京都大学	博士（工　　学）	氏名	Wu Yuehui
論文題目	Hub Location Routing Problem for the Design of Intra-City Express Systems （都市内郵便配達システムの最適設計を想定したハブ配置配送計画問題に関する研究）		

（論文内容の要旨）

Increasing demand for the intra-city express services has recently led to various social problems, such as, high delivery cost, low delivery efficiency, road congestion, air pollution, and so on. The Hub location routing problem (HLRP) is usually employed to optimise networks of intra-city express systems to relieve these problems. Previous studies concerning the HLRP mainly focus on the uncapacitated versions of single-allocation hub location routing problem (SAHLRP). Moreover, only a few studies are related to the un-capacitated version of the multi-allocation hub location routing problem (MAHLRP), which is an extension of the SAHLRP that reduces the inefficiencies resulting from one-to-one assignment of non-hub nodes to hubs. In recent times, parcel delivery is getting greater share in urban deliveries, and therefore, hub and vehicle capacity must be considered when designing intra-city express systems.

With these considerations, this dissertation tries to provide mathematical models for the capacitated single-allocation hub location routing problem (CSAHLRP) and capacitated multi-allocation hub location routing problem (CMAHLRP). Exact and heuristics solutions are developed, and extensive numerical experiments on newly generated benchmark instances are conducted to show the efficacy of the developed exact and heuristics solutions. Finally, a realistic application of the CMAHLRP is undertaken to investigate its economical and social improvements.

The thesis is organised as follows.

Chapter 1 Introduction
Chapter 1 describes the background of this study. It introduces the network topology of intra-city express systems and the role of the HLRP in the design of the systems. Definitions and applications of various HLRP variants and their shortcomings are also presented, which serve as the motivation for this thesis. Finally, Chapter 1 ends with the objectives and outline of this thesis.

Chapter 2 Literature Review
Chapter 2 reviews the literature available for the HLRP and its related problems, including the hub location problem, the vehicle routing problem, and the location routing problem, focusing on their features, classifications, and solutions methods. The literature review found that only the uncapacitated version of the SAHLRP has been optimally solved, and the MAHLRP has never been exactly solved before. Moreover, only a few studies are available for the MAHLRP, where some studies did not consider vehicle capacity or hub capacity, whereas others separated the pickup and delivery.

Chapter 3 Capacitated Single-Allocation Hub Location Routing Problem
Chapter 3 introduces a new formulation for the CSAHLRP first, which can be used to solve its small-sized instances via commercial solvers. To solve larger instances, an exact solution algorithm is proposed for the first time, based on the branch-and-price-and-cut framework, which decomposes the problem into a master problem (MP) and a pricing subproblem. The MP is strengthened by several valid inequalities, and the pricing subproblem is solved by a bidirectional labelling algorithm. Moreover, Chapter 3 presents a meta-heuristic algorithm, named adaptive large

neighbourhood decomposition search (ALNDS), to solve the CSAHLRP on large-sized instances. The ALNDS algorithm generates an initial solution first and tries to improve it iteratively in the form of subproblems. In each iteration, one of the subproblems is selected, and the selected subproblem of the existing solution is destroyed by a destroy operator and repaired by a repair operator to get a new solution. The exact approach and the heuristic approach are tested on the newly generated instances based on the benchmark data set widely used so far. Numerical results indicate that the exact algorithm outperforms the CPLEX in both solution quality and computational time as well as that the heuristic algorithm can find high-quality solutions in reasonable times.

Chapter 4 Capacitated Multi-Allocation Hub Location Routing Problem

Chapter 4 concentrates on the CMAHLRP, where each non-hub node can be served by multiple hubs, and both the hubs and the vehicles are assumed to be capacitated. Furthermore, route length constraints are imposed to ensure the service level. The problem is formulated as a MIP and then optimally solved for the first time by an exact solution algorithm based on the branch-and-price-and-cut framework. In the exact solution, the vehicle capacity constraints are considered in the MP rather than in the pricing subproblem. The ALNDS algorithm developed for the CSAHLRP is also extended to solve the CMAHLRP on large-sized instances based on the following schemes: i) An approximation algorithm is used to approximate the objective function value of the solutions. ii) Non-hub nodes were divided into subnodes to enable multi-allocation option. Correspondingly, the destroy and repair operators do not remove/insert complete non-hub nodes, while only subnodes are considered in these operators. A series of numerical experiments are undertaken on the instances generated from the benchmark data set to test the proposed model and algorithms. The results prove that the proposed algorithms outperform the CPLEX in solving the CMAHLRP as well as that applying the multi-allocation scheme can efficiently reduce the operating cost as compared to the CSAHLRP.

Chapter 5 Case Studies

Chapter 5 introduces the generated case studies based on the realistic supply chain network of a freight company in Tokyo, which consists of factories, warehouses, and customers. In the target network, freight flows are transported from factories to customers via hubs, sharing many common features with intra-city express systems. Three case studies are generated, and the proposed CMAHLRP model and algorithms are applied to these case studies, and the results were compared with the existing approaches. The results indicate that applying the proposed models and algorithms to these realistic cases can efficiently reduce the operating costs and the CO_2 emissions. Therefore, the CMAHLRP can be used to achieve both economical and social improvements in the existing system.

Chapter 6 Conclusions and Future Works

Chapter 6 summarises the research motivation, objectives, methodological frameworks, experiment results, applications, and corresponding findings. This chapter also focuses on identifying future research directions for this research, e.g., proposing more efficient valid inequalities, addressing variants of the HLRP such as with time windows or stochastics factors, and so on.