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TAIWAN HIGH-SPEED TRAINS EMERGENCY DISPATCHING USING ONTOLOGY-BASED, MULTI-AGENT MODEL

Chuen-Chyi Hsieh[1], Te-Che Chen[2], Ting-Wu Ho[3], and Chien-Cheng Chou[4]

Abstract: High-speed rail (HSR) systems have played a more and more important role for today's traveling public. To guarantee punctual, reliable and safe services, modern HSR systems are equipped with sophisticated computerized subsystems for daily operations. However, when a natural or man-made disaster occurs, currently extensive human interventions are needed and, consequently, extended delays and possible injuries may occur if HSR emergency dispatching plans utilized do not accommodate all the conflicts raised. Previous literature shows that multi-agent system (MAS) technology can be utilized to provide decision-making assistance in a distributed and dynamic environment and is often combined with ontology and semantic rules to enhance the reasoning capability. Hence, this research aimed at developing an ontology-driven MAS model for HSR emergency dispatching, and intelligent agents were constructed using JADE (Java Agent DEvelopment framework) and Protégé with SWRL (Semantic Web Rule Language). The proposed model was validated with three real HSR emergency dispatching cases, plus 50 hypothetical cases. Experts from Taiwan HSR company were asked to assess the model performance. The assessment results showed that the HSR emergency dispatching plans generated were similar to those designed by experienced dispatchers, and the time required to develop a plan using the proposed model was significantly less than the time needed in the manual approach. The model is expected to help young dispatchers handle emergency dispatching cases under stress, as well as to strengthen the safety aspect of HSR services. Delays or casualties associated with a train disaster could be reduced if the proposed model is adequately utilized.

Keywords: Multi-agent system, ontology, high-speed rail, disaster response phase, emergency dispatching.

1 INTRODUCTION

Nowadays high-speed rail (HSR) systems have played a critical role in providing efficient transportation services for the traveling public. To maintain HSR service quality, myriad advanced information and communication subsystems need to function properly, along with their operators such as train engineers and dispatchers that cooperate in a disciplined way (Pascoe and Eichorn 2009; Dong et al. 2010). Even before

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[1] Graduate Research Assistant, Department of Civil Engineering, National Central University, Taiwan.

[2] Senior Engineer, Taiwan High Speed Rail Corporation; Former Graduate Research Assistant at Department of Civil Engineering, National Central University, Taiwan.

[3] Engineer, Industrial Technology Research Institute of Taiwan; Former Graduate Research Assistant at Department of Civil Engineering, National Central University, Taiwan.

[4] Associate Professor, Department of Civil Engineering, National Central University, Taiwan, ccchou@ncu.edu.tw

the occurrence of a natural or man-made disaster, current HSR systems include dedicated detection modules that can probe disaster-related events in advance, in order to perform adequate countermeasures (Corman et al. 2012; Cacchiani et al. 2014). Take for the earthquake warning system (EWS) deployed on Japan and Taiwan HSR systems as examples, which involve earthquake detection sensors usually installed every five kilometers along HSR mainlines. In earthquake-prone regions such as Taiwan and Japan, the EWS can detect an earthquake's electromagnetic wave several seconds before it causes any damage. Once detecting the event with an earthquake's peak ground acceleration (PGA) value greater than 40 Gal, the EWS will immediately stop each affected train by sending commands to the train's automatic train control (ATC) module, as well as notify train dispatchers in the HSR operation control center (OCC) to commence designing emergency dispatching plans, aka timetables. In fact, the EWS of Taiwan HSR 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 Japan Shinkansen trains operating at high speed (Kazama and Noda 2012).

Although modern HSR systems have been proven to maintain high-quality service, such systems are not designed to be capable of handling various circumstances that may arise during the disaster response phase (Weng et al. 2014; Yang et al. 2014). It should be noted that unlike conventional rail systems, HSR engineers have little control over their trains, and all kinds of train movements should be defined in a dispatching plan, which is designed by HSR dispatchers in advance with the assistance from their computerized scheduling subsystems. In other words, if a HSR dispatching plan cannot accommodate conflicts reported during the course of a disaster, extended delays or possible catastrophic system failures might occur. It should be also noted that the disaster response phase is defined here as the time period between the occurrence of a disaster and the time point when all on-board passengers have been transported to safe places to disembark. Current HSR scheduling subsystems contain thousands of pre-defined emergency dispatching plans for such circumstances; however, selecting an appropriate plan from such timetable pools still takes much time. In practice, HSR dispatchers simply cancel and/or suspend train services to avoid any potential conflicts, which not only increase passengers' dissatisfaction but worsen emergency situations. After the disaster response phase, at least some adjusted passenger train services can be run if all safety-related issues have been resolved. Hence, the efficient development of an effective HSR emergency dispatching plan would be the most important task during the disaster response phase.

The motivation behind this study is to overcome the problems associated with current human-based practices for HSR emergency dispatching. Making a reasonable and quick decision in such distributed and 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 (Mes et al. 2007; Ning et al. 2011). Literature has shown that the MAS can be utilized to alleviate communication and coordination-related burdens 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 decision makers collaborate (Tran and Low 2008). Within a multi-agent assisted environment, a stakeholder can consultant with a MAS software agent about current situations and ask for suggested decisions. Therefore, this study proposed Ontology-based Multi-Agent (OMA) model for HSR trains dispatching during the disaster response phase. The manuscript is organized as follows: Section 2 describes the proposed OMA approach and implementation details. Section 3 presents the OMA model validation results using real cases from Taiwan HSR. Finally, Section 4 presents research conclusions with future suggestions.

2 METHODOLOGY

2.1 Design of the Overall OMA-HSR Model

A MAS-based architecture, called OMA-HSR (Ontology-driven Multi-Agent model for High-Speed Rail system), was designed to simulate how HSR dispatchers and other stakeholders communicate and coordinate in order to resolve emergency dispatching cases, as shown in Figure 1. OMA-HSR consists of four types of intelligent agents: Train Agent (TA), Depot Agent (DA), Operations Control Center Agent (OCCA), and Power Supply Agent (PA). When a disaster occurs, the OCCA will receive many situation assessment results from field sensors and other report information from the HSR stakeholders. For example, a TA should report its train conditions to the OCCA. The OCCA will then check current system constraints such as blockage of tracks, depot resources availability, and power supply status by sending data request messages to each DA and PA. When all the required data have been gathered, the OCCA will run a series of pre-defined rules, which will be discussed later and are represented in the ontology model, in order to generate a reasonable emergency dispatching plan. Finally, the OCCA will send the emergency dispatching commands to each concerned TA, which will fulfil the goal regarding transporting the passengers to safe places.

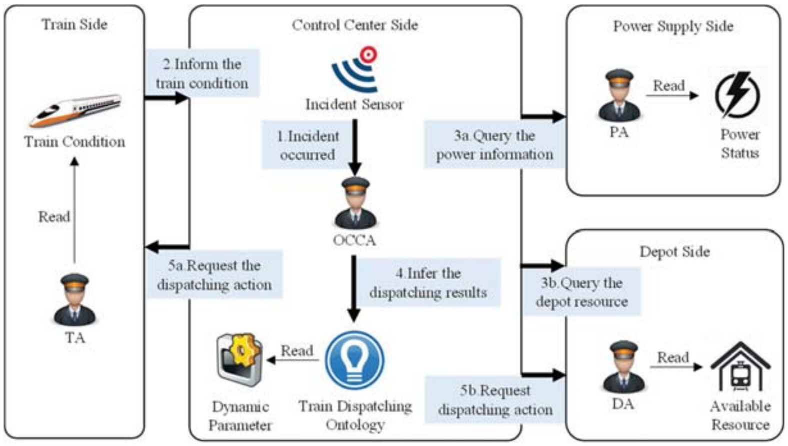


Figure 1: Architecture of the OMA-HSR

2.2 Design of Ontology

Since HSR emergency dispatching decisions are influenced by various interrelated and changeable factors, these factors are organized into an ontology model, as shown in Figure 2, so that both the data collected and the information inferred can be processed in a more systematic and efficient way. Eminent classes are described as follows: Train class, which includes inspection and repair trains (denoted as EngineeringVehicle), passenger trains, etc.; RailwayNode class, which defines a certain location with a railway facility such as Platform inside Station and StablingYard inside Depot; RailwayLink class, which defines one segment of a railway line; Command class, which contains the actions that each affected train's ATC should follow; Incident class, which contains incident-related information.

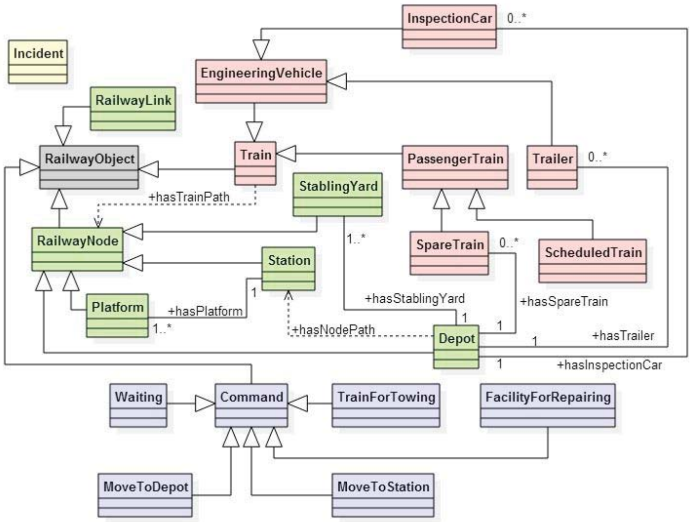


Figure 2: UML diagram of the proposed ontology for HSR emergency dispatching

2.3 Inference Rules

OMA-HSR contains a set of inference rules to represent the knowledge pertaining to HSR emergency dispatching. SWRL technique was utilized to describe these ontological rules. Some of the most important rules are listed and discussed here, including train movement, path existence, depot resource checking, and command control:

- Rule 1: Train Path Existence

Train(?t) ∧ hasLocation(?t, ?t_loc) ∧ RailwayNode(?n) ∧ LocatedAt(?n, ?n_loc) ∧ Incident(?e) ∧ OccurrenceLocation(?e, ?e_loc) ∧ subtract(?v1, ?e_loc, t_loc) ∧ subtract(?v2, ?e_loc, n_loc) ∧ multiply(?v3, ?v1, ?v2) ∧ greaterThanOrEqual(?v3, 0) → hasTrainPath(?t, ?n)

It represents the fact that there is a travel path that does not contain any damaged track between the train and the railway node. The location of the incident is somewhere not between the train and the railway node, causing the train able to move.

- Rule 2: Node Path Existence

Depot(?d) ∧ LocatedAt(?d, ?d_loc) ∧ Station(?s) ∧ LocatedAt(?s, ?s_loc) ∧ Incident(?e) ∧ OccurrenceLocation(?e, ?e_loc) ∧ subtract(?v1, ?e_loc, d_loc) ∧ subtract(?v2, ?e_loc, s_loc) ∧ multiply(?v3, ?v1, ?v2) ∧ greaterThanOrEqual(?v3, 0) → hasNodePath(?s, ?d)

It represents the fact that there is a path that does not contain any damaged track between the depot and the station. The location of the incident is somewhere not between the depot and the station, causing the train able to move between the two nodes.

- Rule 3: Rescue Locomotive Assignment

RL(?tr) ∧ Train(?t) ∧ Depot(?d) ∧ hasRL(?d, ?tr) ∧ isAvailable(?tr, ?a) ∧ equal(?a, true) ∧ hasTrainPath(?t, ?d) → assignRL(?d, ?t)

It represents the dispatching command that a rescue locomotive can move from the depot to the location of the damaged train for towing it back to the depot. It has to consider the availability of each rescue locomotive in the depot as well as other related resources such as the train path.

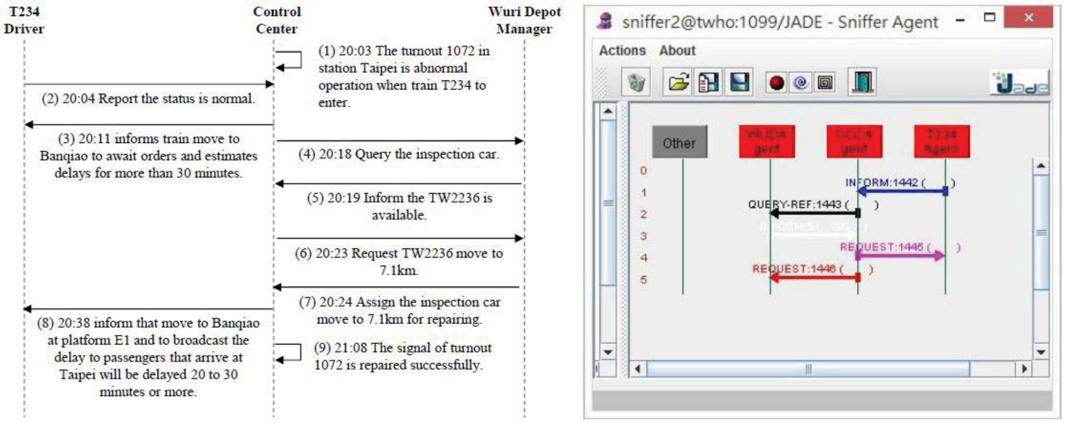
- Rule 4: EngineeringVehicle Assignment

$\mathrm{EV}(?ic) \wedge \mathrm{Incident}(?e) \wedge \mathrm{Depot}(?d) \wedge \mathrm{hasEV}(?d,\ ?ic) \wedge \mathrm{isAvailable}(?ic,\ ?a) \wedge \mathrm{equal}(?a,\ \mathrm{true}) \rightarrow \mathrm{assignEV}(?d,\ ?e) \wedge \mathrm{FacilityForRepairing}(?e)$

It represents the dispatching command that an inspection and repair train can move from the depot to the incident location in order to perform necessary inspection and repairing work for damaged tracks or facilities. It has to consider the availability of each train in the depot as well as other related resources such as the train path.

3 SYSTEM DEMONSTRATION AND EVALUATION

Table 1 lists brief descriptions of three emergency cases in Taiwan HSR that were used to validate the proposed model. These cases were selected because they were designed and implemented by experienced dispatchers and have been regarded by the company as internal teaching materials for illustrating well-handled emergency dispatching. At first, the research team utilized the case data sets to calibrate OMA-HSR, especially for train arrival parameters. This is because the goal of each train agent in the initial version of OMA-HSR was to transport passengers to nearest stations as soon as possible; however, the case data sets revealed that field dispatchers preferred to maintain passengers' satisfaction, implying that impacted trains should move to the stations close to their final destinations as much as possible. Hence, OMA-HSR was modified to accommodate such requirements. Due to the page limitation, only Case 2 is elaborated here to show how human dispatchers handle such situations (Figure 3 - Left), followed by the dispatching plan prepared by OMA-HSR (Figure 3 - Right). The handling sequences of the other two cases are listed and discussed more in a report prepared by the research team (Chen et al. 2016). It should be noted that only some of the events depicted in Figure 3 (Left) were also displayed by OMA-HSR because OMA-HSR concentrated on messages sent between agents. The manual version may contain other events representing real-world inspection and/or repairing activities, which were converted into attribute fields about statuses of railway facilities or trains defined in OCCA and were not displayed in Figure 3 (Right).



(1) 20:03 The turnout 1072 in station Taipei is abnormal operation when train T234 to enter.

(2) 20:04 Report the status is normal.

(3) 20:11 informs train move to Banqiao to await orders and estimates delays for more than 30 minutes.

(4) 20:18 Query the inspection car.

(5) 20:19 Inform the TW2236 is available.

(6) 20:23 Request TW2236 move to 7.1km.

(7) 20:24 Assign the inspection car move to 7.1km for repairing.

(8) 20:38 inform that move to Banqiao at platform E1 and to broadcast the delay to passengers that arrive at Taipei will be delayed 20 to 30 minutes or more.

(9) 21:08 The signal of turnout 1072 is repaired successfully.

INFORM:1442 ( )
QUERY-REF:1443 ( )
REQUEST:1445 ( )
REQUEST:1446 ( )

Figure 3: Dispatching sequence of Case 2: Left - manual version; Right - OMA

Table 1: List of Selected Taiwan HSR Emergency Cases

Date	Event Descriptions	Location	Type
2013/X/X 8:41AM	Train ATC system breakdown: T621 moved to Station let passengers disembark and moved to Depot for repairing. Depot assigned a spare train to Station for replacing T621.	35.6km	Damaged Train
2014/X/X 8:03AM	Abnormal operation of turnout: T234 moved back to Station for waiting. Depot assigned Engineering Vehicle, which moved there to have the track fixed.	7.1km	Damaged Track
2015/X/X 10:59AM	Power supply system failed: T4 moved to Station let passengers disembark and moved to Depot. T321 could not move. Depot assigned a spare train to Station for replacing T4 and Rescue Locomotive, which moved there to tow T321 back to Depot.	247.6km	Both

The evaluation of OMA-HSR consisted of two steps: comparing the dispatching commands listed in the manual version with those generated by OMA-HSR and evaluating the time required to create a dispatching plan in both versions. The research team decided not to consider the time required for real-world inspection and/or repairing activities and concentrated on the data collection and analysis-related activities to form a dispatching plan. Five experts from Taiwan HSR company were invited in the evaluation workshop, including the ones who actually handled the three real cases. In the first step, after reviewing the dispatching plan generated, the experts found that although both versions have the same set of dispatching commands, their execution sequences were different. For example, in OMA-HSR, OCCA agent sent a dispatching command to Train agent (Request 1445) first and then to Depot agent (Request 1446) (see Figure 3 - Right). But in the manual version, the control center contacted Wuri depot manger first and then contacted T234 driver (see Figure 3 - Left). However, because no spatiotemporal conflicts were created in OMA-HSR, and because the final system settings (e.g., each train's position and the availability of each resource) were identical among both version, the experts concluded that OMA-SHR can generate a plan similar to the one in the manual approach. The same conclusions were made for the other two cases.

In the second step, since the research team had embedded a logging function in each message call of OMA-HSR to measure its time duration, the experts were asked to help identify the time needed in the manual version. The minimum time unit used in the manual version is one minute, and the averaged time required for each type of dispatching commands are summarized in Table 2. For example, as for the dispatching type of commands in Case 2, after the train engineer reported the status, dispatching T234 requires 7 minutes in the manual version. Dispatching TTW2236 requires 4 minutes while dispatching T234 to E1 requires 27 minutes. However, the use of OMA-HSR requires averaged 0.15 minute to generate one such dispatching command. The experts explained the use of more time in the manual version owing to the fact that human dispatchers may double-check the correctness of the received data or discuss with their chief dispatchers about the plans.

Additionally, the research created 50 hypothetical cases describing different scenarios pertaining to trains, tracks or stations and mixed types of problems. Among 59 daily operation trains, 20 of them were randomly selected to be brought to emergency stops.

Among 40 sections of the railway line, 20 of them were randomly selected to be blocked due to an assumed disaster. The averaged time duration to generate a dispatching command for the 50 test cases is 0.21 minutes, which shows that if all relevant information has been collected by OCCA, OMA-HSR could generate a dispatching plan within half of a minute, which is far less than the average time required by using the manual approach.

Table 2: Averaged time duration needed for each type of dispatching commands in both versions (in Minutes)

Case	Type	Manual	OMA
1	Informing	1	0.1
	Querying	1	0.1
	Dispatching	7.1	0.12
2	Informing	1	0.1
	Querying	1	0.1
	Dispatching	12.6	0.15
3	Informing	1	0.1
	Querying	1	0.1
	Dispatching	25.3	0.2

4 CONCLUSIONS AND FUTURE WORK

An ontology-driven MAS model, called OMA-HSR, was proposed to assist in HSR emergency trains dispatching. The plan can be used to guide each train’s movement, including passenger trains, spare trains, rescue locomotives, inspection and repairing trains. SWRL and JADE were used to develop the proposed system. Three real cases performed by experienced dispatchers were selected to validate the proposed approach. The comparison results show that OMA-HSR can generate an emergency dispatching plan as good as the original ones, using less time. There are several limitations of OMA-HSR: 1) a linear topology is assumed for the HSR system, i.e., running one track in each direction. However, this assumption is acceptable because most HSR systems are built to connect only the metropolitan areas in a country. 2) Currently all of the incidents data have to be entered into OMA-HSR at the same time, which means incidents can occur simultaneously. However, once an emergency dispatching plan is developed, additional, updated information or parameters cannot be reflected in OMA-HSR. It is a one-pass analyzer. 3) All incidents will be regarded and processed equally. No priority information can be attached to a train in analysis. In the future, if there are some places where spare trains are difficult to reach, OMA-HSR should consider sending ambulances and shuttle buses to such locations, in order to transport the passengers. OMA-HSR should be generalized to cover other types of railway topology, so as to expedite the disaster response phase without compromise its safety.

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