Hub-and-Spoke Logistics Network Design for the Road-based Freight Transportation Company

Project for Algorithm: Analysis and Theory

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Abstract. This project introduces the concept of logistics network design problem including the background and definition. Then it introduces three tasks of logistics network design. Finally, it lists all the requirements and rules for each group. Please read this document carefully and complete the corresponding tasks.
Keywords: Logistics Network, Service Level.

1 Logistics Network Design Problem

The construction of logistics network is an important task for road-based freight transportation company. The logistics network consists two types of nodes: non-hubs and hubs. Hubs are special facilities in the logistics network that serve as consolidation, switching, and transshipment for the traffic either emanating from or destined to non-hub nodes. Hubs are actually upgraded non-hubs and are typically interconnected as a complete hub network. There are two main allocation schemes to connect non-hub nodes to hubs: single allocation (each non-hub is allocated to exactly one hub) and multiple allocation (a non-hub node can be allocated to more than one hub), in which the connections between the hubs and non-hubs are termed as spokes. Correspondingly, the transportation between non-hubs are commonly not directly accomplished, but via hubs to whom non-hub nodes are allocated.

The hub-and-spoke design problem is conventionally called the hub location-allocation problem, which involves determining which non-hubs should be upgraded as hubs and how to allocate non-hubs to hubs in order to provide good service between origin-destination (O-D) pairs. The main advantage of hub-and-spoke network is the economies of scale resulting from aggregating the bulk transportation between hubs. Thus, the transportation cost between hubs usually has a discount factor α compared to that between hubs and non-hubs.

Assume for a road-based freight transportation system, the transportation of freights is carried out via Hub-and-Spoke Logistics Network. Here each origin is assigned to the hub(s) that handle(s) collection and determines the next-hop. A parcel that originates from a non-hub first travels to the assigned hub. At the hub, all the parcels are gathered and loaded into larger and more specialized trucks according to their destinations, and then reshipped to the next hop (another hub or the destination directly).

From the perspective of the freight transportation company, its profit and the service quality for customers are important factors for fierce market competition. A common characterization of "service quality" for both customers and service providers is the delivery duration between a drop-off at an origin and the arrival at the destination. The lower the duration is, the higher the service level maintains. However, due to the existing highway network structure and the geographical disparity, it is difficult to serve each O-D pair at the same service level.

In order to guarantee a high service quality, the road-based freight transportation company asks your team to design a hub-and-spoke logistics network, to ensure that all O-D pairs can be served at

a lower service level, and more origins can be served at a higher service level, while minimize the hub upgrading cost and the operating costs. Here operating costs include transportation cost, which is a linear function with respect to the haulage distance and parcel flow amount on a road, and many other costs like warehouse leasing fee, staff salary, etc.

2 Tasks

In this project, you are required to deal with the three tasks. The relevant data is showed in attached file. Given the distance, traveling time, flow and hub upgraded cost between cities, you should provide the hub location scheme to construct the logistic network to guarantee a high service quality with the lower cost.

2.1 Uncapacitated single allocation hub-and-spoke logistics network design

In this task, suppose there are no capacity limitations imposed on hubs, say, each hub has sufficient capacity to serve all non-hubs. Since the cost to build hubs is a great deal of expenditure, the company will have a budget to upgrade hubs. Also, assume the costs to upgrade each hub are fixed but different.

1. Using single allocation scheme, giving a set of non-hub nodes with pairwise distance information, travel time, and flow demand, please develop a model to construct a hub-and-spoke logistic network, determine the values of the lower and higher service level reasonably. Your model should include the hub selection, the hub-and-spoke allocations, as well as the operation details at each hub (e.g., what is the next-hop at each hub according to the O-D pair).
2. Validate your model based on the given benchmark data set (i.e., Turkish freight transportation company data and the corresponding region map) and then make sensitive analysis for some parameters involved to discuss the influences on the designed hub-and-spoke logistics network.

2.2 Capacitated single and multiple allocation hub-and-spoke logistics network design

In fact, the capacity serving demand centers for each hub is limited. Considering the capacity restrictions of hubs, how to change the model obtained in Task 1? Moreover, when the multiple allocation scheme is selected by the company, how to model the capacitated multiple allocation hub-and-spoke logistics network problem?

2.3 Hub-and-spoke logistics network design with the release time scheduling

As we all know, freights may spend a considerable amount time at a hub during the process of unloading, sorting, handling, and reloading. The loading operation cannot be completed until all the incoming freights that will be loaded on a truck heading to the same destination hubs have been received. This results in additional waiting time for units that arrived earlier. The waiting time may be quite long, depending on how late the latest arriving unit is. Then, after taking into consideration the release time scheduling at hubs and each origin, how to construct the model to formulate the uncapacitated single allocation hub-and-spoke logistics network? How to set the release times of trucks from different origins and at various hubs? In this task, you should give the necessary assumption of the distribution of drop-off information of parcels.

3 Requirements

In this project, you should solve three tasks mentioned in section 2, and provide the problem formulation, problem analysis, algorithm design and algorithm analysis.

3.1 Problem Formulation

Please give the reasonable definition of cost and service level, and formulate the problem formally as a mathematical programming. You need to define variables carefully and model the description of every requirement and constraint mathematically. Moreover, can you convert your programming as an LP (Linear Programming) or ILP (Integer LP)?

3.2 Problem Analysis and Algorithm Design

Firstly, please judge the difficulty of your defined problem. Whether it is in P, NP, NP-Complete, or NP-Hard? Prove or clarify your conclusion.

Next, please design an efficient algorithm to solve the detection problem in polynomial time with respect to the input size. You need to describe your design first, introduce the necessary concepts, symbols, definitions, etc., and write the pseudo code of your design.

3.3 Theoretical Analysis and Performance Evaluation

For each variation of the task, you need to complete the following works:

Theoretical Analysis: For this part you are aiming to distinguish the theoretical properties of your problem and algorithm designs, including the following items:

1. Analyze the time complexity of your designed algorithm.
2. If the problem you are dealing with is in P, then prove the correctness of your design. Otherwise discuss the feasibility or the approximation property of your algorithm.

Performance Evaluation: it includes the following requirements:

1. Based on the provided data, visualize the Logistics Network in each tasks.
2. Test the efficiency of your design by simulations. Talk about the trade-off about cost and service level and provide the optimal solution of three tasks. Analyze the influence of α and other parameters to the optimal solution. You should set the different value of α and other important parameters and visualize the their influence.

3.4 Report Requirements

You need to submit a report for this project, with the following requirements:

1. Your report should have the title, the author names, IDs, email addresses, the page header, the page numbers, figure for your simulations, tables for discussions and comparisons, with the corresponding figure titles and table titles.
2. Your report is English only, with a clear structure, divided by sections, and may contain organizational architecture like itemizations, definitions, or theorems and proofs.

3. Please include reference section and acknowledgement section. You may also include your feelings, suggestion, and comments in the acknowledgement section.
4. Please define your variables clearly. If needed, a symbol table is strongly recommended to help readers catch your design.
5. Please also include your latex source and simulation codes upon submission.