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DECISION MAKING SYSTEM FOR STOPPING HIGH SPEED TRAINS DURING EMERGENCY SITUATIONS

Roberto Sañudo*, Jose Luis Moura, Angel Ibeas

Universidad de Cantabria, Avda Los Castros s/n, Santander, España

Abstract

The following article addresses the application of a series of stop criteria for High Speed passenger trains under emergency situations by using a multi-criteria evaluation system. The line is divided into cantons and a combination of weight assignment criteria are used depending on the local surroundings and the type of incident occurring in such a way as to indicate the suitability of stopping a High Speed train.

Multi-criteria choice is used as a function of the type of incident and the characteristics of the infrastructure to determine the best available place to stop a High Speed passenger train. This model has been applied with a geographical information system (GIS) using simple data visualisation for the position of the train; the program will also support decision taking protocols for stopping all kinds of trains under emergency situations.

The method can therefore be applied to an overall support system for decision making. The speed of the algorithm provides an almost instantaneous reply within seconds of an emergency situation occurring.

Keywords: Emergency situations, High Speed pasenger train, Decission making

* Corresponding author. Tel.: +34 942202294; fax:+34 942201703.
   E-mail address: sanudor@unican.es

1. Introduction

The High Speed train is currently the safest form of transport. The intention of this research is to further improve the safety and comfort of High Speed trains under emergency situations.

This article intends to define stop criteria for High Speed passenger trains when faced with diverse emergency situations where the train is able to stop.

As a complement to an expert decision taking system, this research aims to solve problems more quickly than a human expert can (Castillo et al., 1996). These decisions increase in importance as the response time becomes more critical. If an accident or incident occurs, the reaction and response times are important variables, which need to be considered.

The spatial factor relevant to accessibility (Canudas 2005) is a crucial element when determining the most suitable place to stop a train (Escudero 2009). Minimum distances and time scales also play an important role when deciding on evacuation routes, as do the type of emergency and any consequences it may have. All the above factors have been taken into account in designing the criteria.

The article is structured in the following way: an initial state of the art review is followed by a description of the methodology. The case study is then analysed along with some of the possible solutions, followed by a discussion around the results obtained and the pertinent conclusions drawn from this research.

2. State of the Art

The aim of this article is to establish certain objective criteria supported by experience, which will serve as support for decision makers (Pidd et al., 2003). The control centre is the location where the decision to stop a train is made, nevertheless, it is the driver who has the final decision to stop a train if an imminent danger is detected. The method developed in this research will support the decision making process during emergency situations occurring on High Speed trains, considering the cases where this will be possible and where not.

Exactness in calculation is always important, but even more so with High Speed. A train travelling at 300 km/h covers 5 Km in one minute and can stop over a distance of between 3 and 4 Km, in other words we are dealing with very short time scales and very long distances.

The control centres are able to continuously monitor the line and it is their decision whether to stop a train or not for any reason (danger signs from track blockage, derailment, people falling from the train, or objects on the line, danger on a connecting line, etc). This system will support the decision making process for High Speed trains in emergency situations.

The methodology followed uses ordering and scoring, the stopping place as a function of the physical and technical characteristics of the line and the type of emergency, as well as the type of resulting situation caused by the emergency (accident or incident).

Once each of the track characteristics have been scored, each stretch of track is given an overall score. The end goal of this method will be to include it as part of a special decision making system (Keenan 2003) to be used with High Speed passenger trains during emergency situations. Nevertheless, the method can also be applied to conventional passenger trains and goods trains by carrying out a specific study on the most influential variables in each case (Technical, physical, etc.). The possible alternatives are converted into stretches or cantons along a railway line and the variables are established as a function of the railway line data and type of emergency.

Once the relevant cantons and variables are decided on, the possible choice alternatives are studied. The process is simple: for each stretch (canton) and each type of emergency and for each resulting situation a stop utility function is established about the location of the best place to stop the train.

This article presents a method for determining where a train can be stopped when a determined type of emergency has occurred. A similar case can be found in (Cordera et al., 2009) where multi-criteria evaluation is applied to possible zones for introducing a bike lane in Cantabria (Spain).

The bibliography also provides examples of special decision making systems (Forgionne et al., 2003; Pidd et al., 2003) for emergency evacuations based on accessibility and the optimisation of routes (mainly by road) as well as

methods which used hourly train programming models where the incident has minimal repercussions on circulation through the use of new vehicles or by partially suspending the service (Adenso-Díaz et al.,2003).

This article intends to describe a method for rapidly solving the train stop decision making process for High Speed passenger trains under emergency situations. The method can then be combined with any existing train timetable programming protocol and may form part of future railway safety systems.

3. Methodology

The starting point must be to identify and evaluate the type of emergency situation. The position of the train at that moment must then be established, along with whether an urgent and rapid evacuation is required because of injuries or because of the characteristics and scope of the incident/accident.

This initial data will enable the algorithm to state where the train can be stopped as a function of the variables used and the available options. Certain accidents mean it is impossible to decide to stop the train, such as in the cases of derailment or collision, etc.

The steps involved in the proposed methodology are detailed below:

- Identification of the emergency. Type of incident or accident.

- Evaluation depending on the available data. Is it controllable or not? Is evacuation required, or not? Evaluation of consequences, etc.

- Position at the time of the emergency. The location of the train in the moment when the incident-accident occurs.

- Possible options to be considered. Depending on the range of the train, its brakes and the available cantons, the train will stop in one zone or another.

- Choice of stop location. After identifying the most suitable type of stop location and evaluating other relevant factors the most suitable location to stop the train will be chosen.

  Each of the above steps will be described in greater detail below.

3.1. Identification of the emergency

A classification of accidents is established: derailment, pantograph connection, level crossings, falling obstacles, collision, fire/explosion, decomposition of load, turnout problems (RENFE 1997). Other factors are also included, such as: signalling problems, catenary problems, engine breakdown, climatology factors, human driving error, works on the line, lack of staff/demonstrations, delays for manoeuvres , others (line blockage), (Adenso-Díaz et al., 2003).

Table 1. Type of accidents and their consequences with range of train

	Accidents/incidents	Urgent evacuation	Ordinary evacuation	No evacuation required	Consequence
1.	Derailment	X	X		STOP
2.	Pantograph connection	X	X		STOP
3.	Level crossing		X	X	VARIABLE
4.	Obstacles on line		X	X	VARIABLE
5.	Collision	X	X		STOP
6.	Fire/Explosion	X	X	X	VARIABLE
7.	Falling cargo			X	VARIABLE
8.	Turnout problems			X	VARIABLE
9.	Signalling problems		X	X	VARIABLE
10.	Catenary problems		X	X	VARIABLE
11.	Engine breakdown		X		VARIABLE
12.	Climatology factors	X	X	X	VARIABLE
13.	Human driver errors	X	X	X	VARIABLE
14.	Work on the line	X	X	X	VARIABLE
15.	Lack of staff/Demonstrations	X	X	X	VARIABLE
16.	Delays for maneuvers			X	VARIABLE
17.	Others (track ocuppations)			X	VARIABLE

In other words, the above table makes various suppositions. Accidents resulting from derailment, pantograph connection and collision are assumed to always require an evacuation and there is no possibility of stopping the train without evacuating it, whereas all the alternatives are available in typologies 13, 14 and 15.

3.2. Evaluation

The line is divided into cantons (known as 5km braking cantons), after which the following 2 kinds of data are collected:
- Internal line data: distance to stations, existence of structures (tunnels, viaducts, bridges), number of tracks, junctions.
- External line data: distances to hospitals, emergency centres, built up areas, physical characteristics of the surroundings.

The stop utility function is defined for each canton:

$$U_j = \sum_i^q V_{ji} \propto_{ji} K_j \tag{1}$$

Uj: is the canton stop function. Its highest value will indicate which canton is the most suitable for stopping the train in.

The weighting values Vji and the type of consequences are determined according to the position of the train and the evacuation required. These represent the factors about the surroundings chosen for study in each canton.

Table 2. Values of the V factors resulting from the ordering and comparison criteria by pairs according to each kind of consequence.

V Factors		Evacuation Emergency	Evacuation Normal	No Evacuation
A.	Built up area	0.12	0.13	0.15
B.	Relief	0.06	0.09	0.09
C.	Junctions	0.08	0.14	0.12
D.	Stations	0.10	0.17	0.16
E.	Number of tracks	0.06	0.15	0.12
F.	Tunnel	0.10	0.11	0.11
G.	Viaduct	0.09	0.11	0.10
H.	Emergency centres	0.19	0.07	0.08
I.	Hospitals	0.21	0.03	0.07

The α_{ji} values are the weights of the elements of each factor and they prioritise the elements within the factors (second choice Weight). They also correspond to a homogenisation of the variables which enables them to be compared. A criterion is then established to prioritise the elements of the factors (internal and external) which have already been ordered.

The data contained in each element is fundamental when determining the choice of the most suitable solution and the problem rests in their homogenisation. The analysed and scored elements are shown below.

A. Location, whether or not there is a built up area nearby.
B. Relief (flat land, hilly, water courses) and land uses.
C. Junctions with other railway lines, or crossings with other transport modes.
D. Stations (whether there is a station within or near to the canton, the distance to the nearest station).
E. Number of lines (whether the canton contains only one line or not).
F. Tunnel (is there a tunnel in the canton).
G. Viaduct (is there a viaduct or bridge in the canton).
H. Emergencies (closeness to emergency centres).
I. Hospitals (closeness to hospitals or health centres).

The Kj value represents the constraints assigned to each variable in each canton, 1 is assigned to all the cantons where there is neither a tunnel nor a viaduct as well as to those where the distance or time to hospitals and stations is lower than a given value and 0 for other cases. This represents a safety factor which is useful because it may be of no interest to stop a train in the most suitable place indicated. This factor is also useful in immediately removing a canton which although having a high utility function value is unsuitable for any other reason.
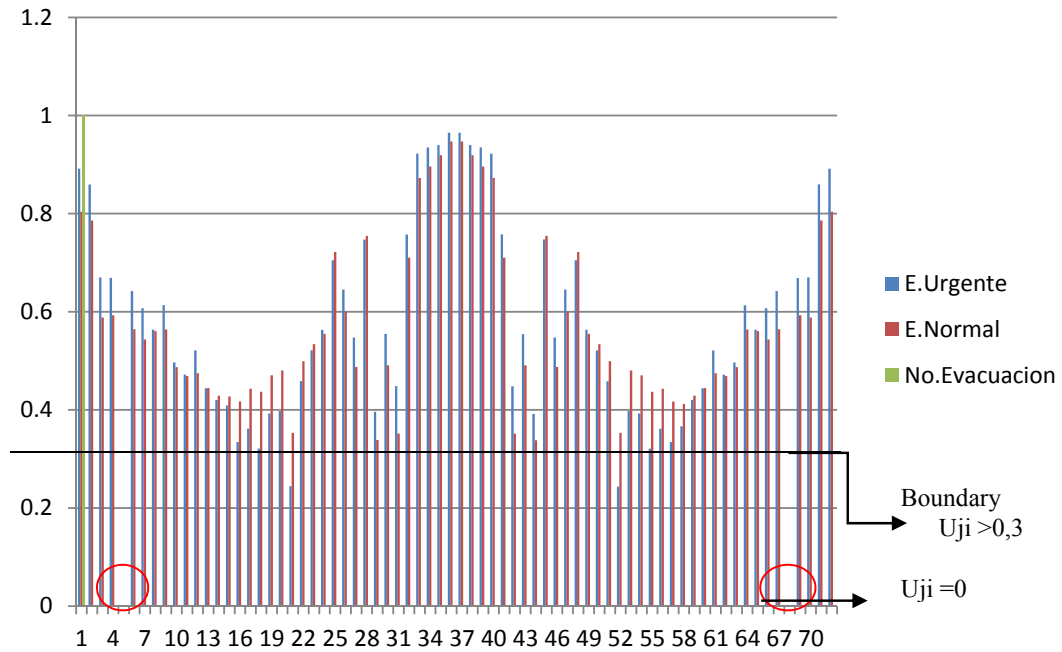
Fig. 1. Graph of the Uji Function for cantons 1 to 72. The clear symmetry of the function where canton 1 is the same as 72, coincides with the two directions of the track.

Sometimes it is possible to stop in certain locations independently of the value of the Uij function. To enable this, constraints need to be imposed on this function:

- Annul the function $U_{ji}=0$, annulling the factor $K_{ji}=0$. Therefore, $U_{ji}=0$ if $K_{ji}=0$.
- Create the value $U_{ji}=$ cte and impose inequalities to exclude train stopping zones $U_{ji} \geq$ value.

The Madrid - Valladolid high speed railway line was analysed, the line was divided into 36 cantons in each direction. The graph shown in figure 1 above demonstrates the symmetry around canton 36. Cantons 1 and 72 correspond to Madrid and 36 and 37 to Valladolid

3.3. Situation when emergency occurs

The analysis starts with the cantons located immediately after the canton containing the train in the direction of movement which is a constraint to guarantee stopping under the safest conditions possible. More or less potential stopping cantons will have to be analysed depending on the type of incident and the range that the train can still travel.

In an emergency situation the train will alert the control centre about the problem; the period from the advice time t0 to the time they order the train to stop t1 is the response time of the control centre. Once this has happened, the driver will activate the brake and the train will slow down and stop, from the activation of the brake and the train

stopping is equal to time t2. The total time from the moment the train informs the control centre about a problem to the train stopping is equal to t0+ t1+t2.

The potential stopping cantons being analysed are those located immediately after the canton containing the train in the direction of travel. This is a constraint which guarantees that the train stops under the safest possible conditions. More or fewer cantons will need to be analysed depending on the type of incident and the range of the train.

3.4. Possible options to be considered

All this information has been used to develop a Visual Basic programme to generate an application within a GIS, in which it will be possible to visualise the train's stopping zone depending on the train data, the type of accident and its potential consequences.

The user will be able to see on a screen where the train will stop depending on the following input data:

- Canton: indicates the canton containing the train when it suffers the incident.
- Type of accident: indicates the type of incident that has occurred, inevitably, there are accidents that stop the train the moment they happen.
- Type of evacuation: whether the accident or incident requires it and depending on the range of the train are determinant factors in deciding whether to stop the train.
- Number of stopping cantons: the user will decide on the number of potential stopping cantons to be analysed depending on the seriousness of the incident.

The location of the train when the incident occurs is established (current canton) and an assessment is made as to whether the train needs to be stopped or not. If the train needs to be stopped we proceed to analysing the most suitable available zone where this can best happen, the programme decides where the stop has to happen depending on the characteristics of the surroundings and the type of evacuation required.

3.5. Choice of stop location

An internal Visual Basic programme has been designed which can be visualised through a GIS.

By combining the Visual Basic programme with all the formulation and the possible results that were previously calculated with the Arcgis programme in the GIS the user can visually see the most suitable zone to stop the train through the user interface of the Arcgis.

This system allows the traffic control centre to manage the stopping of the train in an emergency situation under completely safe conditions within a relatively short time frame. An example of the working of the programme designed in this work is shown below.

The application is accessed through an icon integrated into the base programme (Arcgis-spatial information treatment programme).

A panel then appears for the required input data to be filled in: canton, type of accident, type of evacuation, number of cantons to be analysed.

The data being run and the application will indicate which canton ahead of the train will be used to stop the train in based on the type of accident suffered. To obtain more information than simply the number of the canton and its characteristics, its attributes need to be seen and this is possible using an option included in the Arcgis programme. The application has a zoom which can be used to assess the stopping area in greater detail for planning the rescue operation.
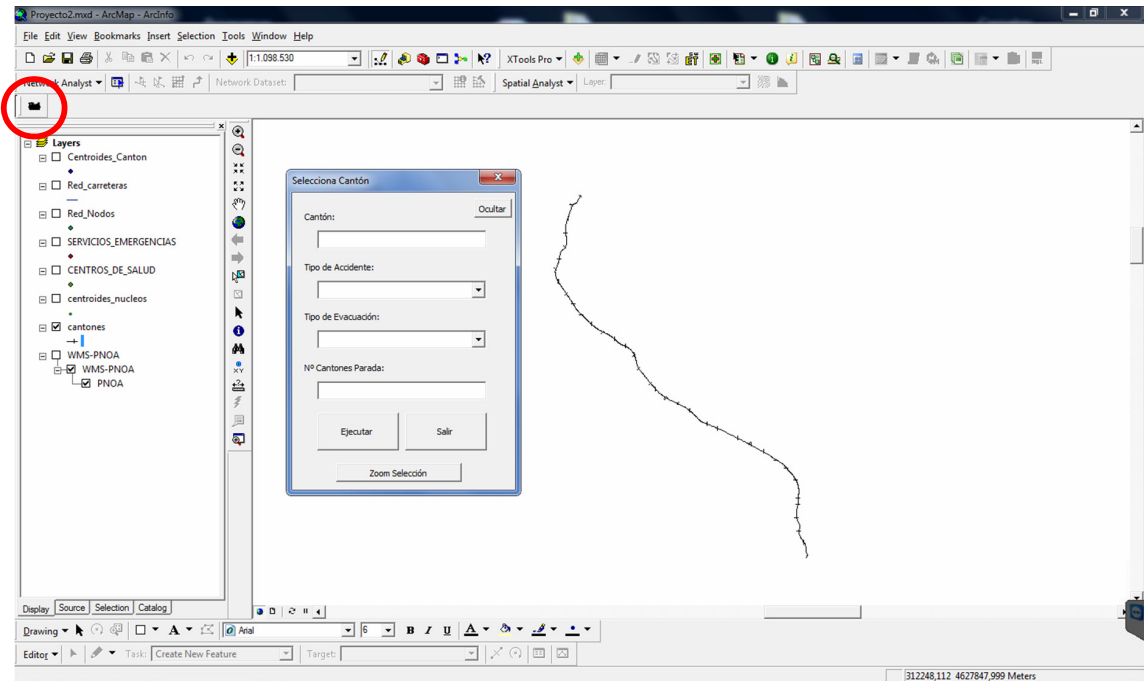
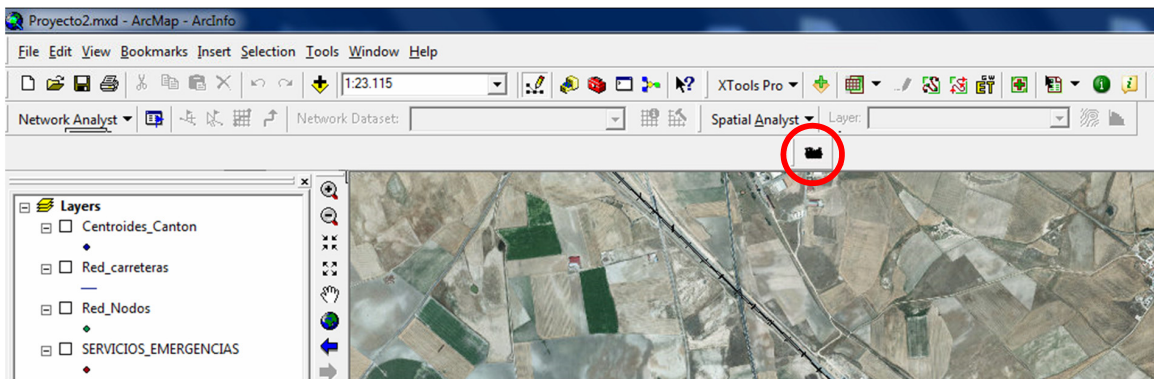Fig. 2. Working the stop choice mode: user interface.

Fig. 3. Running the application

The programme works as a user friendly and quick support system for decision making.

Combining the programme in visual basic with all the formulation and the possible results that were calculated beforehand with the GIS programme Arcgis, one can visualise the most suitable zone for stopping the train using the Arcgis user interface. This enables the traffic control centre to manage the stopping of the train during an emergency under totally safe conditions in a relatively short time frame after the occurrence of the emergency.
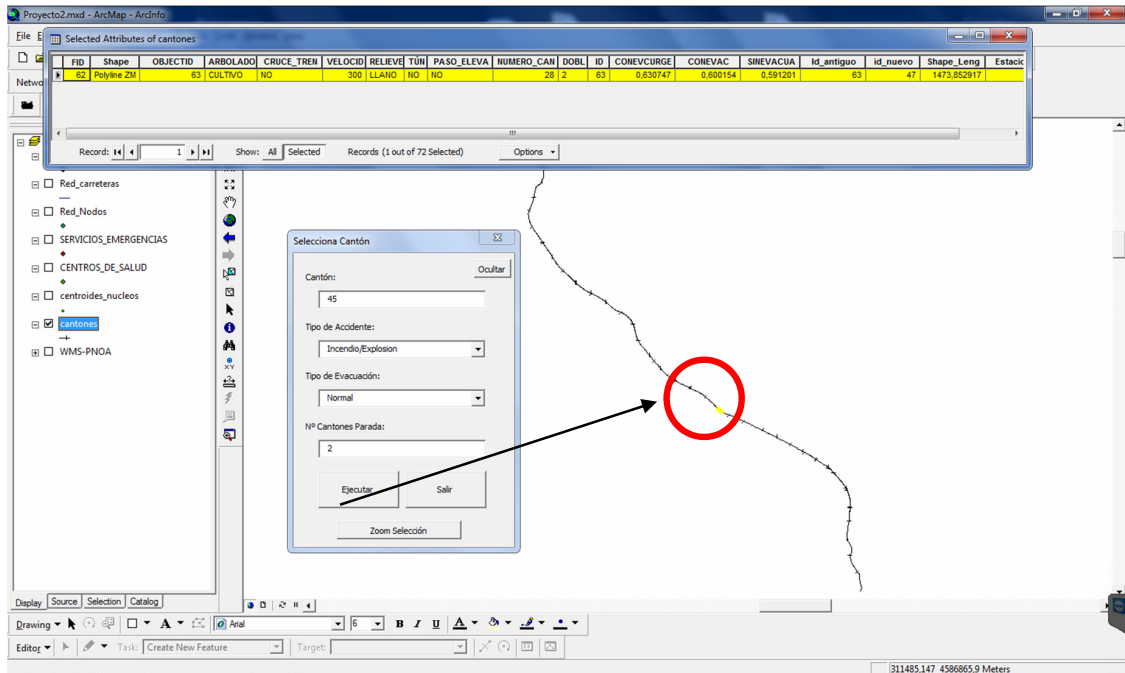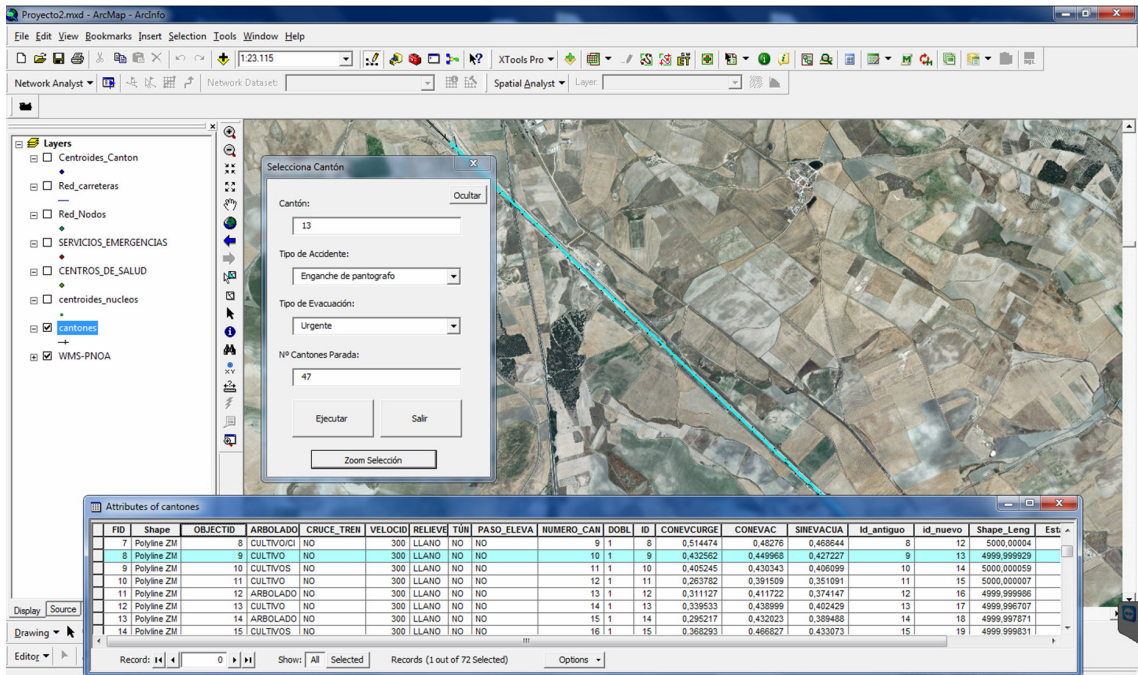
Fig. 4. Result from the data shown in the input field

Fig. 5. Result for the data used in the input field .With relief inserted.

4. Conclusions

A multi-criteria analysis (Saaty 1980) was used on a railway line divided into sections (cantons) to find the most suitable location to stop a train depending on the type of accident/incident suffered, in a very short time frame using minimum calculations supported by a regional GIS.

This method allows all evacuation protocols to be activated as quickly as possible.

The analysis performed allows the situation to be visualised and a response provided in real time with minimum calculation. The response is provided in a matter of seconds. The real case analysis was carried out on the Spanish High Speed line between Valladolid and Madrid.

The programme uses the available data to calculate the optimal location to stop a High Speed passenger train during an emergency situation. The methodology can be applied not only to High Speed networks but also to conventional railways and goods trains. In these latter cases new variables would have to be studied depending on the individual cases.

With a greater supply of geographical information and more precise typologies of accidents and incidents it would be possible to further refine the algorithm so that it provided even more precise data.

Acknowledgements

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