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Discrete choice models to determine high-speed passenger stop under emergency conditions

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Abstract

High Speed railways are one of the most reliable means of transport. Security and reliability are important so the system has to be prepared to take action in case something goes wrong. It is crucial for a railway management plan to have emergency procedures for a quick response in case of incident or accident. In this paper a model is presented that locates the stop of a train in a certain area during an incident or accident using discrete choice models. This model will support future decision making protocols. Random utility theory assigns utility to each corner of the railway network to calculate where the most suitable place to stop the train is depending on variables such as train speed, place of failure, or type of accident or incident, among others. A minimum computational cost model provides results, which support decision-making procedures on high-speed trains during emergency situations. This paper presents a methodology to determine the most suitable place to safely stop a train in the minimum time and the procedure could be included in future safety standards and emergency protocols. Both external and internal data from the railway are calibrated to predict the most likely place to stop. Not only the stop is predicted but the model also considers timetable effects, meaning the methodology can also be applied to schedule-based railway systems, a characteristic that endows the method with great potential since it considers minimal impacts on schedules.

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1. Introduction

Safety on high speed trains is an increasingly important subject and needs to be constantly improved so that railway travel continues to be the safest and most competitive mode of transport. The present article looks to define the stop criteria for a High Speed passenger train under different emergency situations. Expert criteria will be used as the basis for determining the conditioning factors, which influence the choice between where to stop and the need for an emergency evacuation.

Procedures are now required for emergency situations which are supported by experience and backed up by thorough research. The methodology presented in this article is proposed as a decision making support tool under the conditions requiring the train to stop.

This research is developed over various phases, one of which involves the collection of data about the railway line being studied, the Madrid-Valladolid corridor corresponding to the first working stretch of the North and North East area of the Spanish High Speed train network. A thorough assessment of this network is followed by an accessibility study. A data base is created about the line and its environment which contains a group of variables (distance to stations, distance to hospitals, land use, etc.). The line has been divided into sections (cantons) for which the previously chosen variables are known for each kind of incident and as a function of the consequences (whether to evacuate or not). The values of the variables are used in a stated preferences survey asked to experts in railway safety. The replies to this survey are used to model the utility of a stop zone depending on the variables and thereby determine the most important conditioning factors in making the choice to stop with the need for an urgent evacuation.

The article starts with an introduction to the state of the art, followed by a description of the methodology used. A description of the case study, including the data used, is followed by a series of conclusions which as well as identifying and evaluating the results, also contain a series of recommendations for any future research about the subject.

2. Literature review

Up until now it has always been the control centre which has been the decision making body when deciding to stop a train for any reason (possible danger from blockage of the line, derailment, people or objects falling off the train or onto the line, danger on the parallel line, etc.) and, under certain conditions, the driver could decide to stop the train when faced with a situation presenting imminent danger. The method proposed in this article supports the decision making process to stop the train in emergency situations when the emergency allows the train to stop, bearing in mind that reaction times with High Speed have to be very short.

A multinomial logit discrete choice model for multiple answers is presented (with data that is not defined in an ordered scale). Spatial multinomial logit models can be found in the literature applied to residential location and accessibility (Waddel, 1996; Ibeas, et al. 2013; Guo & Bhat, 2001) or for the location choice of residential spaces (for example, homes with only one working or several working residents, or owner occupiers). Other authors have applied discrete choice models in the field of transport planning (Mohammadian & Kanaroglou, 2003). The final aim of the results of this research is to include them in a special decision making system (Keenan, 2003) which would mainly be used in evacuations due to emergency situations (Pidd, Eglese & De Silva, 2003).

The safety rules, technical regulations and contingency plans of the main railway operators concentrate on the reaction protocol for emergencies, the types of incidents that may occur, how to deal with the incident and the criteria for prioritizing which need to be followed for railway traffic. However, none of them speak about the specific procedure to follow to decide where to stop a train which suffers an incident or to make a preventive stop to avoid greater risk. The article provides guidelines to locate the train stop in relation to where it should and can stop for an urgent evacuation. The study also stimulates the analysis about the convenience of stopping or not, which is a novelty because until now no other work has been published about this aspect.

The bibliography contains decision making systems based on train timetable programming models which avoid negative effects on circulation by using new units or by partially suspending the service (Adenso-Díaz, Tuya, Suárez-Cabal, & Goitia-Fuertes, 2003). Linear programming models can also be found in the literature using heuristic approaches and lagrangian relaxation methods (Caprara, Fischetti, & Toth, 2002; Brannlund, Lindberg, Nou, & Nilsson, 1998). All of these works also try to minimize the computing cost, whereas the present study prioritizes the human aspect provided by the experts in assessing the technical indications. In consequence, the focus offered by this article is one of protecting the passenger rather than continuity of service on the network.

3. Proposed methodology

The working plan which includes the proposed method is made up of various stages:

- Identifying the kinds of emergency according to the type of incident or accident and its consequences.
- Expert evaluation of each type of accident and the resulting emergency and: if an evacuation is required and if the emergency can be controlled or not. Determining the required variables to be considered and collecting/processing the data.
- Modeling the choice of stop location from the replies of the experts depending on the most favorable stopping conditions.

A great variety and variability of causes may lead to emergency situations. This study has distinguished three cases as a function of danger and possible results of the incident (Table 1).

Table 1. Type of evacuation based on the results of the accident or incident

Contingency plan	Description
Urgent evacuation	Serious injuries, danger for passengers.
Ordinary evacuation	Light injuries, no danger for passengers.
No evacuation required	No injuries, total service recuperation.

Table 2 shows some accidents or situations which could occur in the railway environment in which one of the contingency plans described in Table 1 needs to be chosen. In addition, the relationship between types of accident/incident with their type of evacuation for each case is presented.

Losing pantograph connection during a long period can stop a train. Problems in level crossing cause collision, derailment. Lacks of energy supply can also stop a train (Catenary problems). Losing cargo cause obstacles on line, which affect railways traffic. Good and bad weather has influence with accidents and incidents (rail dilation, obstacles in track, wheel slip, etc.). Human driver errors and lack of staff (strikes, missing works) can cause also railway incidents and they have relation with Delays for maneuvers.

Accordingly, an evacuation would always be necessary with a derailment, problems with the pantograph connection and a collision. Causes such as fire and explosion, weather, human driving errors, work on the line or a lack of staff may require any of the three types of contingency plans. Under situations of falling cargo (falling materials to the tracks), turnout problems (trains can derail in turnouts), delays because of maneuvers along with other issues that have not been specifically identified in the table do not require an evacuation.

A stretch of High Speed railway between Madrid and Valladolid was chosen for the practical application. The first step consisted of dividing the line being studied into differentiated 5 km long sections (called braking cantons). This distance was chosen because of the braking distance required by a High Speed Train under normal conditions, leaving a safety margin of 1 km. The Madrid-Valladolid High Speed line is made up of 72 5km long cantons, 36 in one direction (Madrid-Valladolid) and another 36 in the other direction (Valladolid-Madrid). This article considers 36 cantons as their characteristics are the same in both directions.

The aim is to calculate the probability of stopping in the 5 cantons next to the location of the train, assuming that the train is able to fulfill this task, in other words, the incident that has occurred allows it to travel along a further 25km of track. Therefore, if the train is located in canton 4 when the incident occurs, an assessment is made about which of the following 5 cantons is the best one to stop in and evacuate the train, if required.

Table 2. Type of evacuation as a function of the accident or incident

Accidents/incidents	Urgent evacuation	Ordinary evacuation	No evacuation required
Derailment	X	X	
Pantograph connection	X	X	
Level crossing		X	X
Obstacles on line		X	X
Collision	X	X	
Fire/Explosion	X	X	X
Falling cargo			X
Turnout problems			X
Signaling problems		X	X
Catenary problems		X	X
Engine breakdown		X	
Weather	X	X	X
Human driver errors	X	X	X
Track works	X	X	X
Lack of staff/Demonstrations	X	X	X
Delays for maneuvers			X
Others (track ocuppations)			X

After making this decision, the next step is of great importance for this study and deals with the collection of the data to be used in the modeling. The factors representing the suitability of the stopping area need to be considered as variables. The aspects that have been collected about each canton and introduced into the GIS are listed below along with the data about the railway infrastructure found to be significant in the models.

- Distance to stations (D).
- Presence of structures: Tunnel (T), Viaduct (V).
- Number of lines (NUM).
- Presence or not of junctions (CR).
- Presence of turnouts (DES).

The data collected for modeling the choice of stopping canton which are not intrinsic to the railway are as follows:

- Distance to the nearest hospitals (H) and health centers (S).
- Distance to Emergency centers (E) such as police station, fire stations.
- Presence or not of a town close to the line (CI), whether the canton is located in an urban area or not.
- Characteristics of the area: geomorphology (G), presence of a river (R), vegetation (CU).

This data is used to design a stated preferences survey for experts in railway safety to choose where to make the emergency stop. The answers to this survey are then used to determine the importance of each variable in the choice of emergency stop using a multinomial discrete choice model which allows the probability of stopping in each canton to be calculated, highlighting the most influential variables on determining the train's stopping.

The discrete choice models are based on Random Utility Theory (Domencich & McFadden, 1975; Ben-Akiva & Lerman, 1985) which postulates that each individual, in this case each railway safety expert, associates an stochastic type of utility to each stop alternative, choosing the one which maximizes its utility.
The utility function of each canton is defined in the following expression:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

Where the term ε_{ij} introduces the calculation of choice probabilities and differentiates this methodology from a regression. This procedure allows us to determine the most probable canton among those available and, therefore, the most suitable canton to stop in, depending on the type of emergency.

The term Vij contains information about the variables, which were explicitly considered in the model's specification.

$$V_{ij} = \sum_k \beta_{kj} \cdot X_{kij} \tag{2}$$

Where the term X_{kij} contains the values of the attributes or variables for each canton available in the choice situation. Each scenario shown to the experts shows the following 5 cantons after the current position of the train as the available alternatives. Each alternative j (Ai Є A) has its utility U_{ij} for each individual i. The term β_{kj} refers to the parameters, which will be estimated by the model and calibrates the perception the individuals have of the accompanying variable. In each choice scenario, the expert has to choose the canton which they feel is the most suitable to stop the train in under an emergency situation. The answers can be used to estimate the effect of each variable as a conditioning factor on the suitability for stopping and to determine the stop probability of each canton.

4. Modeling the effect of the infrastructure and other factors when deciding the stop area at an urgent evacuation

Table 3 presents the results obtained in estimating the multinomial logit train stop choice model run for the 36 cantons corresponding to the direction Valladolid-Madrid and for the case of urgent evacuation.

Table 3. Type of evacuation as a function of the accident or incident

Parameter	Coefficient	t-Test
CI	72.164	67.935
CR	0.106*EXP+18	20.801
T	-45.264	-34.767
CU	-13.376	-22.142
R	-141.707	-111.562
H	-12.018	-296.109
S	-1.701	-28.098
D	-0.324	-9.187
Log likelihood function	-37.224	

The influential variables on the choice are as follows:

- Town (CI): 0 if there is no town in the canton and 1 if there is.

- River (R): represents the presence or not of a river in the canton; 0 if there is a river and 1 if there is not.
- Cultivation (CU): represents the presence of vegetation in the canton, 0 if there is cultivation or vegetation and 1 if the land is open.
- Junction (CR): represents the presence or not of junctions with other railway lines; 0 if there are no junctions near to the canton and 1 if there are.
- Station (D): represents the distance from each canton to the nearest station. Calculating the accumulated distances from the departure station to the arrival station, the longest distance to the arrival station is when the train is leaving the departure station and this accumulated distance gets smaller as the train runs along the line. The present case analyses the accumulated distances in the direction towards Madrid. (See the final column in Table 1).
- Tunnel (T): represents the presence or not of a tunnel in the canton; 0 if there is a tunnel and 1 if there is not.
- Health Centers (S), Hospitals (H) Emergency Centers (E): represent the time from the canton to the nearest health centre, hospital or emergency centre.

The sign of the parameter indicates the marginal utility or disutility of the alternative with respect to the variable, in other words, the choice probability of the canton in question. If the sign is positive, then the associated variable increases the attractiveness of the canton. If the parameter is negative, then this attribute is undesirable under urgent evacuation conditions. The final model shows that the presence of a tunnel has a negative influence, confirming that it is not desirable to stop in the area of a tunnel, while the presence of a hospital is desirable, indicated by the negative sign of the H parameter, confirming that the shorter the distance from the canton to a hospital, the greater is the utility of that canton. The same happens in the case of the distance to the nearest health centre (S) or to the nearest station (D). The presence of a river (R) or vegetation (CU) take utility from the canton, as indicated by the sign obtained for the corresponding parameters. The existence of a nearby town (CI) and junctions with other railway lines (CR) are favorable variables when faced with an emergency stop.

Therefore, after an accident or an emergency situation occurring on a moving train, the stop canton is the one where there is a greater probability that the train will stop based on the expert criteria, in other words, the most attractive canton in terms of possessing the most suitable safety characteristics for the period after the train stops.

5. Summary and conclusions

The fundamental goal of this research is to find a method to determine the most suitable place to stop a passenger train after an emergency situation. The method presented is new and provides objective criteria backed by experience and supported by experts in the field of railway safety which can help the decision making body.

A real case has been studied (High speed line Madrid-Valladolid). Various conclusions can be drawn from the data analysis. The train stop method is simple and is based on internal and external data about the line being studied.

Furthermore, the methodology developed in this research is able to make real time predictions about the location where the train should stop depending on the request for help. If this method is added to a technical application supported by a GIS database then the best stop point could be visually obtained on a screen in case of an emergency occurring. It provides a support tool for decision making with High Speed passenger train services under emergency situations. Further steps are in this direction.

Another point supporting the introduction of this methodology are the minimal computing costs which enable that the process of deciding where to stop the train to be made in real time. Even if more detailed variables were introduced the computing cost would still be minimal.

The methodology presented in this article seeks to endow the decision making process with a human aspect derived from expert opinion to support the current technical legislation which needs to be applied in each case. The location of where to stop a train can be predicted not only from a safety point of view but also to cause minimum impact on circulation by combining the findings of this research with timetable programming systems.

This research can be used as the basis for further more precise studies on stopping distances, introducing concepts such as the load resulting from the train's occupancy (Canudas Porti & Arnedo Peña, 2005). By establishing more accurate measurements of the vehicle and line it would be possible to use evacuation times not only from the train but also to a safe location in the research. The program could be introduced on a national or regional management scale. The characteristics of the railway vehicle also need to be analyzed and considered to know the braking distances more precisely. This aspect also limits the number of cantons used in the study that are in front of the current train. Nevertheless, the method is open to decrease or increase the range of the research to cover only the canton in front of the current train or all the cantons left up to the destination station (or the end of the line).

Future research is proposed to analyze the effects of other attributes, which could act as conditioning factors in the choice of where to stop during an emergency, such as traffic or signaling. All of which are technical variables which need to be considered when determining the stop location.

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