Transportation Research Part C 73 (2016) 65–76

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Railroad caller districting with reliability, contiguity, balance, and compactness considerations ☆

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ARTICLE INFO

Article history:
Received 30 May 2016
Received in revised form 7 September 2016
Accepted 18 October 2016

Keywords:
Districting
Reliability
Contiguity
Workload balance
Compactness

ABSTRACT

Railroad companies rely on good call centers to reliably handle incoming crew/resource call demands so as to maintain efficient operations and customer services in their networks. This paper formulates a reliable caller districting problem which aims at partitioning an undirected network into a fixed number of districts. The demand of each district is assigned to crew caller desks (one primary desk, multiple backups) under possible desk disruption scenarios. We simultaneously take into account several operational criteria, such as district contiguity and compactness, workload balance, and caller desk service reliability. The resulted districting problem is modeled in the form of a challenging mixed-integer program, and we develop a customized heuristic algorithm (based on constructive heuristic and neighborhood search) to provide near-optimum solutions in a reasonable amount of time. Hypothetical and empirical numerical examples are presented to demonstrate the performance and effectiveness of our methodology for different network sizes and parameter settings. Managerial insights are also drawn.

1. Introduction

Railroad companies regularly receive a large number of calls from their customers and business partners (normally via telephone, intercom, computer or other devices) regarding real-time train operation, service scheduling, and resource/crew arrangements in the field. The calls are typically intended for ensuring compliance with all railroad business rules and safety regulations of the Federal Railroad Administration (FRA). Some specific tasks of the calls include (i) contacting individual crew members and directing them to their assigned trains or job locations; and (ii) monitoring system operations, and collecting data and relevant information routinely across railroad divisions and subdivisions for internal and external reporting purposes. Such calls have significant implications on the operational efficiency of the railroad system and hence are important for the success of the railroad companies.

The call center serves as the information and decision hub for a railroad company's production and maintenance activities. The planning of the call center plays a critical role in the allocation and utilization of the railroad's manpower, equipment, and other resources. This is particularly the case when railroads are facing operational uncertainties and the risk of disruptions (e.g., due to adverse weather, train accidents, power outage, labor issues). In case of unexpected emergencies, effective communication and efficient resource (re-)allocation across the railroad network must be ensured via the call center such that backup plans for train timetabling, rolling stock and crew scheduling can be carried out in time – the call center itself must

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☆ This article belongs to the Virtual Special Issue on "Integr Rail Optimization".

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http://dx.doi.org/10.1016/j.trc.2016.10.008
0968-090X/© 2016 Published by Elsevier Ltd.

be functioning reliably so as to be responsible for real-time emergency management and disaster response. Therefore, a good call center design that can reliably and efficiently handle incoming calls across the railroad system is very critical.

Usually a call center for a railroad company consists of multiple crew caller desks, each of which is responsible for the calls from a particular predefined spatial region (i.e., district). A good call center design should have the following characteristics: (i) all incoming call demand can be handled by a properly assigned caller desk under any circumstance, otherwise significant penalty will occur due to disruption to railroad operations; (ii) the expected workload is well balanced across caller desks, so that no desks are too much more occupied than others; (iii) the spatial district served by a caller desk should be contiguous so as to satisfy a number of practical operational requirements, e.g., administrative autonomy for resource/crew reallocation and train traffic management; and (iv) the spatial district corresponding to one caller desk is compact in shape so as to avoid high transportation/logistics costs inside odd-shaped districts.

With all these practical considerations, the railroad call center design problem is closely related to a geographical districting problem. Districting is a well-known problem in the operations research literature. It aims at partitioning a geographical space into sub-districts under various criteria and constraints. Depending on the specific application context, operational criteria may include the district contiguity, district compactness, workload balance, socio-economic homogeneity, etc. In the literature, probably the most intensively studied problem is regarding political districting, which divides a jurisdiction area (e.g., a state or a region) into electoral constituencies such that the political candidates from each area are elected to a parliamentary assembly. The "one man-one vote" principle requires that all districts contain approximately the same number of candidates/voters to avoid benefiting a certain party or candidate. Hess et al. (1965) is among the first several that used mathematical programming techniques to model the political districting problem. An assignment formulation with additional planning constraints was developed and an iterative heuristic algorithm was proposed. But the convergence of the algorithm or the contiguity of districts is not guaranteed. Garfinkel and Nemhauser (1970), on the other hand, considered selecting districts from a set of predefined feasible ones. The various constraints (e.g., contiguity, compactness) were implemented while defining the set of feasible districts (before implementing the optimization model). Mehrotra et al. (1998) adopted a column generation method to solve a similar problem as the one in Garfinkel and Nemhauser (1970). Bozkaya et al. (2003) considered more operational criteria, which were evaluated and incorporated as soft constraints. Health services districting is another application context that aims at partitioning a health service territory into districts and assign a certain amount of medical resources to each district. Blais et al. (2003) studied the districting for a public health clinic where five districting criteria were sought under a tabu search algorithm. School districting problem assigns residential neighborhoods to existing schools, as different important criteria for planning must be taken into account, e.g., the capacity, the accessibility, and the racial balance of each school. Notably, Ferland and Guénette (1990) proposed a decision support system to solve the school districting problem; the system included a network-based mathematical model and used several heuristic procedures to assign network edges (with students located on it) to schools. Other examples of districting problems include sales/market districting (Hess and Samuels, 1971), police districting (Camacho-Collados et al., 2015), waste/garbage collection districting (Muyldermans et al., 2002), etc.

All these traditional districting problems simply focus on partitioning a network/area into districts under some operational considerations. However, most of these studies ignore the fact that in many application contexts, the partitioned districts must be assigned to a supplier/facility, e.g., a caller desk in the call center, for actual service. Traditionally, the suppliers are assumed to be always functioning and thus no backup assignments are needed. Recently, the reliability of service providers (caused by internal or external factors) has caught considerable attention. When a facility fails, all the demands originally assigned to this facility have to either be reassigned to another surviving facility or lose service. In the recent years, many studies started to model probabilistic disruptions, Snyder and Daskin (2005) considered that facilities are subject to independent probabilistic disruptions with identical failure probabilities. Berman et al. (2007) formulated a nonlinear mixed-integer programming model for the reliable location model and designed an efficient heuristic algorithm. Chen et al. (2011) studied a reliable joint inventory-location problem where facilities are subject to disruption risks. In the railroad caller districting problem, the caller desks, which play the role of facilities, are also subject to failure due to technical and personnel reasons. To the best of our knowledge, no work has been done to incorporate service reliability issues into the districting problem. Moreover, it is worth noting that under reliability issues, the traditional modeling methods for addressing various operational criteria (e.g., workload balancing, district compactness, and contiguity) would no longer work – new customized treatment methods are needed.

In light of these challenges, in this paper, we formulate the reliable caller districting problem as a mixed-integer programming model. A series of modeling techniques (e.g., network flow constraints) are adopted to address some of the practical planning criteria: (i) each district must be contiguous; (ii) each district is compact in shape; (iii) workload is balanced across districts. The reliability of caller desk service is also incorporated by introducing reliable desk re-assignments. Note that when desks are subject to disruptions, the expected workload of each district across all possible desk failure scenarios should be considered. Customized solution approach consisting of constructive and neighborhood search heuristics are developed to efficiently solve the mathematical model. Several numerical examples including a series of hypothetical test cases and an empirical full-scale railroad case study are conducted to demonstrate the performance and applicability of our methodology. Various managerial insights are also drawn.

The remainder of the paper is organized as follows. Section 2 introduces the various operational criteria and formulates the reliable caller districting problem into a mixed-integer mathematical model. Section 3 presents the customized solution approaches to efficiently solve the problem. In Section 4, results for both the hypothetical and empirical examples are presented. Finally, Section 5 concludes the paper and discusses future research directions.