planning approach** with regard to operational feasibility and savings in overall costs is analysed for this planning problem.

Introduction

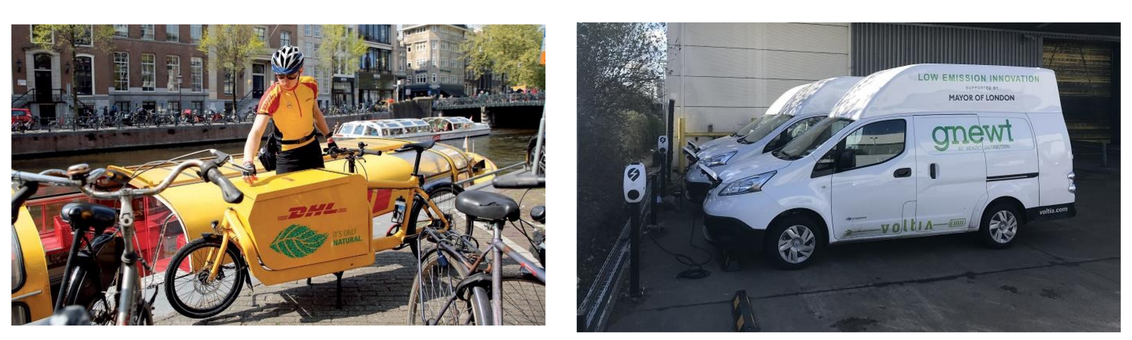

Figure 1. Different types of logistics EVs

With the **increased diffusion of e-commerce**, logistics market is on the move and supports the economic development of the country. However, the growing volumes of freight contribute to traffic congestion and environmental nuisances, especially in **urban areas** (European Commission, 2018).

Recently, there is a trend to use electric vehicles (EVs) instead of conventional internal combustion engine vehicles in city logistics, since EVs are **quiet** and generate **no street-level emissions**. In addition, the volume of **demand** at a node is **uncertain** in the express delivery industry, especially as the e-commerce enterprises enter to or withdraw from promotional activities.

Hence, anticipating demand uncertainty at the **design stage** is crucial in order to determine the **integrated** location and routing decisions for EVs and reduce **risks and costs**.

Methodology

We formulate the R-G-LRP as a set partitioning formulation (**master problem, MP**) to choose candidate depots and paths in the final optimal solution, and a independent robust elementary shortest path problem (**robust ESPPRC**) for each chosen depot to generate feasible paths. Then, the outline of our proposed **exact algorithm** to solve above problems is illustrated in Figure 2.

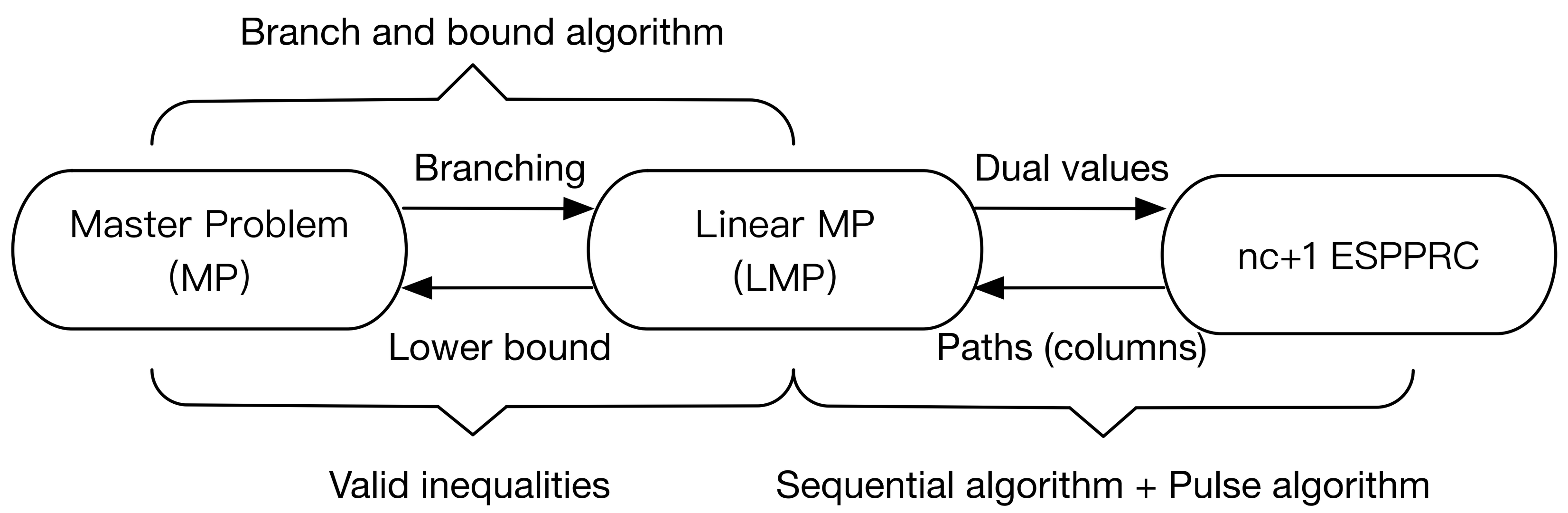

Figure 2. The framework of proposed algorithm

Results

To investigate how the optimal solution is affected by demand uncertainty, we test the protection levels (different Gammas) from 0 to 4 for the instances, **which allow 0% to 100% of customers assigned to a EV to change their demands**.

The numerical results indicate that the robust solutions are more expensive than their deterministic counterparts, with values monotonically increasing as the protection level increases. Furthermore, our robust formulation **can control the level of robustness** of the solutions by adjusting the protection level Gamma, which is very useful and operable for logistics companies to **design their EV delivery systems**.

Figure 3 shows an illustrative example with twelve customers and three potential depots, indicating that the number and location of depots need to be refurbished, the number of EVs and the optimal EV routes are **all affected by uncertainty about demand**.

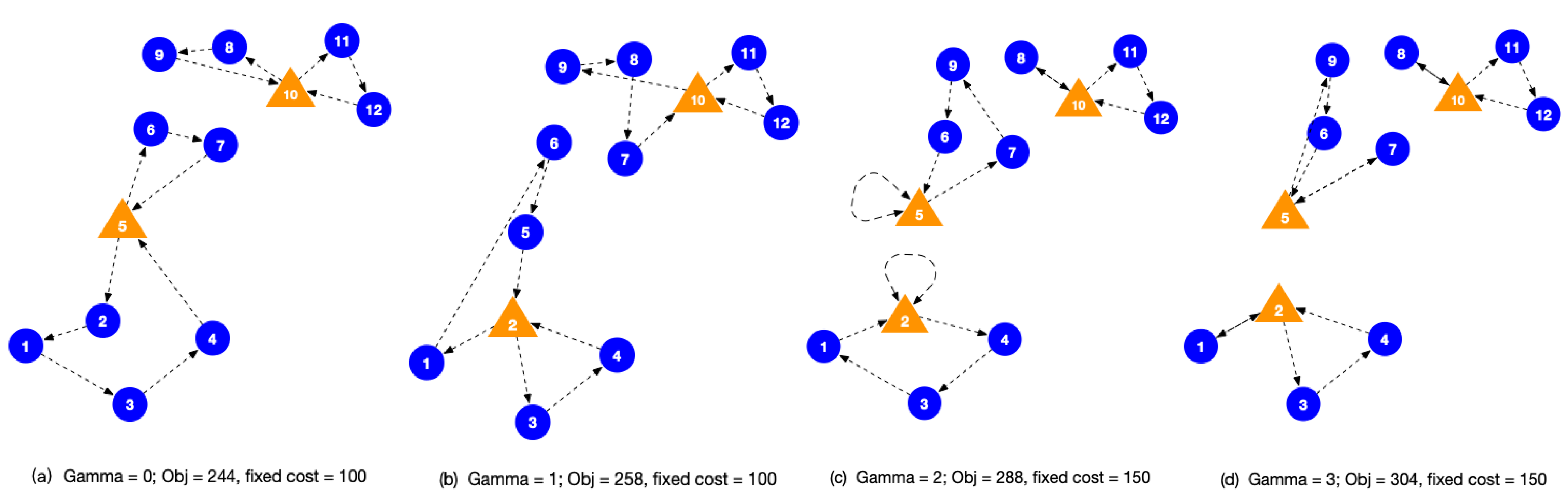

Figure 3. Optimal solutions of a simple testing instance with 3 candidate depots and 12 customers

Literature review

According to our review work, Table 1 summarizes the main contributions to the uncertain LRPs and VRPs literature. As can be seen, no exact approach that considers simultaneous routing and location decisions for EVs and uncertain demand has been developed so far.

Table 1. Summary of the main uncertain VRPs/LRPs contributions

References	Routing	Location	Capacitated	Time windows	Route length	Uncertainty	Algorithm
Albareda et al. (2007)	✓	✓	✓			Stochastic	Heuristic
Sungur et al. (2008)	✓		✓			Robust	Solver
Javid et al. (2010)	✓	✓	✓			Stochastic	Heuristic & Exact
Sungur et al. (2010)	✓			✓		Stochastic & Robust	Heuristic
Ahmadi-Javid et al. (2013)	✓	✓	✓			Stochastic	Heuristic
Gounaris et al. (2013)	✓		✓			Robust	Solver
Gounaris et al. (2016)	✓		✓			Robust	Heuristic
Ahmadi-Javid et al. (2018)	✓	✓	✓			Price-sensitive	Exact
Schiffer et al. (2018)	✓	✓	✓		✓	Robust	Heuristic
Lu and Gzara (2019)	✓		✓	✓		Robust	Exact
This work	✓	✓	✓		✓	Robust	Exact

Conclusion

The R-G-LRP is motivated by installing chargers on chosen depots to support the application of EVs **from the perspective of a logistics company**. In this case, the fixed cost of refurbishing depots is **expensive and most funded by the public**, and the plan of EV deliveries is **sensitive to demand** that is generally random and hard to estimate using probability distributions. Hence, our robust optimization gives a **suitable framework** and proves to be necessary for long-term network structures and operational feasibility. And it seems worthwhile in logistic practice to pursue robust optimization in **strategic planning**.

Future Direction

- Battery recharging time delays
- Customer service time windows
- Both pick up and delivery
- En-route recharging options
- Exploring heuristics such as variable neighborhood search (VNS) to solve large-size instances

ITLS TRANSW

*Corresponding author: Mengtong (Eunice) Wang (wmt15@mails.tsinghua.edu.cn)