The importance of punctuality in rail transport service: an empirical investigation on the delay determinants

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Abstract

The railway system is a fundamental component of the economy of most countries, since it has the capability to transport every day millions of passengers as well as millions of dollars' worth of goods from origin to destination. According to many empirical works and papers, rail, which produces very low CO2 emissions, is one of the most environmentally friendly and safe transportation modes. Moreover, it is appreciated for its high energy efficiency. One of the most common and frequent issue about rail transport is the concept of arrival time, that is of punctuality and delay. The aim of the paper is twofold: it firstly provides a critical literature review on delay categories as a starting point for the development of a new, easy and complete classification of delay based on the link between motivations, causes and responsibility. Secondly, applying this classification, a panel data analysis with fixed effects has been performed to understand motivation and responsibility of the delay on an important Italian interregional railway line. Moreover, the application of survival analysis is used to understand the failure time probability of a train journey and to estimate the percentage of trains that arrive to a destination.

Keywords: Punctuality, rail transport service, railway delay model.

1. Introduction

An efficient rail system is an important element for the development of the economic activities of a specific country or region. Economic exchanges, trade development, the possibility of improving communications and travel are the basis of railway development (Ponti and Beria, 2007; Beria and Grimaldi, 2017).

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Over the time the expansion of rail track has favoured an increase in the productivity of different industries and in the accessibility and competitiveness of various cities and regions with the opportunity for a face-to-face communication process for knowledge production (Kobayashi et al. 1997). As sustained by Romer (1986), knowledge is a non-rival partially excludable good that can be available for firms or individuals through an exchange process that happens crosswise the spatial networks (Batten et al. 1989). However, the use of this transport mode is often curbed by the problem of low punctuality of many trains. Thus, the concept of arrival time (Sahin 1999; D'Ariano et al. 2008), i.e. of punctuality and delay, is one of the key issues to be afforded. The improvement of rail punctuality can help to promote the modal shift from the more pollutant modes to the rail, which is one of the most environmentally friendly transportation systems (Goverde 2005; Lackhove et al., 2011). Punctuality has been defined in literature as: "The ability to achieve a safe arrival at a destination to an advertised timetable" (Glyee 1994) or "a feature consisting in that a predefined vehicle arrives, departs or passes at a predefined point at a predefined time" (Rudincki 1997). As a consequence, the total delay is given by the difference between the scheduled time and the effective time (Mattsson 2007) and it is a crucial topic in the daily operational business of any transportation company (Huisman et al., 2005). For example, the shared use of the same infrastructure by different railway services (high speed, freight transport and local service), with different origins and destinations, speeds and halting patterns, is probably the main reason of the propagation of delays throughout the network (Vromans et al., 2006; Bergantino, 2015). Moreover unreliability, and the consequent delay, happens when there are deviations from the official timetable, getting worse the customer level of service and inducing a probable modal shift (Rietveld Bruinsma and Van Vuuren, 2001; Olsson and Haugland, 2004; Freling et al., 2005).

The aims of the paper are: (i) to propose a new classification of delay based on the link between motivation, causes and responsibility, on the basis of the literature review results; (ii) applying this classification, to better understand motivation and responsibility of the delay on a specific interregional Italian line. A panel data analysis with fixed effects has been performed; the model variables represent technical elements of the train (engine, weight, rank etc.) and other features of the journey (load factor, direction, seasonality, number of stops, etc.). The main research question is which factors positively or negatively affect the performance of a train journey, in terms of punctuality (difference, in minutes, from the effective arrival time and the scheduled one).

Moreover, a survival analysis (Jardine et al., 1989; Andersson and Björklund 2011; Andersson et al., 2012; Andersson et al., 2016) has been applied for the period 2013-2016 on the same railway line, in order to understand the survival rate of the analysed trains.

The paper is structured as follows. The next section presents the rail passenger situation, the rate use and the different thresholds of delay used to identify the train performance in Italy and in other European countries. Subsequently, a literature review on punctuality and delay is provided and the major existing delay categories are identified. In section 4 a new delay classification is proposed, that is then used in the regression model described in paragraph 5. The following section describes the survival analysis by a theoretical point of view and applies it to the same Italian railway line, which has been considered in the regression model. The paper ends with some concluding remarks.

2. Delay and use of rail in Italy: a European comparison

The Italian railway network is 17,000 kilometres long: the ratio between railway network and motorway network is higher than in Spain and similar, but lower, than in France (Policicchio 2007; RFI.it 2017). Although there is a relevant number or railway lines in Italy compared to other European countries, the Italians travel by train far less than in Germany, France and the UK (Albalate et al., 2015).

According to the most recent and available data (2014, from RMMS https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en and ERADIS https://eradis.era.europa.eu/), the average value of the indicator rail kilometres per inhabitant is less than 1000 in UK, 1126 in Germany, 1359 in France and 804 in Italy (Cartmell 2016). Even if in Austria, Sweden and Denmark people travels more by train than in Italy, in other European countries trains are used less on average with respect to other transport modes (in particular, car).In recent decades, Italy has hardly invested in new railway lines to create a high-speed and/or high capacity network, with the purpose to increase the quality and quantity of rail trips, making transport flows more sustainable (Banister 2000; Giuntini 2006; Bergantino et al., 2013). This network has the undoubted advantage to promote the shift of the demand for transport from road to rail, and the introduction of new quality standards also thanks to the pressure of new competitive operators (Curtis and Low 2013; Pendolaria 2016).Although the user of short or medium distance rail transport services has different characteristics and needs than the high-speed customer, there is the need to improve the quality also of these services, in particular in terms of punctuality that is a key issue for commuting passengers (De Luca and Pagliara 2007, Beria et al., 2016). Due to the historical and geographical connotations of Italy, both high speed and "normal" railway services are fundamental components of the national rail system that involves about 21.3 million passengers every day (Relazione sulla qualità dei servizi, Trenitalia 2015) of which more than 5 million of commuters (Pendolaria 2016).As regards delay, the latest Report on the quality of Trenitalia's services (2016) indicates that the percentage of all categories of trains that had more than one hour of delay was less than 1%. Moreover, in 2015 the 91.6% of medium and long-distance trains (so called Frecciarossa, Frecciargento, Frecciabianca, InterCity and InterCity Night) and 97.9% of regional trains were on time. According to the study on the prices and quality of rail passenger services by Cartmell (2016), among the countries with large rail networks, in Germany and Italy the delays in long-distance trains are higher than in other countries. In both countries, less than 75% of the trains were punctual in 2014. However, the data on punctuality of the European railways are not perfectly comparable, because the delay threshold, in minutes, varies by the country according to the type of traffic and purchase modality. The punctuality threshold in Germany is lower than in Italy, particularly on long distance services, as shown in the table 1. In fact, the Italian railway company (Rfi.com, 2017[1]) considers on time the passenger trains that arrive at destination with a delay lower than 15 minutes for long distance services (including interregional ones) and less than 5 minutes for short (regional) distance services. As regards freight trains, the punctuality threshold is based on 30 minutes. These thresholds are frequently higher than in other European countries.

[1] RFI, that is the company of FS group which manage the railway infrastructure, calculates the punctuality threshold for thetraces purchased at least 5 working days in advancethe date of utilization.

Table 1: Delay and threshold in Europe

Country	*Regional Services*	*Long Distance Services*
Austria	More than 5 minutes	More than 5 minutes
Denmark	More than 2 minutes and 29 seconds	More than 4 minutes and 59 seconds
France	More than 5 minutes and 59 seconds	from 5 to 15 minutes due to the category of the journey
Germany	More than 5 minutes and 59 seconds	More than 5 minutes and 59 seconds
Lithuania	More than 5 minutes	More than 5 minutes
Netherlands	More than 3 minutes	More than 5 minutes
Spain	from 3 to 10 minutes due to the category of the journey	from 5 to 10 minutes due to the category of the journey
Poland	More than 5 minutes	More than 5 minutes
United Kingdom	More than 5 minutes	More than 10 minutes
Italy	More than 5 minutes	More than 15 minutes

Sources: Personal Elaboration on various sources

3. Literature review: punctuality and delay in railway transportation

3.1 Punctuality and reliability definition

In the transport sector, focusing specifically on the rail sector, punctuality is an important indicator to understand if the planned travel time is optimal. Dealing with delays is a crucial issue in the daily operational business of any public and private transportation company (Schöbel 2009).Some studies (Harris and Godward 1992; Bates et al., 2001; Cavana et al., 2007) have shown that it is a critical element that companies need to take into account for managing their service and it is a measure of the operations' reliability and performance (Veiseth et al., 2007). In fact, deviations from scheduled time reduce the level of service (Dingler et al., 2010; Nagy and Csiszár 2015; Olsson and Haugland 2004).Punctuality is a complex indicator and not only a simple parameter to be taken into account. From the railway point of view (supply side), it is useful to measure the service quality level and to understand if the infrastructure, even in bad condition, is able to guarantee the connections. From the passenger demand side, instead, punctuality is a fundamental element to plan a journey especially in the case of interchange of different transport modes (Nagy and Csiszár 2015). Landex (2008) argues that when a train is delayed, passengers are also late, and this can influence their life quality and their future transport modal choice.Carey and Carville (2003) underline that the structure and the physical organisation of a railway station and the number of people waiting at a quay for a given train are factors that potentially affect the timeliness of travel.In the literature many definitions of punctuality are available. According to Gylee (1994), punctuality is: "the ability to achieve a safe arrival at a destination to an advertised timetable". Otherwise Rudnicki (1997) defines punctuality as a measured value that is able to indicate if a given known vehicle arrives or departs at a specific point in a previously set time. Subsequently, Hansen (2001) defines the same concept as a percentage of railway journeys that arrive or depart in a specified station of a railway network no later than a specified time in minutes. Moreover, Olsson and

Haugland (2004) describe train non-punctuality as a deviation, usually negative, from the defined timetable.Veiseth et al., (2007) give a definition of punctuality similar to Hansen (2001), as the percentage of trains that arrive on time at their final destinations. However, this percentage is considered as a reductive indicator by Olsson and Haugland (2004) and by Bititci and Veiseth (2005) because some other useful data are hidden (such as the delay and the recovery time for an intermediate stop).Mattsson (2007) use a mathematical equation to define the concept of total delay based on the difference between the effective time and the minimum time scheduled. Noland and Polak (2002) focus their attention on travel time variability that is a measurement of the uncertainty of trip journey times in transportation, and introduce in this concept also delays, early arrivals and cancellations. According to Nystrom (2005), punctuality is an agreement between passengers and the company, one of the most important components of the measured quality of the service. Passengers put high expectations on the reliability of train schedule, which strongly influences the positive perception of the travel (Salkonen and Paavilainen 2010). Harris and Godward (1992) shows that the reliability of the arrival time is often more important than the train rapidity.The shared use of the same infrastructure by different railway services (high speed, regional, interregional and local service, long haul and freight at the same moment), with different origins and destinations, different speeds, and different halting patterns, is probably the main reason for the propagation of delays throughout the network (Vromans et al., 2006). However, the specific delay volume relationship is dependent on the traffic mix on a route (Dingler et al., 2009; Krueger 1999; Bronzini and Clarke 1985). Different train types have different operating characteristics influencing the total delay that a train experience.Heterogeneity in these train characteristics causes additional conflicts, increasing delays (Dingler et al., 2009; Pachl 2002; Leaflet 2005; Abril et al., 2008).

3.2 Categorization of the delay

In literature there are some authors sustaining that unreliability, and the consequent delay, happens when there are deviations from the official timetable (Bruinsma Rietveld and Van Vuuren 1999; Rietveld Bruinsma and Van Vuuren 2001). Unscheduled delays can be caused by numerous events including: mechanical failures, malfunctioning infrastructure, weather conditions, excessive boarding times of passengers, accidents at highway-railroad grade crossings, etc. (Vromans et al., 2006; Carey 1999).Delays may be divided into different categories, but the terminology differs between different authors. Regarding the size of delays, Gylee (1994) defines primary delays as the delays with the greatest impact, while secondary delays as delays that are a consequence of the primary ones. In this last case, the delay of a train spread to the others that are following, causing a phenomenon that is called “cascading effect” by Dingler et al., (2010).The terms primary and secondary delays are used differently in Norway: according to Veiseth et al. (2007), secondary delays indicate the delays caused by other delayed trains, while primary delays are caused directly by the train, not considering the influence of the other ones. Gibson et al., (2002) instead call exogenous delays the primary delays of Glyee (1994) and reactionary delays the secondary delays defined by Veiseth et al. (2007), but with more emphasis on the interaction between different train operators. Carey (1999) underlines that there is a difference between exogenous delays and knock-on delays. The first ones are due to events such as failure of equipment or infrastructure, delays in passengers boarding or alighting and they are equivalent to the concept of secondary delays developed by Glyee (1994). The second ones are directly related to a failure of the train.

Higgins et al. (1995) classify the delay, combining different causes at the same moment. They identify three categories of delay:

- Track related delay: it occurs when a train have a slowdown caused by track problems or a sudden and unexpected stop (e.g. infrastructural problems).
- Train dependent delay: caused when a train is forced to slowdown in a line section for reasons other than track problems (e.g. locomotive failure).
- Terminal/scheduled stop delay: delay that happen in a scheduled stop and is related to loading/unloading, train connections, fuelling and crew problems.

Müller-Hannemann and Schnee (2009) focus their attention on the importance for passengers, but also for railway companies, to have a real-time information system that can up-to-date train status information and provide to a user valid timetable information in the presence of disturbances. They decide to classify the delay, according to the different possible motivations: disruptions in the operational flows, accidents, malfunctioning or damaged equipment, construction work, repair work, and extreme weather conditions like snow and ice, floods, and landslides. In their analysis, they focus on the concept of real time information. The usefulness of immediate information is crucial for the passenger who is able to find alternatives to reach the destination. For example, in Germany, an online system manages every day 6 million of forecast messages about timetable changes and also the latest prediction of the current situation.

Another classification is provided by Nelson and O'Neill (2000). By analysing the U.S. railway lines in the period 1998-2000, they categorize the reasons of delay linked to its nature, identifying (i) engineering causes (referred to tracks, structures, stations, signal and communication instruments), (ii) mechanical causes about the rolling stock and (iii) transportation causes regarding decisions of the railway manager, dispatching procedure. In addition, they define other specific factors related to delay that are construction work, problems related to passengers, extraordinary circumstances and cascade delays deriving from the circulation of freight trains.Mechanical delay is a component that is common for any transport operators and is representative of a failure of a train component. Nelson and O'Neill (2000) found that the major causes in this case are an engine failure, braking system and coach components problems. Moreover, they highlight that 13% of the total delay is due to extraordinary events, such as weather conditions, vandalisms problems with vehicles at crossing lines and police interventions. The authors argue that passengers are not directly responsible for most of the delays, but they are a contributing factor. For example, a train could be delayed by the presence of an incremental extraordinary number of passengers deriving from a train suppression or by the waiting for delayed passengers by the train crew. The influence of the train stops in a railway station on the delay was also studied in deep by Harris (2015), Harris Mjøsund and Haugland (2013) and Harris and Andersson (2007). Analysing the dwell time, that is the whole process of train stop in station, they have made some measurement about the duration of delays in station stops that concern the entire process of boarding and alighting passengers.

A summary of the different types of delay classification provided by the literature can be found in Table 2.

Table 2: Summary of the literature review on delay classification

Delay Classification	*Scientific papers*
Primary and secondary delay	Glyee 1994
Cascade delay	Dingler et al., 2010
Exogenous and reactionary delays	Gibson et al., 2002
Exogenous delays and knock-on delays	Carey 1999
Track related, dependent and terminal stop delays	Higgins et al., 1995
Motivations of delay	Müller-Hannemann and Schnee 2009
Engineering, mechanical, transportation and other extraordinary causes	Nelson and O'Neil 2000
Dwell time	Harris 2015; Harris et al., 2013; Harris and Andersson 2007

3.3 Other literature findings related to delay and punctuality

Olsson and Haugland (2004), using data on Norwegian railway and the Pearson indicator, found a negative correlation between punctuality and the load factor of local trains. In fact, when the load factor is high in peak hours or days there is less punctuality, while in the non-working days and in non-commuting hours the punctuality is better. They analyse also the relation between punctuality and cancelled trains for the Oslo area, finding a positive correlation. In fact, given a certain railway infrastructure capacity, possible traffic problems are due to broken trains on the line (Burdett and Kozan 2006).Infrastructure capacity, in terms of number of trains on a specific line in a predetermined time, is one of the elements that can influence a journey and its possible delay. According to some authors (Dingler et al., 2009; Pachl 2002; Leaflet 2005; Abril et al., 2005), the relationship between performance and infrastructure capacity is negative: as the number of trains increases, the average delay rises, worsening the performance. This relationship is clearly affected by the number of the tracks available on a specific line. Moreover, it is possible to have adjunctive delays in crossing times in a railway station with interchange binary located along a single-track line; in that case, the delay regards not only the train itself but also all the trains traveling along the line in a specific moment.A possible solution to compensate (small) delays is represented by the recovery time. It is a procedure that add supplementary minutes to the total running. The recovery time is decided by the rail companies and differs according to the geographical location or country. Pachl (2002) distinguishes between regular and special recovery time: the first one indicates the supplementary time usually added to running time (as a percentage), while the second one is introduced when there are speed restrictions due to maintenance work (on track, line, powerline, signal, informatics components) or track malfunctions or problematic weather conditions. According to Beyene (2012) and Kroon et al. (2014), since a temporary speed reduction can cause delay that the train is not able to make up during its journey, there is the need to reschedule the timetable on the lines that are involved in this reduction; otherwise a delay is caused. Moreover, the eventual deceleration zones that can be required by a speed reduction could cause a supplementary delay. Both speed limitations and the unavailability of a sufficient number of platforms for all the trains are conditions that can influence the dwell time and can raise the time for boarding and alighting passengers. In the case of unavailable platforms or maintenance work, the role of the circulation manager is very important, in reprogramming the traffic, using the computer systems. He has to apply operational priority rules,taking two important decisions of delay management: the “wait-depart decisions” and the “priority decisions”. The first one is about the choice to maintain or not a connection in case of delay, while the second one concerns the order in which a certain train is allowed to pass on a specific track (Dollevoet et. Al., 2014). In other words, the normal scheduling timetable should be modified giving priority to the most important trains, according to the commercial agreements. These delay management decisions should be taken also in the case of limited capacity of the tracks, as studied by Ginkel and Schöbel(2007) and Schachtebeck and Schöbel (2010). In fact, if two or more trains use the same piece of infrastructure (single track or double track), a priority rule should be given to one of them.

4. New classification proposal

As underlined by the literature review, there is not a common view in defining and classifying the different types and determinants of the train delay. For this motivation the following paragraph is dedicate to a systematic organization of the concept of arrival delay with a classification that takes some insights from some of the works mentioned above but focuses on the delay causes and its responsibility. This new classification will be used into a regression model presented in the next section.

Five macro causes of the delay have been identified, as represented in Table 3.

As regards the first one, the concept of delay due to circulation causes is directly linked to the concept of secondary delay expressed by Olsson and Haugland (2004) and the concept of exogenous delay described by Gibson in 2003. In this case the delay of the train is due to a delay of a preceding train. For example, the train B which follows the train A is forced to stand still outside the station, because the train A uses more time than planned for the boarding and alighting operations.

Table 3: Classification of different delay causes.

Causes of delay
Circulation problems
Train Failure
Infrastructure Failure
Preparation Delay
External Delay

Source: Personal elaboration

The second cause of delay is the train failure: as for other types of vehicles it is possible that a train has a failure and is unable to resume his march (or it takes some time to be repaired on site). This type of failure can occur in the station of departure or during the journey. The possible causes may be represented by a failure of the locomotive, problems with a door of a wagon or a malfunction of some train components.

As regards the third cause, it is possible that the railway infrastructure has mechanical breakdowns (switches, tracks, power lines). This type of failure affects indirectly a train, that has to wait for a despatch order to continue the planned journey. The preparation delay occurs when the trains (engine and/or coaches) are not ready at the starting station. The motivation is related to problems about the availability of the effective material due to failure or absence of the corresponding train, if the material does not arrive from the depot. It is possible that the train is delayed due to failure of the track or the electric line, but in this case is classified as a failure of the infrastructure. The last delay category refers to the external causes, as explained by Nelson and O'Neill in 2000. For this kind of situations (e.g.: intervention of law enforcement, strikes, seismic and weather events, accidents not attributable to railway operators) the role of the railway operator is secondary, but it is important to classify and to analyze this typology to understand its incidence on the performance of a railway journey.

Each of these macro causes is linked to the identification of the responsibility source (excluding the external delay). The model that will be briefly presented in the next section relates to Italian reality, where there are two organisations responsible for the delay:

- RFI, that was established in July 2001 as the 'Infrastructure Company' of the State Railways Group in response to the Community Directive transposed by the Italian Government on the separation between the network operator and the transport services provider; it is responsible for delays due to circulation problems and infrastructure failure.
- Trenitalia S.p.A., that is a 100% owned subsidiary of State Railways, and is the leading Italian company for the management of both rail and passenger freight; it has responsibility for train failure and departure delay.

On the lines where other rail companies compete with Trenitalia, such as Italo-NTV firm, they can be also responsible for the second and fourth types of delay.

Moreover, in addition to above presented macro causes, in the regression model the concept of *physiological delay* has been included. This is a variable that has been introduced to check when there is a delay but there is not a precise motivation and refers to all the mini-causes that may occur during a trip, such as a temporary failure at a door or a slowdown due to previous trains, that are resolved quickly. This last classification is relevant for the model because can allow us to classify also minor delays that are not included in the above presented classification. In our case the physiological delay counts all the delays between 5 to 9 minutes, but it is possible to apply with different limits to another model. It is important to remark that in this model the delay is associated to a specific cause only when a railway journey has more than 9' of delay at the arrival point. This is due to the availability of our data; the rail operator has not provided the motivation for delay lower than 10 minutes. This model is adaptable to other realities with a variation of the range of the performance (related to the concept of delay of the rail operator of a specific country).

5 Regression model

5.1 Description of the model

The aim of the model is the validation of the proposed classification of delay and subsequently the analysis of the value and weight of the different delay determinants from a statistical point, using panel data. The regression model takes inspiration from the study provided by Harris and Godward (1992), who applies a similar kind of analysis to verify which factors would affect the delay of a generic train journey using UK data of the late 80'. They found that distance covered, and train length were statistically significant in determining punctuality. For them it would be realistic to expect the increase in delay to be proportionate to the route length.

The model here presented is applied to a well-defined sample of railway journeys in working days commuting hours (from 6.00 am to 9.00 am and from 16.00 pm to 20.00 pm) in the period 2013-2016. The data, which have been collected from the official web site www.viaggiatreno.it, in addition to the information provided by Trenitalia Long-Haul refer to 16 trains along the Milan-Genoa line (a total of 15,600 observations). The data concern the characteristics of the line, the trip and the train, considering also its performance in terms of time.

The normality of the performance data is confirmed and sustained by the analysis made in previous papers (Goverde et al., 2001; Murali et al., 2010).

The model that is used in this paper is a panel data with fixed effect: a statistical model where the parameters are fixed or non-random quantities, and the single observations about n entities or individuals, or cross-sectional observations are described for two or more moments over time (day, months, years) (Hsiao, 2014).

In panel data, in which longitudinal observations for the same elements, for a fixed effect model exist, the dependent variable should be measured for each individual on at least two occasions and those measurements could be comparable. The term fixed effects estimator refers to an estimator for the coefficients in the regression model including those fixed effects (Allison, 2005; 2009).

Table 4 presents all the variables that are included in the complete model, specifying the typology and the related literature.

Table 4: Regression variables.

Variables		*References*	*Format*
Performance	This variable represents the final arrival time of the journey measured in minutes.	Harris and Goodward, 1992; Harris, 2007; Harris et al., 2013; Harris et al., 2015	Numerical, logarithm of the performance
Causes of delay	Thess variable are related to the motivation of the delay. There is a variables per categories	Abril et al., 2005; Burdett and Kozan, 2006; Landex, 2008; Gibson et al., 2002; Olsson and Haugland, 2004	binary-5 categories
ID_Rail	Numerical		
Model of locomotive	From official Trenitalia Data it was possible to derive the real engine for each train. The 3 locomotives are: e464, e444, e402	Harris and Goodward, 1992; Trenitalia Libro composizioni servizi universali 2013-2016	binary-3 categories
Weight-Weight with brake-Rank	This Variable represent the weight of the train	Harris and Godward, 1992; Trenitalia Libro composizioni	Features of the journey (numerical and binary)

		servizi universali 2013-2016	
Load Factor	This variable represents the estimated load factor for each journey. The estimation is from Trenitalia	Olsson and Haugland, 2004; Alwadood et al. 2012; Harris 2007	Percentage
Costs	This Variable is related to the cost of a single trip in standard second Class.	Bergantino et al., 2013	numerical
Number of_Stops	Number of stops per journey per train	Vromans et al., 2006; Harris 2007; Harris et al., 2013; Harris et al., 2015	numerical
Travel Time	Expressed in minutes it is related to the planned travel time (official Trenitalia Timetable)	Harris and Godward 1992; Carey 1999; Bergantino et al., 2013;	numerical
Direction	This variable is about the effective relation of the journey (Genoa-Milan or Milan-Genoa)	Harris and Goodward 1992; Olsson and Haugland 2004	binary
Morning_Evening	This variable is about the hour of the trip (Morning or Evening)	Olsson and Haugland 2004; Skjæret 2002	binary
Ownership	This variable represents the ownership of the train (Thello, Trenitalia, Trenitalia DPR)	Bentivogli and Panicara 2011	binary-3 categories
Season	The season of the year related to the journey considered	Dobney et al., 2009; Olsson and Haugland 2004	binary-4 categories
Day	The day related to the journey (From Monday to Friday)	Dobney et al., 2009; Olsson and Haugland, 2004	binary-5 categories
year-Date			Numerical
Speed Restriction	The variable assumes value 1 if there is a speed restriction on the track. This variable is unique for all the track, so assume the same value with 1 or more speed restriction	Beyene, 2012; Landex, 2008; Olsson and Haugland, 2004	Binary- 2 categories
Weather Conditions	The variable assumes value 1 if there is a weather alert.	Dobney et al., 2009; Huisman and Boucherie, 2001; Mattsson, 2007	Binary- 2 categories

Source: Personal elaboration

5.2 Regression results

The results of the regression (see Table 5) confirm that all the causes of delay, that are directly related to the logarithm of the performance, are statistically significant in relation with the train performance (with a p value <0.001). According to the coefficients, external causes (such as floods, suicides, fires, accidents at level) are the typology of delay that affect more the performance of the train, followed by train failure, and, with a similar coefficient departure delay and infrastructure failure (electric line, rails, level passes). However, since the coefficients of these variables vary in a small range (1.20-1.15), the impact of these types of motivation on delay is similar. The circulation problems influence on delay, indeed, is smaller. In fact, even if the circulation conflict occurs more frequently than the other causes, it causes minor disadvantages in terms of minutes of delay. The last cause that is represented by physiological delay has, logically, the smaller coefficient of the classification. This is due to the fact that, as explained above, in this category there are only delays from 5 to 9 minutes.

Table 5: Results of regression analysis with all the data (model 1)

Variable	*Coefficient*	*P-value*	*Literature*
Constant	-12.6416	0.055 *	
Circulation	0.82912	0.00 ***	Verified
Train_failure	1.16354	0.00 ***	Verified
Infrastructure_failure	1.15508	0.00 ***	Verified
Preparation delay	1.15063	0.00 ***	Verified
External causes	1.20505	0.00 ***	Verified
Physiological delay	0.50107	0.00 ***	Verified
Weight_Brake	-1.12	0.01 ***	Not in literature
Load_Factor	0.49	0.00 ***	Verified
Costs	0.02	0.12 **	Not significant in this model
Travel_time	-0.03	0.00 ***	Verified
Morning or Evening	0.05	0.17 *	Not significant
Winter	-0.06	0.00 ***	In contrast with literature
Summer	-0.06	0.00 ***	Verified
Monday	0.03	0.02 **	Verified
Tuesday	0.03	0.16	Not Significant
Wednesday	0.02	0.19	Not significant
Friday	0.04	0.006 ***	Verified
Speed Restriction	0.077	0.09 **	Verified
Weather conditions	0.071	0.07 **	Verified
Additional information			

Mean Performance	0.45
RMS Performance	0.60
R^2 LSDV	0.73
R^2 within	0.67
Durbin-Watson	1.84

Source: Personal elaboration using Gretl (http://gretl.sourceforge.net/). Note: the variables not statistically significant and not relevant for the analysis are not in the table

As regards the other determinants, confirming the findings of Olsson and Haugland (2004), Alwadood et al. (2012) and Harris (2007), high load factor increases delay, negatively influencing the train performance; in fact, the coefficient is statistically significant.There is an inverse relationship between total travel time, which is dependent on the trip distance, and delay. The data show that the regional trains have a lower average delay compared to long-hauls trains with longer scheduled travel time.

The costs and morning-evening variables (MOR-EV, that indicates if the journey is done in the morning or in the evening) are not significant in terms of p-value. As regards winter season variable, the model results are in contrast with the findings of Olsson and Haugland (2004), who sustain that the delay increases in winter. Probably this is due to the characteristics of the line analysed and the weather conditions of the regions. In summer season indeed the delay decreases, although this is not supported by the literature.As claimed by Dobney et al. (2009) and Olsson and Haugland (2004), in the initial and the ending working days of a week, Monday and Friday, the delay results greater.Finally, the regression shows that both speed restrictions and weather conditions negatively affect train performance, confirming the findings of Beyene (2012) for the first variable and of Dobney et al. (2009), Huisman and Boucherie (2001), Mattsson (2007) for the second one. In addition, other restricted models were developed, by dividing the data into different categories, according to the direction of the train (from North to South or viceversa) and to the departure time (morning or afternoon). The following table shows the resulting coefficients.

Table 6: Results of restricted models and comparison with model 1 (coefficients value)

Variable	*Model 1: all data*	*Model 2: North-South direction*	*Model 3: South- North direction*	*Model 4: Departure time in afternoon*	*Model 5: Departure time in morning*
const	0.11 (***)	0.16 (***)	0.070 (***)	0.20 (***)	0.03 (***)
Circulation	0.83 (***)	0.78 (***)	0.88 (***)	0.78 (***)	0.73 (***)
Train_failure	1.16 (***)	1.10 (***)	1.22 (***)	1.11 (***)	0.82 (***)
Infrastructure_failure	1.15 (***)	1.14 (***)	1.17 (***)	1.06 (***)	0.91 (***)
Preparation delay	1.15 (***)	1.14 (***)	1.15(***)	1.13 (***)	0.89 (***)
External causes	1.21 (***)	1.17 (***)	1.24 (***)	1.13 (***)	0.87 (***)

Physiological delay	0.50 (***)	0.45 (***)	0.55 (***)	0.42 (***)	0.83 (***)
R^2	0.73	0.67	0.67	0.67	0.88

Source: Personal elaboration using Gretl (http://gretl.sourceforge.net/).

It is possible to observe that there are very small differences between the general model and the models considering only one direction. The results of model 4 and 5 are much more interesting: in the morning the variables infrastructure failure and departure delay are more relevant than the external causes variable and the other causes. The external causes are more important in afternoon trips. The weight of the physiological delay is higher in the morning than in the other cases.The R square is similar for the first three sub-models while it is much higher for the morning trips model.

6 Survival Analysis

6.1 Definition of survival analysis and censoring

The survival analysis is a statistical method to analyse the expected duration of time until a specific event happens. It may be applied to different issues, for example in the epidemiological area, the event of interest may be the death of a patient or the relapse following a disease or the response of a patient to a specific treatment. In general, in the survival analysis literature, death or failure, is considered the "event of interest". It is also called reliability analysis in engineering, duration analysis in economics, and event history analysis in sociology (Miller. 2011; Kleinbaum and Klein, 2010; Cleves, 2008).

The first step in a survival analysis is the calculation of "survival time", as the difference between the time to event occurred and the time of entry into the study of a statistical unit and it is typically a positive number (Despa, 2010).

According to the general theory and concepts of survival analysis and model estimation (Kiefer 1988; Lancaster 1990; Klein and Moeschberger, 2005), it is possible to underline that:

- Survival functions generate a hazard function for a consumer i, that describes the probability of defeat at time t, that is indicated as hi(t).
- The hazard function can be transformed into a survival function, which represents the probability Si (t) that a consumer survives at time t conditioned to the fact that it is "alive" at t-1 time, that is Si (t) = (Si (t-1) x 1-hi (t)), with Si (1) =1
- S(t) is constant in the time interval between two events. S(t) is a step function that changes its value only if the event happens.
- Time to event: The time between the subject's entry into the study until a particular "outcome".

In this technique, some units of analysis are censured, i.e. removed from the observation before failure, if for a certain period are no information, or when they leave the study, or if the study ends before the outcome of interest is revealed. They are counted as "alive" for the time they were followed in the study. Furthermore, it is important to remember that dropouts are related to outcomes and treatment and they can distort the results.

There are two different types of censoring: left and right. Left censoring occurs when an observation is below a certain value, while right censoring when it is above a certain value, but in both cases the exact value in unknown.

Examples of censored observations are (Klein and Moeschberger, 2005):

- end of study
- inability to follow the subject
- the minimum time t until a subject "survived".

There are several fields in which it is possible to use and analyze data with this technique (health, mechanical, railway). It is important to underline that the data distribution is not normal but exponential, Weibull and log normal distribution, as described in Table 6.

Table 7: Survival Analysis Distribution.

Distribution	*S(t) Survival function*
Exponential distribution	$e^{-\lambda t}$
Weibull distribution	$e^{-\lambda t^{\gamma}}$
Log normal distribution	$1-\phi\left(\frac{\ln(t)-\mu}{\sigma}\right)$

Sources: Miller, 2011; Carlin and Louis, 1997; Cox and Oakes, 1984. Note: ϕ is the cumulative function of the normaldistribution.

6.2 Applications of the survival analysis to the railway sector

To the best of our knowledge, in literature only few applications of the survival analysis to the railway field can be found. The aims of these applications are very different than those of our analysis, because they do not concern the rail delay issue.

Jardine et al., (1989) used survival analysis to determine the risk of failure of diesel locomotives in Canada within the maintenance-related repair cost process. In their paper, they have decided to concentrate their attention on checking the Weibull form of the hazard function. They apply the failure time concept to the components of train equipment which have a well-defined point of failure after a length of time. Moreover, they consider some censored data that are determined when the engine has a motor change for another reason (e.g. a scheduled overhaul), or when “failure” has still not occurred before the endof the observation period.Grube-Carvers and Patterson (2015) use survival analysis to test the relationship between urban rapid rail transit and the beginning of gentrification in the three largest cities of Canada.More recently, Andersson et al., (2016) used survival analysis to estimate the cost of renewal of railway tracks. They used a sample of censored data containing nearly 1,300 observations on the Swedish main railway lines. They use a Weibull distribution to understand the failure time and develop a regression models to estimate the deterioration elasticities for total tonnage as well as for passenger and freight tonnages separately.

6.3 Application of survival analysis to Milan-Genoa railway line

The survival analysis has been applied to 15,684 train data relating to the Milano-Genoa line (equally divided in both directions) in the period 2013-2016 only in working days. The failure event is represented by the suppression of the train, that consequently does not arrive at the destination. The data censored to the right is represented by trains that did not have the cancellation, because they have not final destination in Genoa; in fact, there is a number of journeys that finish in other destinations such as Ventimiglia/Nice Ville (West) or La Spezia/Livorno (East). It is important to underline that the right censoring is not present in the South-North direction since all the trains have their final destination in central Milan.The objective of this analysis is to test the data and verified the results with the declared percentage of the quality reports produced in the same years by Trenitalia ("Relazioni per la qualità del servizio di Trenitalia", 2013, 2014, 2015, 2016). In these documents there are the data of trains that arrive to a destination and the percentage of cancellations. The spatial survival analysis (Ibrahim et al., 2005; Grube-Cavers and Patterson, 2015) can be very useful to check if there are any points (e.g. climbs, mountains) that can cause train failure. This analysis is useful also from a forecast point of view as it is possible, through estimates, to hypothesize what percentage of trains will arrive at their destination. Due to the data it is possible to understand the exact position of the train when there is the event (suppression) from a temporal and geographical point of view. Although this sample is not representative of the entire national railway system, the results of the analysis is even confirmed by the data provided by Trenitalia in its quality reports. In fact, as shown by Figure 1, in all the models the survival rate is close to 99% and Trenitalia declare that more than the 98% of the analysed trains arrive at destination. It should be pointed out therefore that the arrival is not related to the average train delay.Stata software was used to perform this analysis with the STS function (Cleves, 2008; Lambert and Royston, 2009).

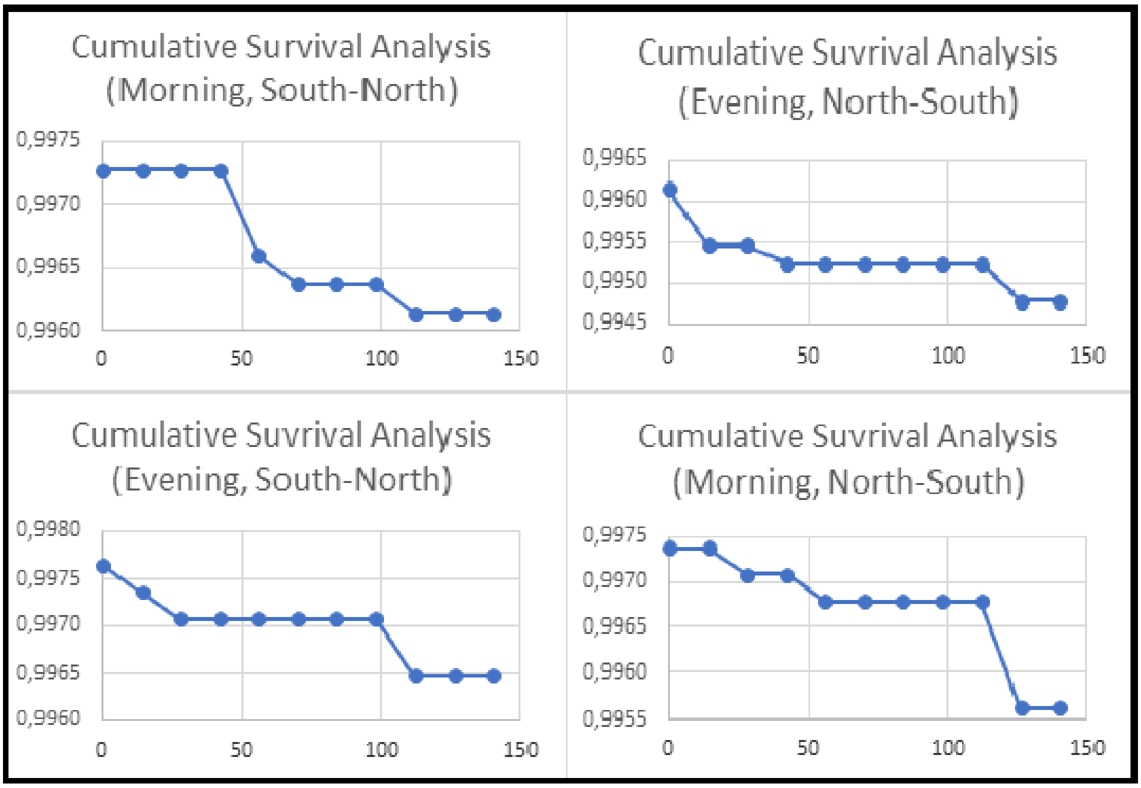

Figure 1: Survival Analysis 2013-2016.
Source: Personal Elaboration using Stata and Excel on official data from Viaggiatreno.com

7. Conclusions

One of the most challenging goal of nowadays is to make more sustainable the growing passengers flows, rebalancing the modal shift in favour of train, that is less pollutant and energy consuming than car. Since the value of travel time in transport modal choice is often more important than the price, the issue of train punctuality is of key importance. Understanding the most frequent delay causes and their relative weight compared to the others can help the rail companies in identifying the most effective strategies to improve punctuality, positively affecting the choices of the travellers.

The present paper gives a contribution to the existing literature in different ways. First, since there is not a common view in defining and classifying the different types and determinants of the train delay, a systemic classification of delay causes, and its responsibility is proposed and developed on the basis of the results of the literature review. Second, it is the first analysis on the delay determinants performed in Italy, where there is a specific railway system, with different characteristics than other European countries, in the use, investments and also in the definition of the thresholds considered to identify if a train is on time or not. This analysis has been developed by using panel data regression models, focusing on an important railway line of the Northern Italy, connecting the most important Italian economic city (Milan) with another urban area (Genoa) in which a key port is located. The regression analysis includes more variables than the majority of the other works on this issue, indicating which are the main causes of train delays, generally confirming the results of previous works but also determining the importance of new factors and giving a weight to each determinant for the considered line. Third, the paper applies – to the best of our knowledge – for the first time the technique of survival analysis to determine the probability of train arrival at the destination on the same line. The resulting survival rate is confirmed by the empirical observations made by the railway company, Trenitalia, in its quality reports, suggesting the statistically goodness of the analysed sample.

In the future it would be interesting to extend both the econometric and survival analysis to other lines or, if the railway operator will be available to provide information (since today this was not possible), to the whole Italian railway system, making comparison between different lines, regions and periods of time. A possible other application can concern the railway systems of other countries. Finally, another possible step would be the consideration of the concept of seasonality in the survival analysis, checking if the number of trains, that arrive to a destination, differs according to the travel season (Dobney et al., 2009; Olsson and Haugland, 2004).

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