Expert Systems With Applications 61 (2016) 39–52

Contents lists available at ScienceDirect

Expert Systems With Applications

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

An agent-based support system for railway station dispatching

Taomei Zhu*, Jose Manuel Mera, Berta Suarez, Joaquín Maroto

Railway Technology Research Center (CITEF), ETSII of Technical University of Madrid-UPM, José Gutiérrez Abascal 2, 28006, Madrid, Spain

ARTICLE INFO

Article history:
Received 21 December 2015
Revised 6 May 2016
Accepted 7 May 2016
Available online 13 May 2016

Keywords:
Railway station operation
Agent-based
Local dispatching
Decision-making
Dynamic optimization

ABSTRACT

For those railway stations without being automated, railway traffic dispatching still depends on dispatchers, especially under disturbed circumstances. In this study, an agent-based support system, named D-Agent, is developed to assist human dispatchers to make decisions in station operation. To this end, the common knowledge and possible difficulties concerning a station dispatcher in his/her routine work are firstly studied, and the D-Agent is proposed with the purpose of working out practicable solutions to these challenging tasks as a dispatcher does. Then the general model of the D-Agent is established, containing five basic modules: local database, knowledge base, skill base, reasoning mechanism and communication interfaces. The internal skills of the D-Agent are designed to execute various tasks in different scenarios. Besides, a skill extension of the D-Agent with mathematical formulations is particularly discussed in this paper, to find feasible and optimal traffic control solutions in disturbance situations such as train delays and route conflicts. The D-Agent is designed to learn from its own experimental history in applying different skills, and evaluate the skills by preference weights of alternative solutions in a particular task. This procedure allows the agent to have potential for continuous improvement. To verify the applicability of the proposed support system, a D-Agent for a terminal station of subway is simulated. The numerical example of train delays and route conflicts shows that the D-Agent can generally perform as a station dispatcher in fulfilling the specific tasks, estimate the traffic state in different operation strategies and support the decision-making of favored solutions. Significantly, it indicates that the mathematical methods can also been employed by an intelligent agent.

1. Introduction

Routine work of railway station nowadays can be partly controlled by a train dispatching control system or a centralized traffic control system. It mainly contains the infrastructure and train states monitoring in the scope of station and its boundaries of neighbor stations, regular train dispatching and route control at the station, etc. However these control systems are insufficient to make operational decisions once the occurrence of disturbance gets frequent, particularly at the junctions with dense traffic. Meanwhile, the station dispatchers encounter increasing challenges of coping with all local traffic information shown in Fig. 1 and of making quick decisions in part rescheduling and regional rerouting.

In order to speed up the calculation and optimize operations, some effective methods have been proposed in some concrete tasks, such as Integer Linear Programming and Mixed Integer Linear Programming in scheduling and routing optimization. However, for the diverse forms of information involved and high dependence on the operational rules and experience in the dispatching problem, each pure mathematical method may hardly cover all aspects. On the other hand, in real-time dispatching a human dispatcher may have little time to employ models at the moment when the problems actually occur. So it is still urgent to develop a more intelligent support system for railway traffic dispatching that can indeed reduce the difficulty for human dispatchers. It has to combine the advantages of human and machine, correspondingly flexible employing the expert experience and rapid computing, and allow the promising algorithms and methods to play roles in interactive environment. The main aim of this work is to design such a support system with the first-layer capacity of automation in executing specific knowledge-based tasks and the second-layer capacity of decision-making in reassigning the train orders and routes in a short time once disturbances are detected.

Hansen (2009) stated that efficient traffic management support systems must be able to simulate the effects of different dispatching measures and support traffic controllers by frequently updating the actual timetable and ranking the dispatching options according to their expected performance. Based on an investigation of existing algorithms and methods for train routing problem, we propose an agent-based dispatching support system, called D-Agent, for station operation. In (Macal & North, 2006), apart from the

* Corresponding author.
E-mail addresses: taomei.zhu@alumnos.upm.es, zhtm126@gmail.com (T. Zhu), citef.jmmera@etsii.upm.es (J.M. Mera), citef.bsuarez@etsii.upm.es (B. Suarez), joaquin.maroto@upm.es (J. Maroto).

http://dx.doi.org/10.1016/j.eswa.2016.05.011

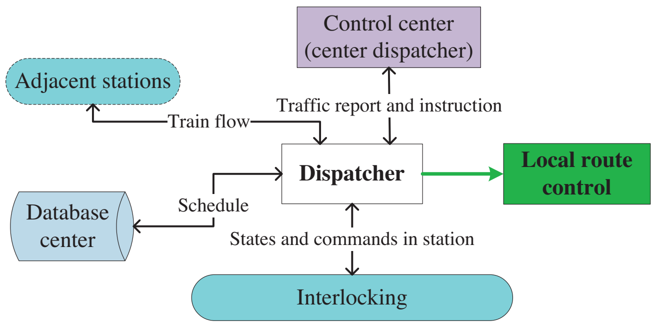

Fig. 1. Routine situation of a station dispatcher.

concepts and the general process of agent-based modeling and simulation, the authors still implied why and when to use this approach. Considering the background of railway traffic, we describe the specific reasons of adopting the agent-based approach (D-Agent) in station dispatching as follows.

(a) A D-Agent aims at supporting traffic management and optimization on station layer, where the local schedule (a part of the schedule of the entire network) can be set as the reference of all its behavior.
(b) The agent can be flexibly equipped with a variety of knowledge and methods. It provides the foundation for simulating and testing the possible effects of different measures. Owing to its internal reasoning mechanism and evaluation function, it can furthermore generate advice in decision-making.
(c) Significantly, a well alive agent is dynamic. Based on the accurate collected data of actual train positions and speeds, conventional events and potential conflicts can be predicted in advance. Thus corresponding dispatching advice is possible to take effect in subsequent operations.
(d) Furthermore historical data and experience may help the agent to update its knowledge and skill bases. Meanwhile, it is possible for the agent to introduce new knowledge or modify its existing rules by learning.
(e) It is in a bigger system rather than being isolated, i.e. it works in an environment where it has the interaction and communication with other agents. It collects data from the environment and other agents, and in turn it gives feedback with information for negotiation and cooperation.

In other words, the D-Agent is designed and developed to meet the above propositions. Hence the focus of this study is the internal functional design of D-Agent, which has to be prepared for the station operation as an assistant and even a substitute of human dispatchers in future.

The remainder of this paper is organized as follows. Section 2 surveys some important previous work in literature of which some references have inspired the partial work of this paper. Section 3 presents the general structure of D-Agent, whilst Section 4 proposes the internal flexibility of the agent to learn and apply extended skills. Section 5 provides an example of D-Agent and discusses how it works to support the station operation. At the end, Section 6 concludes the paper and prospects the future work.

2. Literature review

2.1. Routing problem at railway stations

Routing and rerouting problem is usually considered as the detailed scheduling and rescheduling for trains at stations in consideration of all concrete station yards, safety constraints, and user requirements. Various representative mathematical models have been proposed on this detailed layer. Such as the model based on node packing formulation (Zwaneveld et al., 1996) whose key idea was that any two nodes (representing possible routes for trains through the station) have to be not connected by edge (indicating the route incompatibility), so that any two train routes in solution are compatible and can be simultaneously assigned. The model calculates the maximum number of trains that can be safely routed through the station. An updated version named weighted node packing formulation was presented in (Zwaneveld, Kroon, & van Hoesel, 2001), inheriting the algorithm based on pre-processing, valid inequalities, and a branch-and-cut approach for solving the routing problem to optimality. In (Lusby, Larsen, Ehrgott, & Ryan, 2011) the authors surveyed on the important contributions for junction routing problems, including the models based on node packing problem (conflict graph) (Zwaneveld et al., 1996; Zwaneveld et al., 2001), alternative graph (D'Ariano, Corman, Pacciarelli, & Pranzo, 2008; D'Ariano, Pacciarelli, & Pranzo, 2007; D'Ariano, Pranzo, & Hansen, 2007), constraint programming (Rodriguez, 2007), and set packing problem, etc. where the authors particularly declared the last model. Then in their continued work (Lusby, Larsen, Ehrgott, & Ryan, 2013; Lusby, Larsen, Ryan, & Ehrgott, 2011) the authors proposed a set packing inspired formulation with a time interval track section (tints) resource based constraint system, and developed a branch-and-price approach to exploit the flexible solution of the routing problem dynamically.

The models above are commonly formulated by Integer Linear Programming (LP) or Mixed Integer Linear Programming (MILP) where the decisions of train order or whether to be assigned a certain route are presented as binary variables, while the entry and exit times of trains at particular track sections are often presented as continuous variables in MILP formulation or handled as integers in LP formulation. Although the time consumption of these formulations is a fatal defect when the problem size or solution space gets very large, there are quite a few models being formulated by LP and MILP with various objective functions (such as minimizing the total travel time or total delay, or total cost associated with train), and typically the optimal solutions of each problem are achieved by graph and tree search algorithms. For example, narrowing down to the routing problem, Törnquist and Persson (2007) proposed a MILP formulation that probably represents a highly complex setting such as a railway network with a large number of tracks, and contains context-dependent constraints related to both passenger and freight trains, including practical restrictions, connections and tolerance of delays. Different objective functions, respectively to minimize the total delay of traffic and to minimize the total cost associated with final delays, are used in this formulation. And a heuristic approach was suggested to integrate in the branch-and-bound procedure to produce optimal or near-optimal solutions of the problem. In the continued work (Törnquist, 2012), a complement greedy algorithm for fast delivering good solutions was further developed and evaluated for the previous problem. In another MILP (Sato, Tamura, & Tomii, 2013), the dissatisfaction of passengers was included in the objective, where train operations, passenger behaviors and the inconvenience are simultaneously expressed by integer linear inequalities. More comprehensively, both objectives of minimization of train delays and maximization of passenger satisfaction were pursued in (Corman, D'Ariano, Pacciarelli, & Pranzo, 2012). Besides, other forms have been introduced such as in the MILP of (Meng & Zhou, 2014), the track occupancy on single and double tracks is reformulated using a vector of cumulative flow variables, as well in (Pellegrini, Marlière, & Rodriguez, 2014) the infrastructure is represented by fine granularity.

Models and approaches for routing problem at railway junctions or stations are fundamentally attempted to obtain feasible solution of certain conflict (either timetable or dispatching), then fur-