INTELLIGENT EMERGENCY MANAGEMENT SYSTEM FOR RAILWAY TRANSPORT

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ABSTRACT

Nowadays, a major safety challenge in rail transport is to manage the incidents and emergencies in the most efficient possible way. The current contingency plans tend to be based on static procedures not taking into account how real-time conditions affect them.

Consequently, the decision-making process may well suffer delays and the possibility of occurrence for human mistakes could raise since the required measures are expected to be carried out under important pressure. In this study, focused on commuter trains, railway safety is enhanced by a new intelligent emergency management system which aims to support the operator tasks in a real-time incident or emergency situation. This cyber-physical system is composed by two main modules: one on board the train, including sensors and GPS, and other integrated in the control centre addressing four computational models. Those models cover (1) the detection of different types of incidents/emergencies using the information received from on board sensors, (2) the calculation of the evacuation process (if necessary), (3) the selection, estimation of routes and communication with emergency services required for each event, and finally (4) a provision of actions to support the operator decisions. Communication between modules is provided by GPRS due to actual technology available in the pilot trains. This system has been implemented in an actual railway line in Cantabria (Santander-Cabezón de la Sal) and three practical demonstrations were defined based on several use cases, which were tested using a pilot facility incorporating all sensors and devices installed in those trains. Results demonstrated the benefits of the new system.

1. INTRODUCTION

According to the last report of 2019 of the National Commission for Railway Accidents only in Spain during 2018 one serious accident (an impact against a landslide), nine events at railroad crossing, two fires and other thirty-one different types of serious incidents took place. This demonstrates the importance of managing such undesirable events in the fastest and safest manner via transportation policies.

Over the last decade, Intelligent Transportation Systems (ITS) have implemented new features, addressing safety and security issues. The importance of enhancing the protection of critical transportation infrastructures, due to the wide range of risks which impact their proper functioning, is shown in studies as Janusova and Ciemancova (2016) through different examples of goals and roles of using ITS in railway transport and its potential benefits for decision-making process of transport operators or emergency responders.

Regarding intelligent systems developments, there is a wide variety of areas and applications. As shown by Qureshi and Abdullah (2013), ITS technology operates in diverse fields of transportation through management systems of freight (e.g. Commercial Vehicle Operations (CVO) or Advanced Fleet Management System (AFMS)), transit (e.g. Automatic Vehicle Location (AVL) or Travel Assistance Device(TAD)), incident (e.g. Critical Incident Management System (CIMS) or Cyber Physical System (CPS)) or emergency (e.g. Emergency Management Information System (EMIS) or Multi-Commodity Stochastic Humanitarian Inventory Management Model (MC-SHIC)), all with the aim of improving safety. Other example of ITS applications is shown in (Shi and Ni, 2015) with the analysis, model and framework of Railway Intelligent Transportation Systems (RTIS) and its applications as the Transportation Management Information Systems (TMIS) or the Automatic Train Identification Systems (ATIS), among others. The application of this technology in urban transport is shown in (Qin, Yuan and Pi, 2016) introducing Urban Rail Intelligent Transportation Systems (URITS) divided into five layers (perception, communication, integration, operation and service) providing communication signals, integrated supervision and operations management.

Moreover, some research works have been done to improve individual components of the system. Developing an online real-time model which represent the normal behaviour of train trajectory, anomalies in train speed during the whole route from the departure location can be detected (Kang, Sristi, Karachiwala and Hu, 2018). Results from the validation of the system through simulations shown a sensitive improvement detection up to 22%. Another example proposes a security incident detection technique based on rough sets theory using a Multilevel Intelligent Control System (MICS) within ITS (Chernov, Butakova, Karpenko and Kartashov, 2016). Network security incidents were defined as a cause-effect chain of events for their classification (e.g. system malfunction incidents, incidents caused by user errors, intentional cyber-attacks). The proposed technique gives rise to a simple and fast calculation. Another important component of transportation is the travel time information, stressing the fact that the longer delay of train arrival means longer waiting time for passengers. To provide better service, researchers from India presented in (Krishna and Yugandhar, 2013) one of the first attempts at real-time short-term prediction of arrival time for ITS applications through the development of three modules (vehicle section module, base station section module and user mobile section module) integrated in a comprehensive system. The arrival time calculation uses the train location and the station location through Global Positioning System (GPS) modules placed on board the train and at each station.

One of the most recently published studies deals the implementation of satellite navigation elements for rail transport (Nedeliakova, Hranicky and Cechovic, 2019). An advantage of the functions is that it can be integrated in current technology systems and with new digital devices.

ITS have been also integrated with other intelligent systems from other type of transport. In (Osipitan, 2016) combining intelligent transportation system for roadways and an intelligent rail system technology developing an Intelligent Grade Crossing System (IGCS) which improves the security of highway-rail intersections.

Based on the importance of ITS, several countries have carried out their own studies to measure the benefits of implementing these technologies to their railway service. In 2012, China analysed the situation of their railway infrastructure, taking into consideration that it is its cheapest means of mass transportation, and how this infrastructure could be affected by the implementation of Rail Intelligent Transportation Systems (RITS) (Jiang, Yang, Yuan and Xu, 2012). This analysis established five sustainable development strategies which offer a transportation solution minimizing environmental impact and contributing to social and economic prosperity. Similarly, Tokody, Schuster and Papp (2015) developed an ITS ensuring the highest reliability implementation, taking into account technical and technological characteristics, probability of system failures and theories of normal accidents, reliability organizations and flexible engineering planning. Also, they paid special attention to safety risks of software and hardware products. Efficiency, safe operation and convenience, as well as the increment of the adaptability of the system were the key aspects considered by the authors for ITS development. In Poland, new concepts and innovative technologies were also implemented as the European Train Control System (ETCS), a subsystem of the ERTMS (Kornaszewski, Chrzan and Olczykowski, 2017). The idea of the ETCS is based on the digital track-vehicle transmission, supplying the engine driver of information concerning locations of trains, allowed speed or the closure of a level crossing. The GSM-R radio communication complete the system.

In essence, the stress produced by emergency events to control centre operators increase the likelihood of making mistakes. Emphasising that responsibility to manage emergency events through a decision-making process it is crucial to minimize risks and emergency consequences. Hence, the application of ITS is certain to provide elements to the operator for decision-making process. In this sense, the purpose of this study is to support the operator during the decision-making process slightly improving its activities.

This paper provides the explanation and characteristics of the four models integrated in SIGNAL system elaborating the corresponding communications protocols and the validation experiments conducted.

2. METHODOLOGY

SIGNAL is a cyber-physical holistic intelligent management system including both on board and control centre modules, see Figure 1. While the former, managed by the train driver, receives information from train devices as smoke and fire sensors, speedometer, accelerometer and GPS, the latter integrated in the control centre hardware aims to support the operator tasks during an incident. The control centre is composed by four independent models.

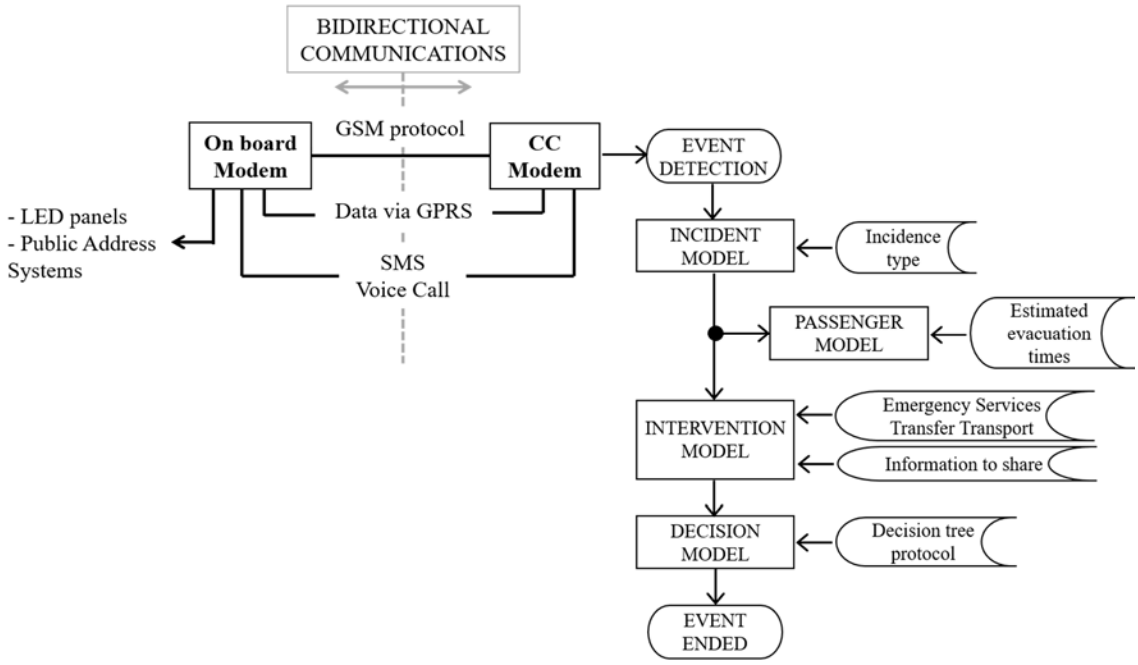


Fig. 1 – Intelligent Emergency Management global scheme

Based on the available technologies installed in the railway vehicles selected for the practical demonstrations, the communication between both modules is provided via General Packet Radio Service (GPRS) using User Datagram Protocol over Internet Protocol (UDP/IP). Likewise, in order to provide Voice Call and messaging services Short Message Service (SMS) and Global System for Mobile (GSM) communication are used. In case of a “dead man” warning from the train driver cabin, the communication between control centre operator and passengers through LED panels and audio system installed in the train is also feasible. The location of the train in both modules is shown through a Global Information System (GIS).

The characteristics of the four models developed are defined as follows:

1) Incident model. Through constant reception of train location via GPS and current status of sensors installed on board, it is able to detect different types of incidents in real-time clustered as can be seen in Table 1. To elaborate this classification an extensive review was conducted founded on previous railway emergency events.

Id.	Incident Code	Incident Designation	Sensors/Devices
1	NOGPS	GPS signal lost	GPS
2	FTEC	Stop due to a breakdown of rolling stock	Speedometer
3	DESC	Derailment	
4	FEVIAJE	Emergency break by passenger	Accelerometer
5	FECOND	Emergency break by engine driver	
6	FEHM	Emergency break for “dead man”	
7	IMPC1	Minor running-over due to the impact against a small object	
8	IMPC2	Major running-over due to the impact against a large object	
9	INCN	Fire in rolling stock	Fire detector

Table 1 – Incidents and its relation with sensors.

Once a sensor achieves threshold values capturing an abnormal behaviour, the model alerts both the driver and control centre. Communication is implemented using the following frame structure to receive and report the current status of the sensors:

UUUU; YYYYMMDDHHMMSSCC;EVENT;LON;LAT,SPD,SPDU

Where UUUU is the train unit identification, YYYYMMDDHHMMSSCC indicates time (Year, Month, Day, Hour, Minute, Second and Second hundredth) noted as DT for simplification, EVENT is the incident code from Table 1, LON is the GPS longitude, LAT is the GPS latitude, SPD is the instant speed (m/s) and finally SPDU is the instant speed-up (m/s^2).

Once an anomalous frame has been detected, the system initiates a voice call between the control centre operator and the engine driver to verify the incident. In case of reception of “dead man” incident code or similar code preventing the establishment of voice call, the operator immediately initiates the protocols for direct communication with the passengers using LED panels through the following frame:

UUUU;DT;MSGD;FMT;’MESSAGE’

Following the above notation, MSGD contains the message to be displayed and FMT controls the display mode being B-normal, R-blink and S-rotary.

Similarly, a Public Address system (PA) could be employed by control centre operator to remotely configure the audio devices installed on board allowing direct voice communication with passengers to provide instructions.

UUUU;DT;AUDIOV;ON/OFF

Where AUDIOV is the corresponding tag of the system and ON/OFF indicates the current status of the devices.

2) Passenger model. In case of remaining inside the train was not a safety alternative for passengers, this model runs stochastic simulations to calculate the total evacuation time under different conditions. The total time (T_{total}) is calculated by two terms: the egress time from the train (T_{egress}) and the movement time of passengers (T_{mov}) towards the access point for the alternative transfer transport (see Equation (1)).

$$T_{total} = T_{egress} + T_{mov} \tag{1}$$

Focus on the first term, trains are characterized as narrow spaces that limits the people movement inside, prevailing the queues discipline. According to (British Standards Institute, 2004; ISO, 2015) the required evacuation time for rail cars comprises two main variables: 1) the time of the first few occupants to reach the exit (movement time) and 2) the flow time of the rest of passengers through the available exits. The chance for passengers to leave the train is determined by the opening of exits, prior notice from the crew. The random flow rate of passengers through exits is expected to be the most decisive variable to calculate egress time. Also, flow rates depend on the operative conditions: the urgency (i.e. evacuation or normal alighting) and the evacuation destination (i.e. high platform, rail tracks). Hence, four egression classes were implemented: evacuation to platform, evacuation to tracks, alighting to platform and alighting to tracks. Data used for flow rates f are based on empirical data provided in (Cuesta, Abreu, Balboa and Alvear, 2017; Capote, Alvear, Abreu, Lázaro and Cuesta, 2008; Nelson, 2002; Norén and Winér, 2003) and its minimum and maximum values are shown in Table 2. The number of passengers (n_{occup}), the number of available exits (n_{doors}) and their width (w_{doors}) are also components of Equation (2). Train occupation is calculated using Equation (3) where n_{max} is the maximum occupation and P_{occup} is the occupation density assumed as 20, 40 and 80 %.

$$T_{egress} = \frac{n_{occup}}{n_{doors} * w_{doors} * f} \tag{2}$$

$$n_{occup} = n_{max} * \frac{P_{occup}}{100} \quad (3)$$

The second term is the movement time of passengers from the train to the transfer transport, which may have two situations, egress to platform or egress to rail level. Both distances are namely d_t. Equation (4) shows the corresponding formula to calculate the movement time.

Finally, walking speeds (v_i) are taken from empirical data (Chandra and Bharti, 2013; Henderson, 1971) (see Table 2). The movement time for each passenger is t_{mov_i}, the number of passengers is denoted as i and the total number of walking speed values is n_p (depending on train occupation load).

	Flow rate (per/s)		Walking speed (m/s)	
	Min.	Max.	Min.	Max.
Evacuation to platform	1.23	3.84	0.5	3
Evacuation to tracks	0.85	1.45	0.3	2.1
Alighting to platform	0.93	0.96	0.4	2.2
Alighting to tracks	0.56	0.69	0.2	1.4

Table 2 – Flow rate through exits and walking speed values.

$$T_{mov} = \max_i(t_{mov_i}) \qquad 0 < i < n_p \quad (3)$$

$$t_{mov_i} = \frac{d_t}{v_i} \quad (4)$$

Note that flow rates and walking speeds are random variables used to determine the evacuation times through Monte Carlo stochastic simulations, as it is described in (Alvear, Abreu, Cuesta and Alonso, 2014). Moreover, the time calculated from the Passenger model is the 95th percentile of the total evacuation time, resulting of sum up the 95th percentiles of each term (egress time + movement time).

3) Intervention model: this model supports operator and improve time required. The model works under real-time conditions using the information provided by previous models. The conceptual approach is based on defining the emergency services to report the situation and which data should be shared with them (the existence of injuries, access points to the railroad, etc.). To determine that, the model has a decision tree logic which guarantees the optimal information flows to external services. The intervention model also determines the nearest emergency services from the incident location, being essentially the advanced implementation of the geographical coordinates of each service. Finally, the model calculates the estimated arriving times of the corresponding emergency services and transit transport using OpenStreetMaps service (https://www.openstreetmap.org).

Mapping of railroad access points through video recording or GIS must be defined in advance to implement the corresponding information in the system, establishing three levels of access: free (without obstacles), medium (separation systems easy to take off) and no access (impassable areas).

4) Decision model: this model shows a summary of the actions taken during the incident/emergency and helps the operator to verify all those decisions and actions. It is based on a sequence of statements/decisions and is represented as a decision tree.

After each model and the communications between modules were developed, they were integrated in a main software called SIGNAL. The interface of the module on board emulator is shown in Figure 3 and the control centre interface is shown in Figure 4.

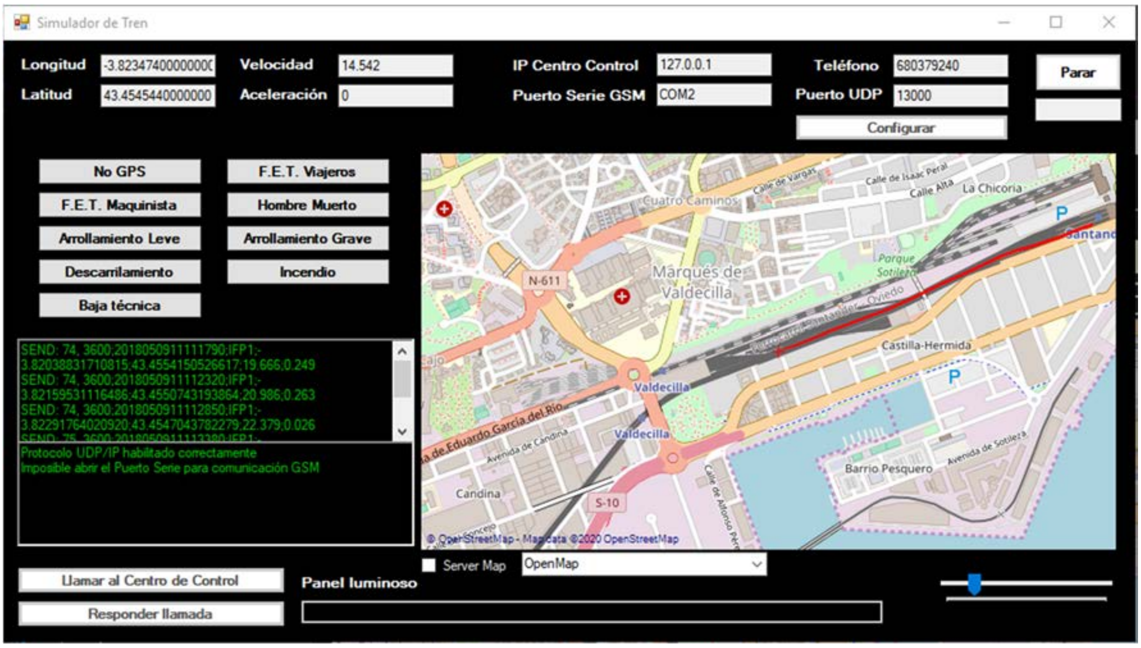


Fig. 3 – On board module interface.

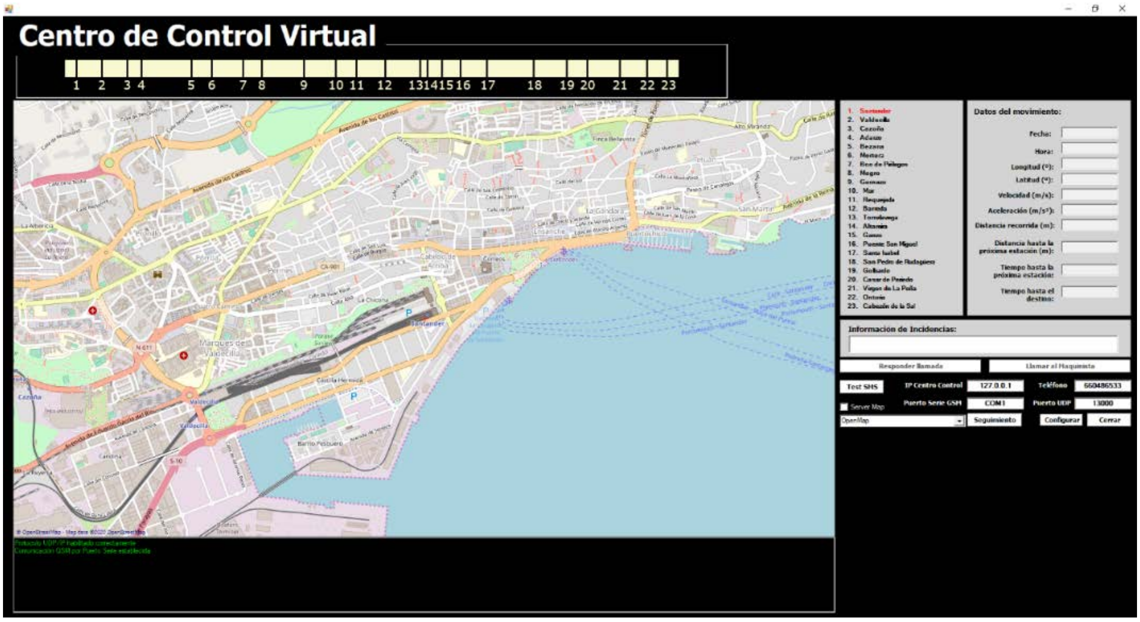


Fig. 4 – Control Centre module interface.

3. SOFTWARE VALIDATION

The evaluation of the proper functioning of SIGNAL was realized through the validation of a set of technical requirements in three use cases. The selected line was Santander-Cabezón de la Sal located in Cantabria (Spain) and operated by Renfe-Feve Railway Company. This line is approximately 48.6 km long and has 23 stations or halts. This line is operated by commuter trains with three coaches of 15.24 m long, 2.35 m width and 4 exits per coach (1.2 m in width each). The maximum speed is 80 km/h due to some operation constraints of the track.

The use cases selected were derailment, emergency brake by engine driver and fire in rolling stock as they cover the validation of all elements of the system. Firstly, a possible scenario was described and executed for each incident with their following descriptions:

Derailment. Partial derailment because of a landslide. Only derails the final coach and it is not overturning any coach. Due to the severity of the situation the presence of injuries is possible. The train occupation is between 20-60%. Passengers can wait for the transfer transport inside the train because the situation is assumed to be safe enough.

Emergency brake by engine driver. The engine driver pushes the emergency brake bottom due to the presence of a car on a railroad crossing. The train can stop before impacting because the engine driver starts the braked-on time. The incident is solved as a false alarm.

Fire in rolling stock. A problem in rolling stock produces a fire that affects the third coach. The train continues operating to reach the next station. They are no injured passengers. The train occupation load is between 20-60%. Evacuation to a platform becomes necessary when the train arrives at the station.

A methodology was defined to conduct the use cases. Each test should start with the constant exchange of frames showing normal operation conditions of the train. At a given time, the on board simulator activates the corresponding incident. The alarm appears at the control centre and the operator calls to the engine driver using a voice communication protocol GSM. For derailment and fire, the driver confirms the incident, but in the emergency break it established a false alarm because the train can continue the route. Then, for the use cases with a verified incident, the Intervention model runs and it allows the operator to implement the corresponding information from the engine driver. The Intervention model provides the course of actions to carry out (i.e. notification to the emergency services and mobilizing transfer transport), if it is necessary.

The operator notifies to the emergency medical services, firefighters and police services for the derailment case and it notifies to firefighters and police services in the fire case.

Also gives the location of the incident, the nearest access points and other relevant information (injuries, overturns,…). Then, the operator calls the engine driver to give him the estimated arriving times of the emergency services. The Passengers model works when it is necessary. Here, it calculates the times for a normal alighting in the derailment case and for an evacuation to platform in the fire case. The operator notifies to the transfer transport of the nearest access point to the railroad and the engine driver of the arrival times. The operator should be alert for possible changes until the incident is over. Its last responsibility is to check the decisions and actions carried out based on the Decision model.

4. RESULTS

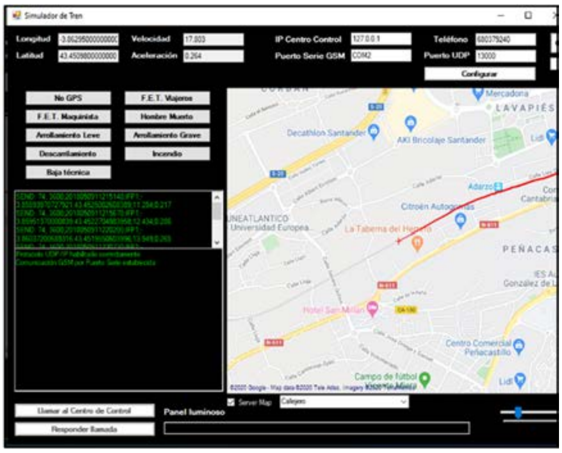
This section includes the validation of each model developed, the verification of operation and autonomy of both interfaces and the entire communications among modules. To limit the number of figures shown in the paper, we decided to include only those corresponding to the complete derailment use case development, since this use case deals all features of SIGNAL.

Table 3 shows a timeline with the corresponding interfaces and description of each moment during the development of the derailment use case. The first element of the temporal sequence X corresponds to the aspect of both interfaces in a normal situation during the train trajectory. When an incident occurs, the software detects it and an alarm is shown on the control centre interface as in the second element of the temporal sequence

X+1. In that moment, the Incident Model interface is activated as an emerging panel (third image of timeline). This panel enables the communication between the operator and the engine driver to confirm the incident and implement the corresponding information. Then, the interface of the Intervention, Passengers and Decision Models appeared (this moment corresponds with the X+3 element of the sequence). Through this screen, the models provide the corresponding results to the operator who can supply them to the engine driver and also notice to the services and transport.

Progress, description and interfaces

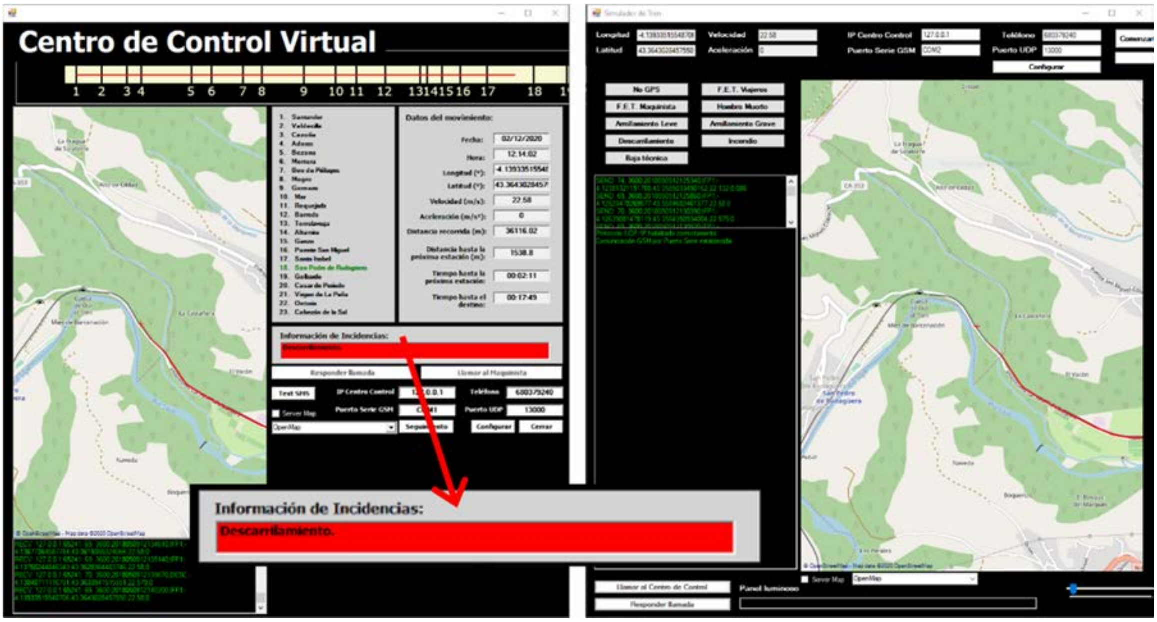
Time: X
Description: Control centre and train software working in a normal situation.
Interfaces:



Time: X+1

Description: Control centre and train software when an incident detection is produced.

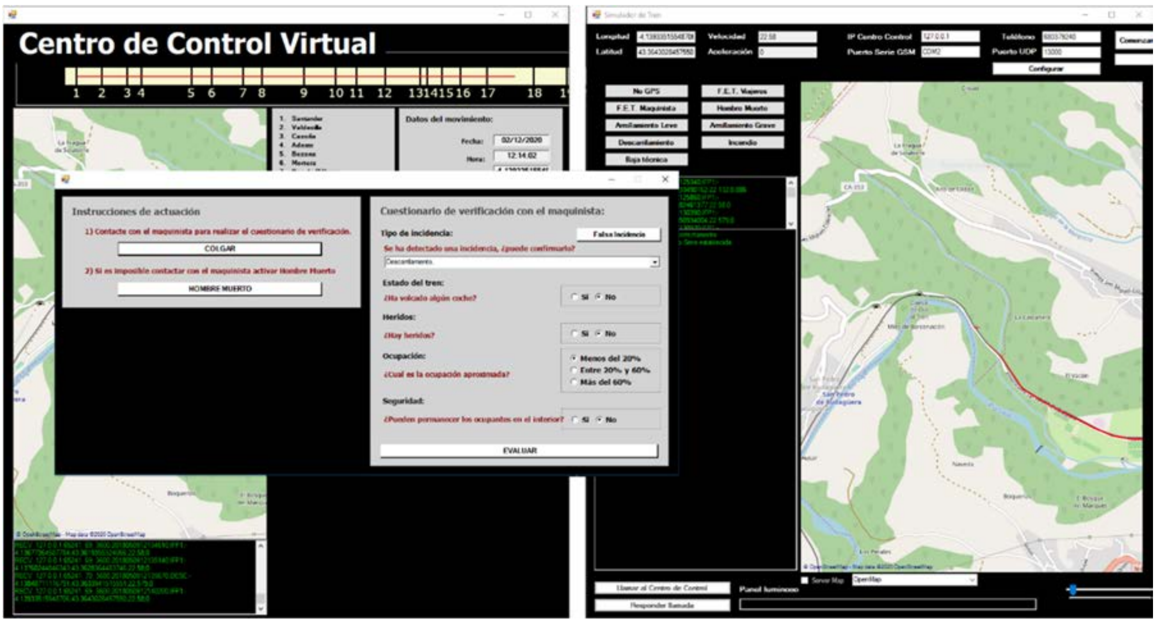
Interfaces:



Time: X+2

Description: Control centre and train software when the Incident Model works. Through a voice call (operator-engine driver) the incidence is confirmed. The first parameters about the event are implemented in an emergent window.

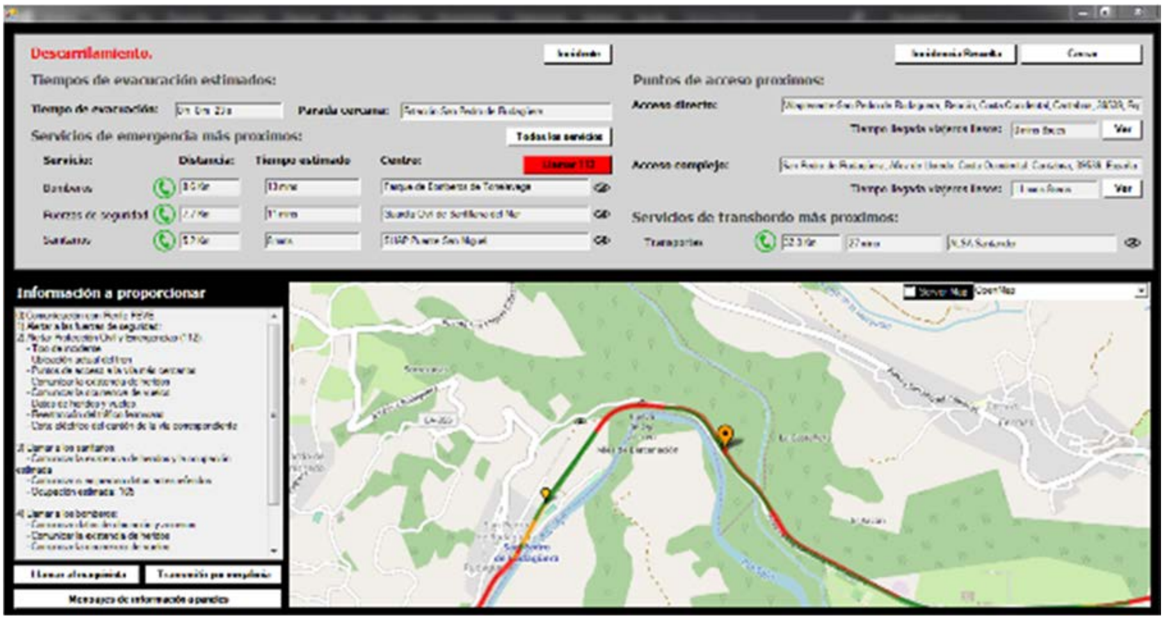
Interfaces:



Time: X+3

Description: Control centre interface meanwhile the Intervention, Passengers and Decision Models are working. Through this interface it is possible notice the emergency services and transit transport and inform the engine driver about the times.

Interfaces:



Time: X+4

Description: Incidence ended.

Table 3 – Development of the derailment use case through a timeline illustrated with images of the process.

5. DISCUSSION AND CONCLUSIONS

Safety and security for passengers of mass rail transportation systems is a major challenge. An incident or an emergency management with people involved is a serious and complicated process. To contribute to the improvement of railway transportation, we developed a prototype of an intelligent emergency management system. The aim is to support the operator tasks of a control centre in the decision-making actions in real-time and reduce the possibility of making mistakes at the minimum. To achieve the objective, we developed a module on board a train that can communicates and shares information from train sensors to the module integrated in the control centre hardware. This module is composed by four models that detect incidents automatically, that calculate evacuation times in a few seconds and that provide emergency management support in real-time.

The case studies have shown that the proposed system does its job opening the field to new application opportunities to emergency management response in rail transport.

First, it is possible to determine the nearest access point to the location of the emergency in a few steps. This is very useful for the emergency services that waste a lot of time defining the best entrance point. Furthermore, the system can be able to provide the type of services (emergencies or transfer transport) to demand their help. This is essential for a better work conditions of the services that are really necessaries. Second, the bidirectional communication among engine driver and control centre operator (or among operator and passengers in case of a dead man of the engine driver), reduces the global anxiety due to the exchange of information in real-time. Finally, the supporting given to the operator is crucial to decrease their responsibility, to reduce its stress and, consequently, to improve the incident management and also passengers safety.

The presented system provides consistent and reasonable results while providing demonstrated benefits. The system would drastically reduce evacuation, intervention and decision times. This paper goes beyond other contributions since it proposes the development and use of a real-time intelligent management system for incidents in rail transport. The next step is to achieve the completely installation and integration of the prototype in a real environment.

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