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Rapid transit network design: considering recovery robustness and risk aversion measures

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Abstract

Rapid transit network design is highly dependent on the future system usage. These spatially distributed systems are vulnerable to disruptions: during daily operations different incidents may occur. Despite the unpredictable nature of them, effective mitigation methods from an engineering perspective should be designed. In this paper, we present several risk averse measures for risk reduction in the rapid transit network design problem based on a set of finite scenarios to represent the disruptions' uncertainty. As a counter-parts of the typical risk neutral strategy, some measures that are presented are aiming to minimizing the impacts of the worst scenario in the network operation, and another additionally, takes into account different risk reduction profiles. Some computational experience is presented.

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Keywords: Rapid transit network design, disruption management, stochastic, risk aversion, Value-at-Risk, robustness, recovery.

1. Introduction

Rapid Transit Network (RTN) design is highly dependent on the future system usage (Cadarso and Marín, 2015, 2016). Such networks are urban mass public transportation systems which operate in metropolitan areas and feature frequent train services. When designing a new network, the infrastructure designer must account for the fact that passengers will use the new network if the trip total cost is lower than the current options: when facing a new Rapid Transit Network design (RTND) there is usually another transportation system already operating in the area where the RTN is to be built or extended. The RTND problem aims at maximizing the demand coverage by the new network subject to design and budget constraints, all while considering demand decisions when evaluating different alternatives (Escudero and Muñoz, 2009; Cadarso and Marín, 2015).

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Spatially distributed systems are vulnerable to disruptions: during daily operations different incidents may occur. Despite the unpredictable nature of them in terms of location, time, and magnitude, effective mitigation methods from an engineering perspective should be designed. Dealing with these uncertainties is a key ingredient for providing a resilient network for daily operations. The more the network is able to absorb these disruptive negative effects, the more resilient the network is. In order to find resilient network designs, different research techniques such as deterministic static, two-stage stochastic optimization and robust optimization may be applied, among others. Solutions may be recovered after data perturbation, i.e., after a disruption has occurred. Because the recovery of the system may not be as expensive as the introduction of robustness, we introduce here the concept of recoverable robustness to the RTND problem (Cadarso and Marín, 2016).

This work presents a model for designing a rapid transit network considering the network reliability under the point of view of recovery robustness and risk theory. The model is a balance between the traditional approaches of transport demand coverage and the recovery of disruptions (Laporte et al., 2011; Codina et al., 2014).

We present a new approach to the RTND problem where the uncertainty is related to the passenger service demand disruption. It is represented by a finite set of scenarios. The novelty of this approach is the introduction of risk aversion in the network design. It consists of a set of risk averse measures as a counter-part of the probably most popular strategy, as it is the risk neutral one, where the uncertainty is explicitly considered in the constraint system. One of those risk averse measures, we have so-called it, VaR2 is a variant of the classical Value-at-Risk (that we have so-called it VaR1), where the risk reduction of the total cost due to the service disruption over the scenarios is performed based on a modeler-driven set of profiles. For each of those weighted profiles the minimum regret excess cost on the related threshold is performed and, additionally, a bound should be satisfied on the expected excess cost over the scenarios, besides explicitly considering the uncertainty in the constraint system. Due to space limitation, we have left for the extended version of the paper the treatment of new risk averse strategies as the expected conditional VaR and the expected conditional measure for a mixture of the first- and second-order stochastic dominance strategies.

2. Problem description

The aim of the RTND problem is to design a new network which covers as many trips as possible. The next two paragraphs describe the network infrastructure and the passenger demand.

The network consists of arcs and nodes. We have two different types of nodes denoted by: centroids and stations. Centroid nodes are those where the demand is generated or attracted to. Station nodes are those where the network is built on and where demand enters and leaves the network. We model the infrastructure as a graph with nodes, and with the set of feasible arcs linking them. Arcs may represent: alignments in the RTN, dummy arcs between origin centroids and any station, dummy arcs between stations and every destination centroid, and arcs between any origin-destination pair, corresponding to the current network. Each node has an associated construction cost and each arc a pair of weights: the construction cost and the distance. Since resources are limited, a budget constraint on construction costs is imposed.

Passenger demand is characterized by an origin and a destination. We define passenger groups as follows: $w = (o_w; d_w; g_w)$, where $o_w \in N$ is the origin centroid, $d_w \in N$ the destination centroid, and g_w is the passenger group size. The demand will be realized through the available paths in the new RTN or through a path within the current network. Each passenger group $w \in W$ will choose a unique path based on the generalized trip cost. The generalized cost is defined as the distance between origin and destination. This distance is equal to the sum of all the arcs' distances in the path for the new network, and equal to u^w_{cur} for the current network, which is a given generalized cost (alternative modes of transport). Because u^w_{cur} is uncertain, i.e., congestion may affect the generalized cost, we also introduce the congestion parameter μ_w.

3. Deterministic static pure 0-1 model

The Rapid Transit Network Design (RTND) problem aims at obtaining a network design in order to decide at which nodes to locate the stations and how to connect them so as to attract as many passengers as possible to the new network, by minimizing the routing and construction costs, see some variants in Cadarso and Marín (2016); Escudero