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Design of a reliable logistics network with hub disruption under uncertainty

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ABSTRACT

In this study, we design a reliable logistics network based on a hub location problem, which is less sensitive to disruption and it performs efficiently when disruption occurs. A new mixed-integer programming model is proposed to minimize the total sum of the nominal and expected failure costs. This model considers complete and partial disruption at hubs. In addition, we propose a new hybrid meta-heuristic algorithm based on genetic and imperialist competitive algorithms. We compare the performance of the proposed algorithm with a new lower bound method in terms of the CPU time and solution quality. Furthermore, we conclude that a considerable improvement in the reliability of the network can be achieved with only a slight increase in the total cost. Finally, we demonstrate that the networks designed using our model are less conservative and more robust to disruption compared with those designed based on other robustness measures.

1. Introduction

Strategic decisions about the locations of new facilities, boosting distribution networks, and cooperating with new parties are required in most industries. Industrial companies must locate manufacturing facilities as well as distribution centers, which need to be positioned near retail outlets. Thus, the success of these industries depends greatly on the quality of the location-related decisions. Similarly, governments must make decisions about the locations of hospitals, police offices, schools, fire stations, and other facilities. In each case, the location of a facility has a significant effect on the quality of the logistics network.

In general, logistics networks are responsible for transferring and distributing flows between a set of origin and destination nodes through a number of intermediate facilities. In most previous studies of this problem, it has been assumed that the facilities are always available. However, logistics networks designed according to this assumption may encounter serious problems if they fail to consider disruption in any component of the network, and thus they would become ineffective when the facilities are subject to failure. Recently, logistics networks have become increasingly complicated due to their size, the services required, the nature of customer assignments, the utilization of several components, and associated network flows.

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Thus, a small failure in a component may propagate throughout the system and cause a huge inconsistency in the network, which further imposes a tremendous cost, with irrecoverable or difficult to recover effects on the network [1].

Facilities might fail due to several intentional/unintentional reasons such as natural disasters, equipment breakdowns, supplier cutouts, explosions due to process hazards, labor strikes, and terrorist attacks. Peng et al. [2] highlighted the short-term and long-term effects of disruption in logistics networks such as increases in costs and the time of transportation, delivery delays, and inventory shortages, as well as negative financial effects. Thus, enterprises must aim to design a reliable logistics network in order to cope with these short- and long-term inefficiencies.

In this study, we consider the problem of designing a logistics network as a hub location problem (HLP), which comprises origin, hub, and destination nodes. In a hub network, a set of intermediate nodes are located as hubs, and origin and destination nodes (spokes) are allocated to these hubs. Hubs are responsible for consolidating, transferring, and distributing flows through the network to obtain economic profits. After a hub network has been designed, it can be very difficult and costly to modify the design. Therefore, it is necessary to design a reliable logistics network that remains available and efficient in the presence of many types of disruptions.

In classical HLPs, it is usually considered that the topology of the hub network is not changed after the hubs have been located and spokes are allocated to the hubs. It is also assumed that the hub nodes are always available and no event can disrupt their performance. However, these are not valid assumptions if the located hubs are subject to failure and they may become unavailable due to disruptions caused by intentional or unintentional reasons. Disruption at hubs can belong to two types: complete and partial disruptions.

When a hub node is completely disrupted, the hub becomes unavailable and the spokes originally allocated to it must be reallocated to other (operational) hub nodes, which usually incurs higher connection costs (i.e., re-allocation cost). During partial disruption, although the hub node may be still available, the service rate or the capacity of the hub is degraded to a lower level. If service rate degradation occurs, the hubs become congested and the incoming flow must wait to be processed. During capacity degradation, the capacity of the hub is degraded to a lower level and the hub is unable to process the entire arrival flow (i.e., the capacity of the hub is decreased). Therefore, disruptions in a hub network can greatly affect the performance of the logistics network.

The main aim of this study is to introduce a new mathematical model for designing a reliable logistics network based on a HLP under disruption, where the flows should be transferred between each pair of origin-destination nodes via a given set of links. A brief survey of previous research (Section 2) shows that few previous studies have addressed the design of a reliable hub network, where hubs are subject to complete and partial disruption, and thus they may fail to process the flows. In addition, in real settings, after designing a hub network, some parameters (e.g., demand, distance, time, and cost) in the problem may change due to uncertainty, but most previous studies have not adequately addressed how uncertain parameters might affect the network design. The uncertainty in parameters may come from a variety of sources, but collecting historical data is as difficult as estimating the probabilities of the parameters. Hence, we utilize the robust optimization approach proposed by Peng et al. [2], which provides an alternative method for coping with uncertainty but without requiring probabilistic information about the input parameters.

The main contributions of this study are as follows.

- We design and model a new reliable logistics network as a HLP by considering the possibility of disruption in the hub facilities.
- We consider the effects of two different types of disruptions: (1) hub availability, i.e., complete disruption; and (2) hub capacity, i.e., partial disruption.
- We develop a service level constraint that considers disruption of the capacity.
- A new hybrid solution approach is proposed by combining a number of efficient solution approaches from recent research, i.e., stochastic programming and robust optimization.
- An efficient lower bound approach is proposed to find a near-optimal solution in a reasonable amount of computational time with few gaps.
- We propose a new hybrid self-adaptive meta-heuristic algorithm based on genetic algorithms and imperialist competitive algorithms (ICAs).

The remainder of this paper is organized as follows. Section 2 describes previous research in the area of hub networks by considering disruptions in the hub facilities. Section 3 explains the problem and the mathematical formulation, and the robust optimization approach is presented in Section 4. The new lower bound and meta-heuristic methods are introduced in Section 5. Computational results are provided in Section 6. Finally, we give our conclusions in Section 7.

2. Literature review

Most previous studies of disruption in networks are based on the classical p-median [3] and uncapacitated fixed-charge location problems [4]. Both of these problems locate facilities and assign customers to the located facilities to minimize the total transportation (and/or construction) cost, where all facilities are assumed to be totally available and reliable. Some recent studies have considered facility location in the presence of random disruptions and interested readers may refer to a comprehensive review by Snyder [5]. Most previous studies in this area considered disruptions in a facility location problem, so most of this section deals with studies related to the facility location problem in the presence of disruption.