

Railway collision risk analysis due to obstacles

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Abstract

In the following article, the risk of a train suffering an accident by collision is analysed in conjunction with an unexpected obstacle on the track. This study is applied to high velocity railways, although this could be reflected towards any other lines. Various measures associated with the risk of accident, can be defined accordingly: the probability of being engaged in an accident, the time on risk and the critical velocity. Subsequently, the elements which alter the previous measures are analysed. These elements are related to rolling stock, to the railway infrastructure and the density of the traffic. A model is proposed to obtain the appropriate risk measures of a configuration of these elements, and to compare and evaluate the impact of different configurations. This model is applied to the case study based on data of a high velocity line in construction in Spain.

Keywords: railway collision risk, probability, stochastic process, high speed.

1 Introduction

Railway accidents can be produced due to a wide variety of causes, for instance, signalling systems failures, human errors, problems in rolling stock, collisions with obstacles on the track, sabotages, etc., or a contribution of all the above. This article is focused on a concrete type of accident, that produced by the collision of the train with unexpected obstacle on the tracks.

Although the study proposed is valid for whatever type of railway, special importance is placed on those of high velocity, wherein the distances involved in brake emergencies of the trains can be prolonged for a longer distance. The gravity of the accident also drastically augments when high velocities are considered. In these types of railways, the margins of the track usually are well protected, however, fallen obstacles (vehicles, rocks etc.) from points above the level of the track can appear in these points. For example, like in the elevated



bridges, in the entrances and exits of the tunnels, and in valleys or narrow mountain passes.

Some topics related with this kind of accidents have been discussed from different points of view in the last years: from the viewpoint of the systems of detection (EG, Jin et al.[1] or Fujita and Okano [2], from the reaction against an emergency (Bin [3]), from the general risk in the lines of high velocity ([Leighton and Dennis [4]) or the methodology of the approval of security (E1 Kousi et al.[5]). In this article the model proposed allows to evaluate the risk of accident by collision with obstacles on the track, given the characteristics of the infrastructure, the rolling stock and the traffic. This model will permit quantifying the impact of the possible strategies for the improvement of the security: installation of automatic detection devices of obstacles on the track, construction of physical retaining barriers, limitations of velocity in the conflictive areas, etc. With this information, it will be able to establish for each line some objective criteria that will permit identification and elimination of critical points, optimising the investment to achieve equipment and works of security. From another angle, the model could be used for designing the traffic, by permitting to evaluate the risk associated with each traffic stage, taking into account its density and the characteristics of the rolling stock utilised.

The elements which have an influence on the risk of accident, so they should be taken into account to evaluate the risk, are enumerated in section 2. In section 3 various measures associated with the risk of accident by collision with obstacles are defined. They will further serve to compare and evaluate risks in accidents under distinct hypothesis. Section 4 dedicates itself to present the theoretical models developed to evaluate the measures associated with the risk of accident. In section 5, results are obtained in a case study, and in section 6 conclusions are evidenced in the regards to having completed the study.

2 Characterisation of the elements determining the risk of accident caused by collision of obstacles

The elements that influence in the risk of accident by collision with obstacles on the train track are diverse, and can be divided in the one's inherent to the infrastructure, those that correspond to rolling stock and those related to the exploitation.

1. From the infrastructure:

A point of risk represents a concrete point on the track (entrance or exit of the tunnel, flyover, etc.) which is considered potentially hazardous, concerning the risk of falls of the obstacles at a point. It is characterised by:

- **Falling Rate:** is the estimated rate of appearance of obstacles in that point (average number of falls per unit of time). It is difficult to estimate, being very small and dependent from varied factors.
- **Maximum visibility:** as defined presently it is the maximum visibility that the driver of the train has at the risk point. The authentic visibility



will be a percentage of the above mentioned, depending on the weather conditions.

- **Time of automatic detection:** assuming that a automatic detector of obstacles has been installed in the point of risk, it is the time delay to reach the traffic control centre the signal informing that there is an obstacle in the given point from its fall.
- **Time of manual detection:** It is the average time that the warning of the obstacles in the way (from its fall) takes to arrive at the traffic control centre by non-automatic means. It will be an estimation.

Other elements of the infrastructure that are associated with the railroad:

- **Slopes of the railroad:** It is imperative to have the profiles of the physical slopes to calculate the time and distance when applying the emergency brake.
- **Time of communication:** It is the time that it takes the order of the emergency brake process from the traffic control centre to the train.

2. From rolling stock:

- **Mass in normal shipment:** Total of the train in normal conditions.
- **Time in reaction:** it is the time that it takes for the emergency brakes to act since the order is received in the train.
- **Maximum reach of the headlights of the train:** It is only necessary when the train circulates at right, thus reducing the visibility at this juncture.
- **Strength of braking process:** it is the curve of effort in the braking process of the train in function of the velocity of the train.
- **Air resistance:** it is the curve of air resistance of the train in function of the speed of the train.

3. From the exploitation:

- **Cinematic profiles:** speed-space and time-space profiles, defined from the origin to the destination of the train at regular spatial intervals.
- **Time of last control:** time in which the last check-up was done to find out if there was an obstacle at the point, by non-automatic means.

To make an analysis of accident risk during a temporal horizon the characteristics of composition and density of the traffic during the horizon will have to be defined as well.

3 Measures associated in respect to risk of accident

1. Risk of accident

Given a configuration of the elements described previously, it will be defined *risk of accident* as the probability that one accident take place given the present configuration.

When a set of points of risk and trains are considered, risk accident is defined as the probability that at least one accident takes place.

2. Time on risk of a train at the point of risk.



Because the risk of accident calculation assumes known the falling rate, and this rate is difficult to be estimated, another measure independent of this data, is defined:

Time on risk of one service in a point of risk is defined as the period during if an obstacle were to fall in the given point of risk, the collision of the train with the obstacle would result unavoidable.

3. *Critical velocity* of a train at a point of risk

Critical velocity of a train at a point of risk is the maximum velocity that the train could reach in the point, in such a way, supposing that there is an obstacle, the driver can sight it and brake the train to avoid the collision. In other words, it is the maximum velocity to avoid the collision without any detection in advance. It is independent from the falling rate.

4 Theoretical models

4.1 Point of risk model

Assuming that the fallen of obstacles are due to random effects, the collection of variables $\{N_t\}_{t \in T}$, where N_t represents the number of falls in a point of risk in the interval $(0, t]$, it can be modelled like a Poisson process of parameter λ , where λ is the *falling rate at the point*. With this model the number of falls in that point in the interval time $(t_1, t_2]$ follows a Poisson distribution, therefore,

$$P(\text{no fall at the point of risk in interval } (t_1, t_2]) = e^{-\lambda(t_2 - t_1)} \quad (1)$$

To model the falls as a Poisson process is reasonable because, from one aspect, they can be considered rare occurrences. From another aspect, it implies that the time between two consecutive falls follows an exponential distribution, and it does not have memory, which seems logical as a hypothesis. Moreover, the probability does not depend on the initial instant of interval only of its length (it is an stochastic process with stationary and independent increments.)

4.2 Time on risk model

This model determines the time on risk of a train in a point of risk. In this calculation, four different times intervene:

- *Time of detection*: is the minimum between the automatic and manual time of detection.
- *Time of last control*
- *Time of communication*
- *Time on risk braking*: time needed at normal circulation to cover the emergency brake distance.

To obtain the time on risk braking, emergency brake distance is computed through simulation. In the simulation model must be taken into account the



characterising elements of infrastructure and rolling stock. Also space covered in the time of reaction will be added to evaluate the named *space on risk*.

From this value the time on risk braking can be determined using the cinematic profiles of the train, calculating the time that the train runs in that space in normal circulation conditions.

From the prior value the time on risk calculation depends on the following cases:

- a) If the space on risk is less than the visibility distance

$$\mathbf{Time\ on\ risk = Time\ on\ risk\ braking}$$

- b) If the space on risk is more than the visibility distance

- b.1.) If there is a system to detect obstacles, automatic or manual,

$$\mathbf{Time\ on\ risk = Time\ on\ risk\ braking + Time\ of\ detection + Time\ of\ communication}$$

- b.2) If there is not an obstacle detection system:

$$\mathbf{Time\ on\ risk = Time\ of\ last\ control}$$

4.3 Risk of accident of a train in a point

From previous models, it is clear that no accident will be occur at a risk point if no obstacle fall happens at that point during the *time on risk*. So, from the point of risk model, the probability of this will occur is

$$P(\text{no accident at point } i) = e^{-\lambda_i \text{Timeonrisk}} \quad (2)$$

and thus, the risk of accident is

$$P(\text{accident at point } i) = 1 - e^{-\lambda_i \text{Timeonrisk}} \quad (3)$$

4.4 Critical velocity of one train at one point

To calculate the *critical velocity* is supposed the train nears the point of risk at a constant speed, increasing the speed until the first one for that the space on risk is greater than the visibility distance.

4.5 Risk of accident considering a set of points and trains

Previous models are intended to calculate the individual risk of a train accident in a point of risk. To calculate the risk of the complete route of a train or different trains, these risks have to be accumulated.

At the point of risk model increments independence has been assumed and, as a result of the security conditions, there is no flapping of intervals of time on risk at a point for different trains. Therefore, and because the probability that no accident is the probability of no accident in any point of risk by any train



considered, this probability will be the product of all the probabilities obtained independently. So, considering I points of risk and J trains

$$P(\text{NO accident with } I \text{ points and } J \text{ trains}) = \prod_{i,j} P(\text{NO accident at point } i \text{ of train } j) = \prod_{i,j} e^{-\lambda_i \text{Timeonrisk}_{ij}} = \prod_i e^{-\lambda_i \sum_j \text{Timeonrisk}_{ij}} \quad (4)$$

and subsequently the risk of accident in terms of probability will be

$$P(\text{accident with } I \text{ points and } J \text{ trains}) = 1 - \prod_{i,j} e^{-\lambda_i \text{Timeonrisk}_{ij}} = \prod_i e^{-\lambda_i \sum_j \text{Timeonrisk}_{ij}} \quad (5)$$

5 Results

To obtain the results of the model described, a high velocity line has been considered, whose length is 500 km, and 300 points of risk in each sense, corresponding to elevated places over the track and entry and exit tunnels. Lacking of historic statistics, the same falling rate has been considered in all points. The study has been developed for mixed traffic with 2 types of trains: of 350 km/h and 200 km/h maximum velocity.

Two types of studies will be presented:

- **Analysis of risk associated from the passing of one train by one point.** The influence is analysed from the distinct elements implied over the different measures defined, associated to the risk of accident in a point.
- **Calculation of the total risk of a railroad.** Assuming a determined line of traffic, the risk that an accident takes place in a temporal horizon has been calculated, for different values of the falling rate of obstacles on the track.

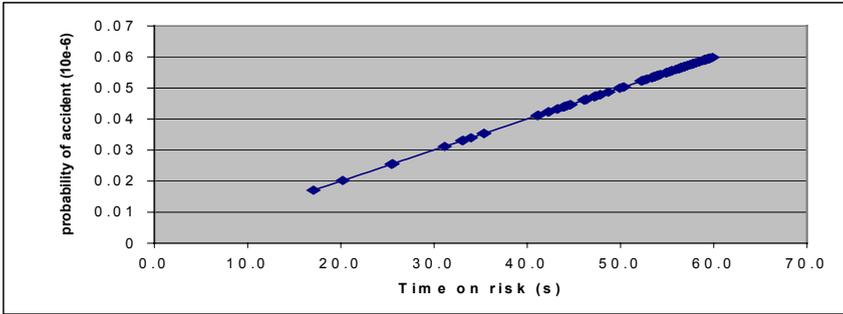
5.1 Risk associated with the passing of a train by one point

This study is focused on analysing the elements that intervene in the measures associated with the risk of accident in the passing of a train by a risk point, as well as the relation between them. The falling rate considered has been 1 obstacle/year in the whole railroad, divided likewise in all the points of risk.

5.1.1 Relation between the probability of accident and risk time

A graphic is shown below with all the times on risk obtained for a train running through the line, from least to most, and their probabilities of accident associated. A 350 type of train and detection of fallen obstacles in all possible points have been considered.





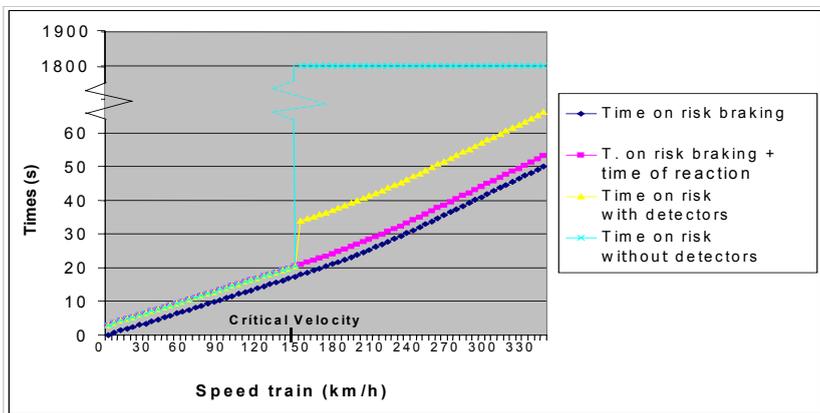
As can be observed, the relation appears to be linear, not exponential. The reason is because the falling rate in a point is very small, so the values on the exponent are very close to zero, being able to consider it lineal., as states, $1 - e^{-\lambda t} \approx \lambda t$, λt small enough.

The consequence is that the time on risk is a valid measure to compare the risk of accident in different points or under different suppositions, maintaining the proportion existing between the time on risk also for the probabilities. In such cases, the risk of accident can be obtained as the product of time on risk by the falling rates estimated.

5.1.2 Relation between the risk of accident and the velocity. Effect of the detection systems of obstacles.

For this analysis a point of risk of the railway has been selected, and the speed of the train has been varied to observe the effect regarding the time on risk.

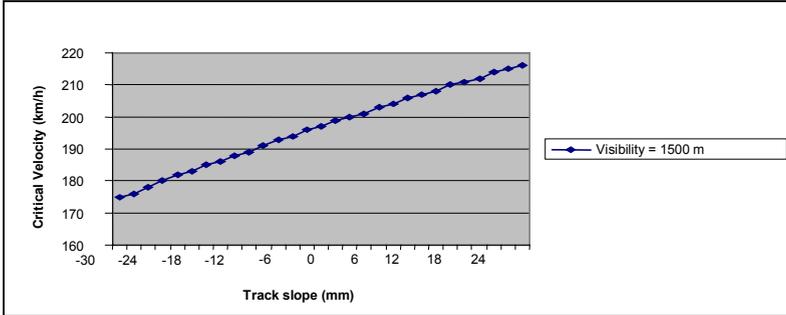
In the following graphic four functions are shown. The first graph represents the time to cover the emergency brake distance in normal speed. The second one represents the time on risk braking. (Total time on risk, if the velocity is lower than the critical velocity). The third graph is the total time on risk if there is a detection system at the point and the fourth if no type of detection exists.



Notice that when a detection system exists, time on risk follows a relationship almost linear with the velocity, with the exception of the discontinuity. This is an important outcome, showing how the risk by collision with obstacles in the track increases in lineal form with the velocity of the train.

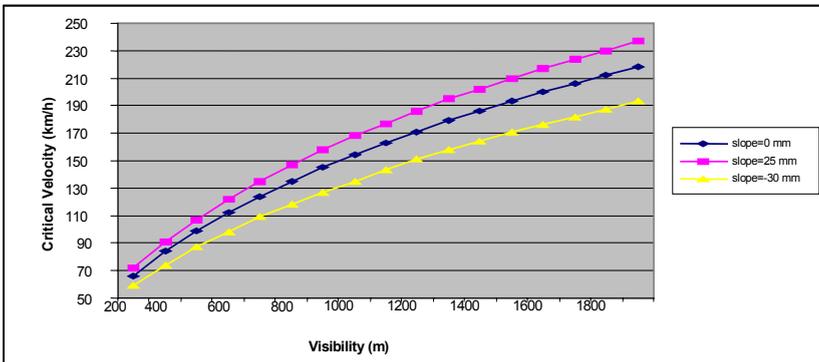
5.1.3 Factors that influence in the critical velocity: slope and visibility

In the following graph the variation of the critical velocity with the slope is shown, varying it between the minimum and maximum limits of the line. The relationship is practically lineal and of great influence (until 40 km/h)



Next graph shows the variation of the critical velocity with the visibility. The slopes given are at their minimum in the line (200m is the potential reach of the lights of the train), the void, and the maximum in line (1800m).

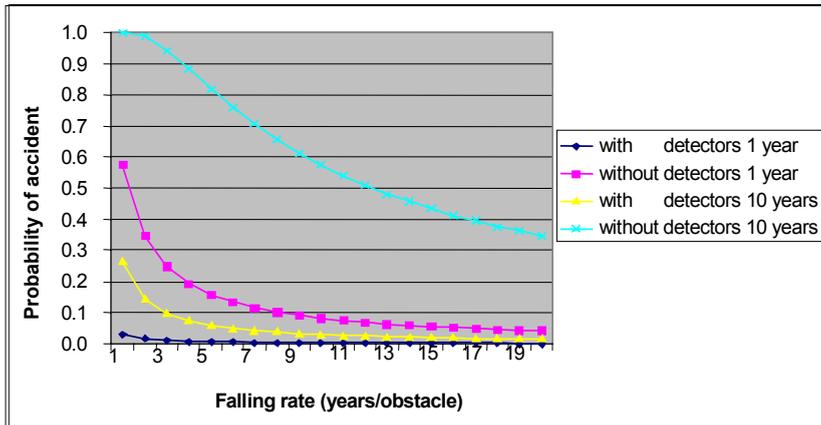
Observe that the variation of the critical velocity with the visibility is exponential, therefore these variations are smaller for high values. In addition, the values of critical velocity should be observed, the maximum is 240 km/h. This value is outweighed by the normal speed of trains of type 350, so the installation of detection systems in the whole line would be necessary, or at least in points where the presence of an obstacle cannot be detected even by manual detection (minimally travelled).



5.1.4 Calculation of total risk of accident in the line

In this analysis the model of risk of accident for a set of trains and points of risk will be used, taking into account temporal horizons of 1 and 10 years. It has been taken into consideration a daily traffic of 11 daytime trains and 3 nocturnal ones for each of the 2 types of trains considered, in both directions.

In the following graphic the results obtained are shown. The vertical axis corresponds to the risk of accident by collision with obstacles, and the horizontal the inverse of the falling rates, this is, the average number of years between two consecutive falls of obstacles in the line.



The results can be summed up in the following:

- Without detection systems installed, the risk of accident is clearly unacceptable for the whole range of rates studied. The values for 10 years would vary between 30% up to 100% and in the study for 1 year the exponential growth for rates inferior to a fall every 8 years.
- With detection systems installed the risk decreases dramatically. In the study of 10 years, in the worst case scenario (one fall per year) reaches up to 26% and in that of 1 year it remains very low, 3% in its worst possible case.

6 Conclusions

In the article the elements influencing in the risk of accident by collision with obstacles have been presented, as well as several measures associated. Models have also been presented to obtain these measurements, and from the application of these models in a case study the following conclusions have been obtained:

- In the analysis of one point and one train, the risk of accident and the time on risk are related in lineal form, serving this measurement, that does not depend on the falling rate, to compare different points and trains.
- From that analysis also it is deduced that when there is a detection system installed, the risk of accident increases in lineal form with the velocity, not



exponential, but if there is not, the risk increment quite substantially, regardless the velocity.

- The critical velocity is seen influenced by the slope lineally and by the visibility exponentially.
- The critical velocity is violated systematically for trains of high velocity, and sometimes for other trains, so detection systems are absolutely needed.

The most important conclusion is that installing detection systems implies a very high decreasing of the risk of accident. Decisions about where preferentially it should be invested will be depending on the estimation in each point of risk of the falling rates. To maintain the risk in admissible limits, the falling rate of obstacles in the line shouldn't be high. As criteria, in view of the graphs of risk, it should be maintained in the flat area of the graph.

In another way, in points of risk in which have been installed systems of detection of obstacles, it has to be taken into account that these systems can be out of service in some cases. In such a case, if the objective is to maintain the same level of risk, it will be necessary to reduce the velocity of the train until the time on risk is equal to the value when the system is in service.

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