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Design of multi-agent emergency dispatching model to strengthen resiliency of Taiwan high-speed rail system

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Abstract

Although HSR (high-speed rail) systems can provide good service quality, such the systems have not been designed to handle disaster-related events very well, i.e., the trains dispatching work during a disaster. In other words, if there is no experienced train dispatchers in the control center of a HSR system, extended delays and possible catastrophic system failures might occur, thus exacerbating the impact caused by the disaster. Recently, a novel approach called the multi-agent system (MAS) is being increasingly used in transportation applications. Within a multi-agent assisted environment, a stakeholder such as train driver and depot manager can consultant with the corresponding MAS agent about the best trains dispatching strategy. The proposed ontology-based, multi-agent model was tested by using Taiwan HSR real dispatching cases. The results show the potential of assisting train dispatchers in handling disaster scenarios in a more efficient and effective way.

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Keywords: Emergency dispatching; Multi-agent system; Ontology; High-speed rail system; Resilience;

1. Introduction

Nowadays high-speed rail (HSR) systems have played a critical role in providing efficient transportation of passengers. To guarantee the HSR service quality, myriad advanced information and communication systems, high

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skilled train dispatchers and engineers, etc. all need to work together in a disciplined way. Even before the occurrence of a disaster, current HSR systems usually include dedicated warning modules that can probe any disaster-related symptoms to protect both the passengers and the systems from the disaster impact. As such, HSR passengers can expect punctuality of the timetables, reliability of the systems, and safety of their journeys [1, 2]. Take for the earthquake warning system (EWS) deployed on Japan or Taiwan HSR systems as an example, which involves earthquake sensors usually installed every five kilometers along a HSR mainline. In earthquake prone regions such as Taiwan and Japan, the EWS can detect an earthquake's electromagnetic waves several seconds before appearance of the first earthquake damage. Once detecting the event with an earthquake's peak ground acceleration (PGA) value greater than 40 Gal, the EWS will immediately notify dispatchers in the HSR operation control center (OCC) of current situations as well as automatically stop each affected train right away by sending commands to its automatic train control system (ATC). In fact, Taiwan HSR EWS successfully shielded the entire system from the 4 March 2010 Jiasian, Kaohsiung earthquake with a 6.4 magnitude. Only one train was slightly derailed with no casualties. As for the 2011 off the Pacific Coast of Tohoku earthquake, there was no derailment report on Shinkansen trains operating at high speeds [3].

Although current HSR systems have been proved to be able to maintain passengers' safety in case of a disaster, such systems were not designed to be able to handle the following events very well, i.e., the associated dispatching work done during the disaster response phase. In other words, if HSR responsible personnel, such as field engineers, engine drivers on trains, dispatchers in the OCC, and maintenance crews in depots, do not well perform the follow-up work, extended delays and possible catastrophic system failures might occur, thus exacerbating the impact caused by the disaster. It should be noted that the disaster response phase defined here is the time period when an emergency dispatching plan is required for a HSR system to transport affected passengers to safe places as well as to send inspection and/or engineering trains to repair damaged infrastructure or equipment. After the disaster response phase, at least some adjusted passenger train services can be run if all safety-related issues have been resolved. It should be also noted that unlike conventional rail systems, HSR systems always require a timetable to govern each train movement, even during the disaster response phase. Hence, generation of a feasible emergency dispatching plan, which contains the timetable to be followed by various types of trains, is the most important task during this time period. Actions of the emergency dispatching plan may include sending a spare train from a HSR depot to the location of the damaged train to transport the passengers, and sending a track inspection train from a HSR depot to examine the damaged railway infrastructure. Literature showed that due to human emotional behaviors and consequent errors under stress, HSR emergency dispatching plans generated were not always reasonable [4]. Literature also indicated that in one conventional rail system, casualties did occur during the first several hours of a disaster largely due to a poor emergency dispatching plan.

In order to design a reasonable emergency dispatching plan, all responsible personnel distributed over the entire HSR system are required to work jointly, so that the OCC dispatchers can collect necessary information from the field, process a vast amount of data from sensors, and create a feasible emergency dispatching plan to be carried out by each ATC, all within a very short period of time [5, 6]. In reality, a lot of inherent uncertainties can make this decision-making process more intricate. For example, a power supply system might become unstable intermittently under such circumstances, which complicates the process by altering the dispatching rules dynamically [7]. To tackle the problem, it is needed a systematical method to assist all HSR responsible personnel in crafting a reasonable emergency dispatching plan.

The motivation behind this study is to overcome the problem associated with current human-based practices for creation of a HSR emergency dispatching plan. Making a reasonable and quick decision in such information-rich, dynamic environments is essential to this kind of problem. Recently, a novel approach called the multi-agent system (MAS) is being increasingly used in transportation applications. Literature has shown that the MAS is suitable to solve a communication and coordination problem in a distributed environment. Presently, the MAS is often combined with a well-designed ontology model capturing the domain knowledge to strengthen its reasoning capability, in order to help project stakeholders collaborate in the decision-making process [8]. Within a multi-agent assisted environment, a project stakeholder can firstly consultant with a software agent of MAS about current situations and suggested actions and then make the corresponding decision. Therefore, this study proposed an Ontology-based Multi-Agent (OMA) model for emergency trains dispatching in HSR systems during the disaster response phase. This combined approach has not been seen in the field of HSR emergency dispatching from the