AN APPROACH TO PREDICT DESIGN CHOICES IMPACT ON RAILWAY SERVICE DEPENDABILITY

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Abstract

Service Dependability has been recognized in the transportation literature as an effective measure of transit systems service quality. Being a stochastic measure of the delay collected by a train in a generic travel, it may be profitably utilised as an indicator to choose, among different options, the design solution able to increase the level of satisfaction of the final user as well. In this paper the authors present a procedure for estimating the impact of design choices, dealing with subsystems architecture, basic components reliability performances or maintenance policies, on the service quality provided by a railway or metro system. The procedure is based on the use of an innovative modular simulator, developed by the authors. Through a Monte Carlo approach and a suitable post-processing of the results of the simulated samples, the tool provides the user with a set of indicators for estimating the service quality and the effectiveness of different traffic and fleet management policies, as well as maintenance strategies, in both rated and degraded operating conditions. The simulation results for a case study dealing with a railway High Speed application are presented and discussed. Such study aims at estimating the impact of loco and feeding system failures, as well as of the adopted maintenance strategies, on the quality of the service provided by the transportation system. At last, the authors propose an analytical expression to estimate Service Dependability for the analysed case study, fully customisable by the simulation outcomes.

Keywords: Reliability, Maintenance, Railway, Train delay, Monte Carlo.

Presenting Author's biography

Stefano Savio received the Ph.D. degree in Electrical Engineering from the University of Genova, Italy, in 1989. Associate Professor at the Electrical Engineering Department of Genova, he is author of more than 100 papers, most of them dealing with the Product Assurance assessment for industrial and transportation systems, as far as modelling and simulation oriented to RAMS prediction are concerned. As far as applied research is concerned, he was Evaluation Manager of the EU projects MARCO and COMBINE, Project Coordinator of the EU projects COMBINE 2 and F-MAN, and is currently Leader of the Work Package *Reliability and Economics* within the EU project UNIFLEX-PM.

1 Introduction

In order to evaluate service quality, it is to say the measure of the level of satisfaction of the users, the parameter Service Dependability may be introduced [1]. Service Dependability (*SD*) is usually defined as the probability that a train, during a generic travel, collects a delay *d* not greater than an allowable quantity δ. Such a parameter is related to service quality as it takes into account the major request of the passenger, which every day utilizes railway and metro transit systems: for the user, in fact, only short and rare train delays are acceptable. The first step to evaluate *SD* is to identify all the failure modes of the system components, estimate the probabilistic occurrence of such events and correlate failure modes impact with both the locos allowed performances and the mutual interactions among the vehicles.

Some of the authors have already analysed the problem from an analytical point of view, demonstrating that such approach is possible in very simple situations only. For instance, it is possible to evaluate the probabilistic impact of loco electrical drive failures on the running time of the vehicle [2], considering it as a stand alone unit (no interactions with other vehicles) and only in the case heavy simplifications are introduced.

If all the other railway or metro subsystems (Electrical substations, overhead line, signalling system, …) are taken into account, as well as their relevant failure modes, the mentioned approach becomes impossible and the only solution is the adoption of simulation tools [3], where the prediction of the Reliability, Availability and Maintainability (RAM) performances of each subsystem plays a fundamental role. In such a context RAM prediction can be defined as a simulation process to identify the occurrence of failure events and repair actions for each macro-component (subsystem) and analyse the effects of both failures and (corrective and preventive) maintenance operations on the performances of the transportation system under investigation, as far as traffic behaviour is concerned.

Starting from rated conditions, where all the subsystems are correctly operating and departure and arrival times are the scheduled ones, the proposed tool [4] generates by Monte Carlo method the Times To Failure (and Times To Repair) for each basic component and performs a detailed analysis of the traffic evolution whenever a failure event occurs, identifying the delay collected by the trains, till rated conditions are reached again (taking into account repair actions as well). The result of such analysis represents a sample of the delays population, and the collection of a suitable number of those samples (simulations), integrated with a suitable statistical post processing, allows the designer to estimate the actual quality level of the system, detect possible bottlenecks and define the required corrective actions to be implemented, if any. Moreover, it is worth mentioning that other *SD* indicators, different from the one previously defined, can be statistically estimated by the tool utilising the same simulation procedure (for instance, an *SD* indicator related to the number of lost runs in a metro application).

2 Simulation approach

When the railway or metro system is operating in rated conditions, a failure event in one (or more) of the technological macro-components (subsystems) may occur. This failure may imply a partial or total loss of the ability of the macro-component in completing its mission and, conversely, a decrease in the quality of the service provided by the entire transport system (trains delay or loss of runs).

The proposed tool basically consists of two different simulators, duly integrated and interacting:

- a traffic simulator;
- a failure simulator.

The former analyses the traffic behaviour taking into account all the constraints deriving from the rated or degraded performances of the different macro-components, while the latter, based on the Monte Carlo method, generates the failure occurrences for those macro-components and the "rules" that apply when each different failure is injected into the system.

The design has been carried out by the authors in order to achieve an optimal compromise between modelling accuracy and computing time, and to fulfil two main requirements:

- flexibility, related to both the input data and output results, and dealing with the possibility to analyse systems with different layouts, characteristics of rolling stocks, schedules, fleet management and maintenance policies, and to estimate different user defined *SD* indicators;
- modularity, dealing with the possibility to implement a new model for a subsystem by just adding the relevant module, without any further modifications (each module is a "black box" interacting with the others through a suitable interface only).

The traffic simulator can perform the analysis of the trains dynamic movement over a track characterized by:

- any number of passengers stations and freight terminals;
- any number of maintenance depots or marshalling yards;
- any gradient profile;
- any number and configuration of Electrical substations (ESSs);
- fixed or moving block signalling systems.

Each train is characterised by its own length, weight, rolling and aerodynamic drag characteristics, and different locos can be taken into account through the definition of their own weight and their relevant traction effort and deceleration curves. At last, different traffic and fleet management policies, as well as maintenance strategies, can be defined and implemented. As far as the failure simulator is concerned, the Monte Carlo method [5] has been chosen for the generation of the Times To Failure (TTFs) and of the Times To Repair (TTRs) of the different subsystems over a predefined time horizon, once known the reliability and maintainability characteristics of their basic components. The Time To Failure and the Time To Repair are random variables characterised by their relevant Probability Density Functions (PDFs). The knowledge of such PDFs is mandatory for performing the RAM analysis of the system, as the Cumulative Distribution Function (CDF) $F(t)$ of a random variable can be computed starting from the relevant PDF $f(t)$ as it follows:

$$F(t_0) = \int_0^{t_0} f(t)\,dt \qquad (1)$$

being $F(t_0)$ the probability that the stochastic variable t is not greater than a given value t_0 and assuming $t \in (0, +\infty)$. For each value of the random variable t in $(0, +\infty)$, $F(t)$ assumes values uniformly distributed in (0, 1). So, samples of the random variable t distributed according to $F(t)$ can be obtained generating a random number in (0, 1) and subsequently inverting $F(t)$.
For instance, if the random variable t is exponentially distributed, the relevant PDF $f(t)$ can be expressed as:

$$f(t) = \begin{cases} \lambda \exp(-\lambda t) & t \geq 0 \\ 0 & t < 0 \end{cases} \qquad (2)$$

where λ is a constant, and the Cumulative Distribution Function $F(t)$ is:

$$F(t) = 1 - \exp(-\lambda t) \qquad (3)$$

If the TTF of a component is characterised by such a distribution, a sample can be generated solving the following equation:

$$\text{TTF} = \frac{\ln(1-F)}{-\lambda} \qquad (4)$$

where λ is the reciprocal of the component MTTF and F is, for any sample to be generated, a random number in (0, 1) get by Monte Carlo method. The Monte Carlo based approach has been adopted by the authors due to its flexibility [3], as it allows to carry out the failure analysis for components whose TTF (or TTR) is characterised by any distribution (exponential, Weibull, lognormal, …).
According to the reliability connection of the basic components of the subsystem (series, parallel, stand-by, load sharing, k-out-of-n, …) and the level of detail chosen for modelling its real structure, a performance constraint at the subsystem level is then associated to each failure occurrence to drive the traffic simulator.

3 Subsystems reliability modelling

The example proposed by the authors in this paper is related to an autotransformer supplied AC fed railway system, whose principle scheme is shown in Fig. 1.

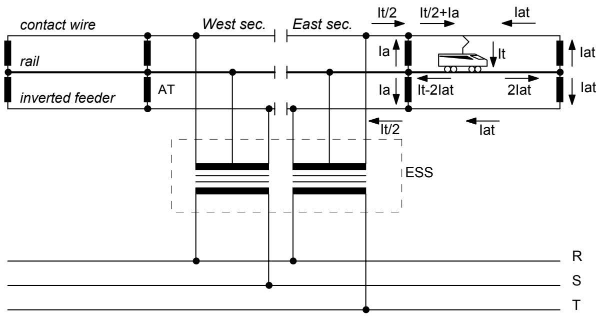

Fig. 1 Principle scheme of the feeding system

The above mentioned railway electrification system, utilized, for instance, in France and Italy for High Speed tracks, is made up of isolated sections (named in Fig. 1 West and East sections), where the contact wire, the rails and the inverted feeder are fed by single phase transformer groups placed in an Electrical Substation (ESS) and equipped with a central tap secondary winding (55 kV, 60 MVA, 50 Hz rated voltage, power and frequency). The central tap is connected to the rails while the remaining terminals feed the overhead line and the inverted feeder. Along the line autotransformers (AT – 15 MVA rated power) are connected at a distance ranging between 10 and 15 km: the primary is connected between the overhead line and the inverted feeder, while the secondary is connected between the inverted feeder and the rails; each line section is always closed at its end on an autotransformer. Fig. 1 shows also the distribution of line currents with the assumption of ideal autotransformers and perfect symmetry between the contact wire and the inverted feeder.

3.1 Traction unit model

As far as the running vehicles are concerned, the authors have modeled, from the reliability point of view, a multivoltage vehicle designed for the Italian High Speed Railway System [6, 7]. Stated that the all the needed information and details can be retrieved in [8], it is worth mentioning that the overall structure of the vehicle consists of three equivalent modules, each composed of one motoring coach and two towed coaches. The propulsion system of each module is made up of an asynchronous motor drive, with four induction motors, 550 kW rated power each.
The reliability model of the traction unit has been suitably implemented into the tool in order to provide the traction power availability of each running train during the simulation: when a failure occurs the rated acceleration is suitably decreased during the start-up phase and the maximum speed set accordingly during the cruising phase. At last it has been supposed to have always available a constant deceleration both in

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rated and degraded conditions. When an immobilising failure occurs (no traction power available), the running time is computed as the passenger travel total time: the time from the departure till the stop along the track is summed to the time required by a spare unit, starting from the nearest station, to reach and take on board the passengers and to complete the travel. In this case no failure is supposed to occur in the spare unit.

3.2 Electrical Substation model

In Fig. 2 the scheme of the Electrical Substation is shown, where HVC1 and HVC2 represent the high voltage connections, each including measurement equipment, one isolating switch and one breaker. HVBB1 and HVBB2 are the high voltage busbars sections, each made up of high voltage busbars and two isolating switches. HVIS1-2 represents a couple of isolating switches which allow the reconfiguration between HVC1 and HVC2 in the case of a failure of a high voltage connection.

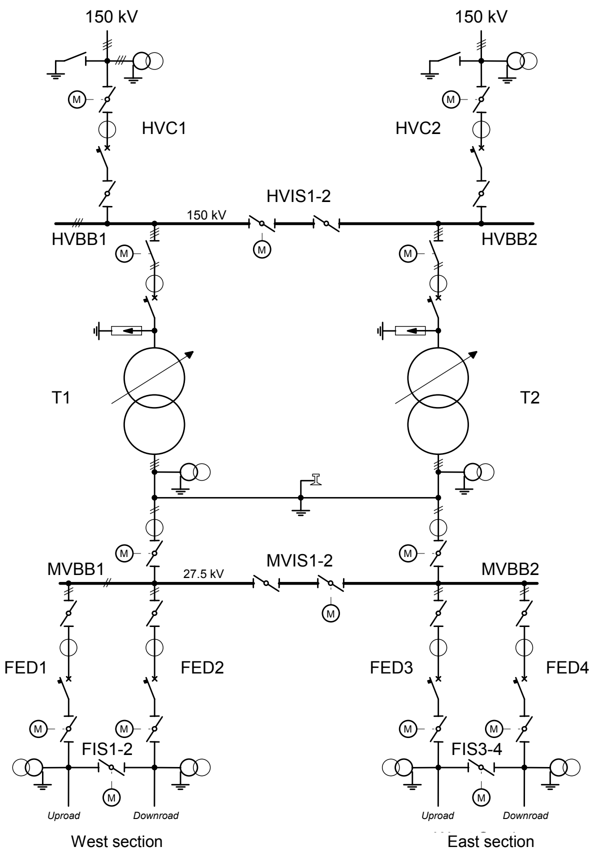

Fig. 2 Electrical Substation scheme

T1 and T2 are the transformer groups, each including one single phase transformer with the above mentioned characteristics, measurement equipment and one breaker. MVBB1 and MVBB2 represent the medium voltage busbars sections, each made up of medium voltage busbars and three isolating switches. MVIS1-2 represents a couple of isolating switches which allow the reconfiguration between T1 and T2 in the case of a failure of a transformer group. FED1, FED2, FED3 and FED4 are the AC railway system feeding sections, each including measurement equipment, one isolating switch and one breaker. Finally, FIS1-2 (FIS3-4) is an isolating switch which allows the reconfiguration between FED1 and FED2 (FED3 and FED4) in the case of a failure of a feeding section of the West (East) line section.

Once known the structure of the Electrical Substation and its operating principle, it is possible to build the relevant Reliability Block Diagram (RBD) as shown in Fig. 3, where the acronyms utilized are the same of Fig. 2.

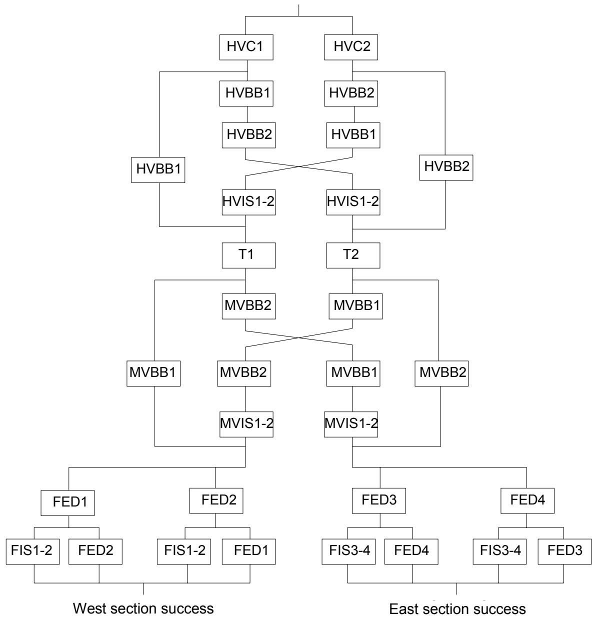

Fig. 3 ESS Reliability Block Diagram

Such a diagram translates the physical and/or functional links among basic elements which allow the Electrical Substation to successfully complete its mission but it doesn't provide information about the impact the failure of some basic components may have at the system level. For instance, if just transformer T2 is affected by a failure, the East section may be fed by transformer T1 (through a reconfiguration action) but the overall power available for the trains running on both sections is halved.

For such reasons, a thorough analysis has been carried out in order to estimate the allowed maximum traction power as a consequence of the failure of the basic elements of the Electrical Substations and/or the autotransformers. The analysis has been developed by modelling the equivalent electric circuit of the system (ESS, autotransformers and trains) with the assumption of four traction units running on the track fed by the ESS (two units for each section, one on the uproad and the other on the downroad). Such an assumption is judged conservative as it refers to a headway of 5 minutes with trains running at 300 km/h. Some of the outcomes of the analysis are reported in Tab. 1, where the symbols utilized for identifying the

failure configurations can be easily derived from the schematic architecture of the electrical feeding system shown in Fig. 4.
In particular, Tab. 1 presents the traction power percent decrease ΔP that should apply as a consequence of different failure events. The values have been estimated so that neither the ESS transformer units nor the line autotransformers operate above the rated conditions, and the pantograph voltage drop does not exceed a maximum predefined value.

Tab. 1 Traction power decrease

Failure configuration	ΔP [%]
AT11i failed	20
AT12i failed	25
AT11i and AT12i failed	30
No power from T1i	40
No power from T1i + AT11i and AT12i failed	50
No power from T1i + all ATs failed	60

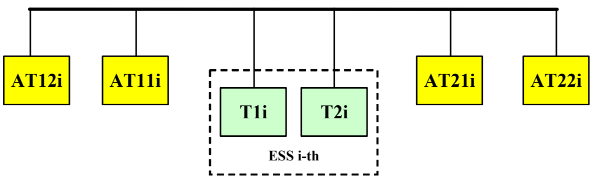

Fig. 4 Schematic architecture of the feeding system

As previously mentioned, other failure configurations, although really remote, have been analysed. For instance, the complete black-out of the Electrical Substation, which implies the neighbouring ESSs fed the trains running on the failed section by a suitable line reconfiguration.
The reliability model of the electrical feeding system has been implemented in the simulator and it provides constraints about the allowed maximum traction power for each running train whenever a failure affects one or more basic components of the Electrical Substations and/or the autotransformers.

4 Simulation results

In this chapter the authors present the results dealing with the simulation of a High Speed railway system, whose track layout is depicted in Fig. 5 together with the position of the Electrical Substations.

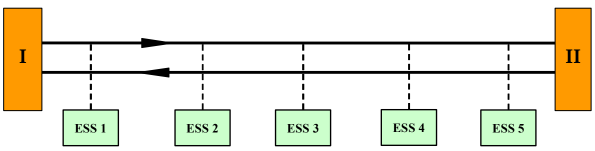

Fig. 5 Track layout and Electrical Substations position

In the simulated railway system, a double track line connects two passenger stations. Station I is 250 km far from Station II and the track is flat everywhere but in two sections, each 25 km long, characterised by a ±12‰ slope (positive slope for trains leaving a station). The two sections are placed 50 km and 175 km far from the departure station respectively.
The maximum allowed cruising speed is 300 km/h, but a speed restriction (80 km/h) is present when the train approaches the arrival station. The railway line is equipped with a moving block signalling system, and a maintenance depot is present at each passenger station. Travelling time equals about 58 minutes and, according to the adopted headway (15 minutes) and timetable, eight trains are contemporarily present over the track. At last, eight spare units are available at the beginning of the simulation in the depot of each passenger station.
Five Electrical Substations feed the overhead line together with twenty autotransformers (not depicted in Fig. 5). Electrical Substations are 50 km far from each other, and the autotransformers of each West (East) single section are 12.5 km far from each other.
The procedure proposed by the authors has been utilised for computing conventional measures, such as the mean delay of the train, but has been also used for the estimation of the Service Dependability (*SD*), which can be defined by the following relationship, where d is the stochastic variable "delay" and δ an allowable quantity:

$$SD = \Pr\left\{d \le \delta\right\} \tag{5}$$

The authors have analysed about 73000 train runs by performing six replications of a simulation carried out over a time horizon of 10000 operating hours. In the following Tab. 2 the reliability data for the ESS blocks depicted in Fig. 3 and for the line autotransformer are reported. Reliability data for loco drive blocks can be retrieved in [8]. In such a context it is worth mentioning that loco model takes also into account mechanical parts (boogie).

Tab. 2 Feeding system blocks failure rate

Block	λ [failures/h]
Transformer group	4.0 e-6
Autotransformer group	2.2 e-6
Other blocks	1.0 e-6

For electrical and electronic components an exponential distribution of the Time To Failure has been assumed, while for the boogies a normal distribution has been supposed. At last, locos can be maintained at the depot level only.
The results depicted in the following refer to two different case studies (Case A and Case B). In Case A it has been supposed to adopt a maintenance strategy which calls for a preventive maintenance action on the mechanical equipment of the loco (boogie) every 1000 operating hours. Case B refers to a situation where preventive maintenance actions are carried out every 2000 operating hours. For both case studies, the effect

of a preventive maintenance action is an 80% renewal of the mechanical equipment.
Fig. 6 shows the delay histogram for Case A. For a better readability the authors have preferred to show delayed trains only and to associate each delay interval to the number of the delayed trains, computed as a percentage with respect to the overall number of delayed trains.

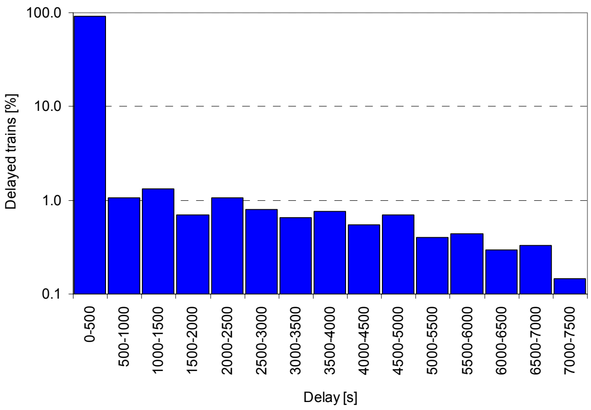

Fig. 6 Delay histogram (all failures – Case A)

Thanks to the information provided by the simulation tool about the cause (failure event) associated to each train delay, the authors have subdivided the overall sample of train delays into two subsets: the delays sample due to loco failures and the one associated to ESS+AT failures.
The following Fig. 7 and Fig. 8 show the delay histogram, for the aforementioned two subsets (Case A). In Fig. 7 each delay interval is associated to the number of the trains delayed by a loco failure, computed as a percentage with respect to the overall number of trains delayed by that cause. The same applies to Fig. 8 for the trains delayed by ESS+AT failures. Tab. 3 and Tab. 4 present the results of the measures performed on the observed samples (Case A): the mean value of the distributions is shown together with the estimated standard deviation σ_m of the sample means.

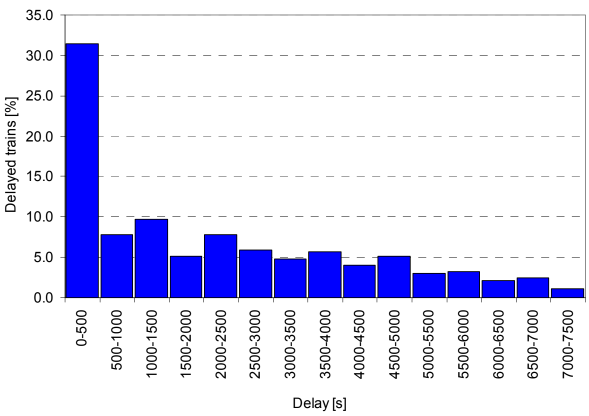

Fig. 7 Delay histogram (loco failures – Case A)

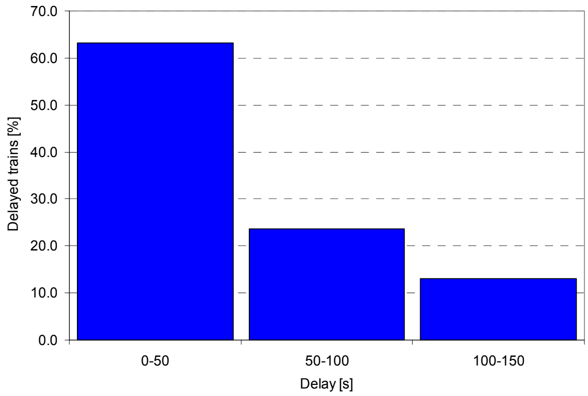

Fig. 8 Delay histogram (ESS+AT failures – Case A)

Tab. 3 Post processing measures (Case A)

Measure	**Value [s]**	
	Delayed trains	All trains
Mean delay	339	25.5
Std deviation σ_m	14	1.1
90% SC limits	339 ± 23	25.5 ± 1.9
95% SC limits	339 ± 28	25.5 ± 2.3

Tab. 4 Post processing measures (delayed trains – Case A)

Measure	**Value [s]**	
	ESS+AT failures	Loco failures
Mean delay	46.1	2201
Std deviation σ_m	0.7	77
90% SC limits	46.1 ± 1.2	2201 ± 127
95% SC limits	46.1 ± 1.4	2201 ± 153

As far as the mean delay is concerned, Tab. 3 and Tab. 4 also show the results of the analysis carried out by the authors in order to estimate the Statistical Confidence (SC) limits and the associate probability (90% and 95%). Being the number of the observed delays equal to about 750 and 4750, for loco failures and ESS+AT failures respectively (Case A), the authors have assumed that, according to the *central limit* theorem, the means of the sample are normally distributed.
Fig. 9 shows the behaviour of the delay Cumulative Distribution Functions for the whole set of the observed trains (Case A). In particular, the curves represent, given a generic time *t*, the probability that the delay is less than *t* and so furnish the estimate of the Service Dependability of the system. The curve characterised by a continuous line has been directly derived from the simulation results, while the curve characterised by a dashed line has been plotted by approximating the delay histogram with an exponential distribution, through the mean value of Tab. 3. Fig. 10 and Fig. 11 show the conditional Service Dependability (Case A), plotted taking into

account just the delays due to loco failures and ESS+AT failures respectively. Each curve (continuous line) represents given a generic time *t*, the probability that the delay is less than *t,* stated that a delay has occurred due to the related cause (loco or ESS+AT failure). Once again, the dashed line has been plotted by approximating the relevant delay histogram with an exponential distribution, through the mean values of Tab. 4.

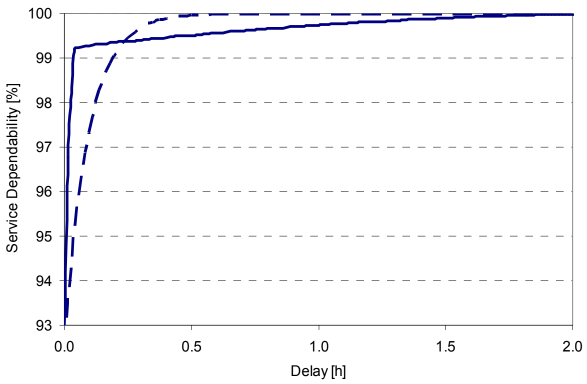

Fig. 9 *SD* behaviour (Case A)

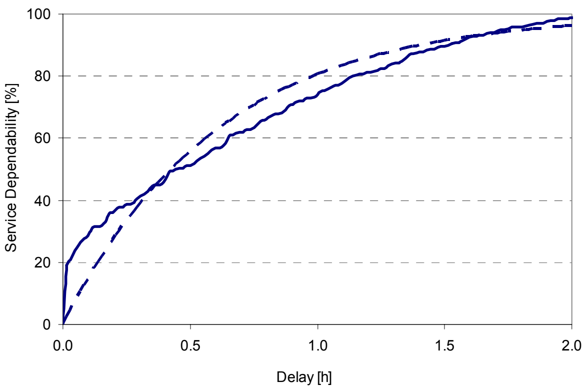

Fig. 10 Conditional *SD* behaviour (loco failures – Case A)

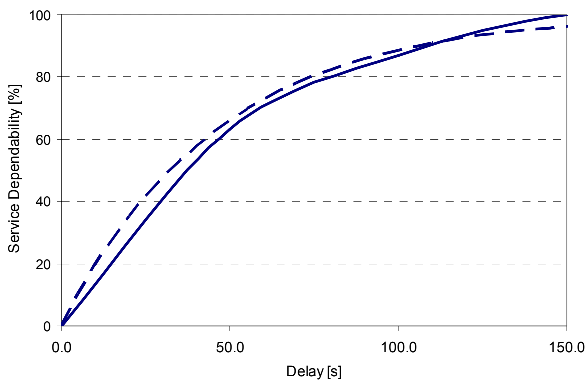

Fig. 11 Conditional *SD* behaviour (ESS+AT failures – Case A)

Stated that the availability of an analytical expression would be really precious for the *SD* estimate, Fig. 9 testifies that an exponential approximation, despite its very simple formulation, appears not fully acceptable for the simulated case study.
Although the problem could be solved by adopting best fitting procedures, the authors have conceived a different and more direct approach, formalised in the following relationship (6):

$$SD(t) = P_{nd} + \exp\left[-\frac{1}{d_{m\_Loco}}t\right]P_{d\_Loco} + \\ + \exp\left[-\frac{1}{d_{m\_ESS+AT}}t\right]P_{d\_ESS+AT} \qquad (6)$$

where:
P_{nd} = no delay probability
d_{m_Loco} = delayed trains mean delay (loco failures)
P_{d_Loco} = delay probability due to loco failures
d_{m_ESS+AT} = delayed trains mean delay (ESS+AT failures)
P_{d_ESS+AT} = delay probability due to ESS+AT failures

Relationship (6) can be fully customised by simulation results, and its effectiveness for the analysed case study (Case A) is testified by the following Fig. 12, where the Service Dependability behaviour already presented in Fig. 9 (continuous line) is once again depicted, but the dashed line has been now plotted by utilising (6).

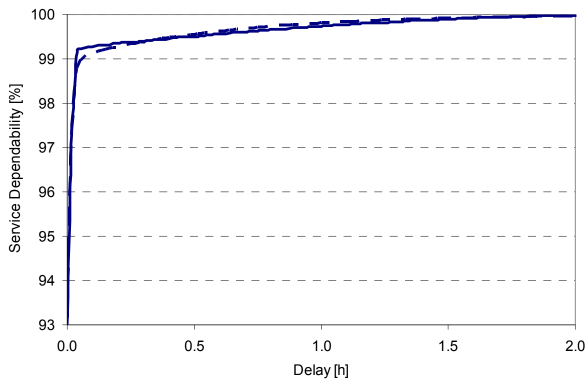

Fig. 12 *SD* behaviour (Case A)

In the following part of this chapter the results dealing with Case B are reported; the same computing hypotheses and plotting procedures already described for Case A apply.
Fig. 13 shows the delay histogram for Case B (delayed trains only), while Fig. 14 and Fig. 15 show the delay histogram for the two sample subsets, dealing with loco and ESS+AT failures respectively.
Tab. 5 and Tab. 6 present the results of the measures performed on the observed samples of Case B: the

mean value of the distributions is shown together with the estimated standard deviation σ_m of the sample means. An estimate of the Statistical Confidence (SC) limits, together with the associate probability (90% and 95%), is also reported.
It is worth mentioning that the number of the observed delays equals, in this case, about 1050 and 4550, for loco and ESS+AT failures respectively.

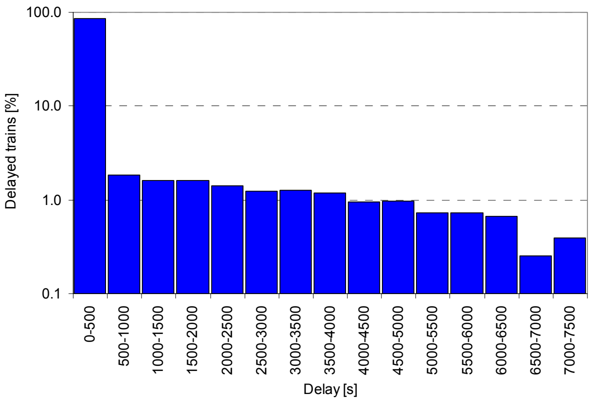

Fig. 13 Delay histogram (all failures – Case B)

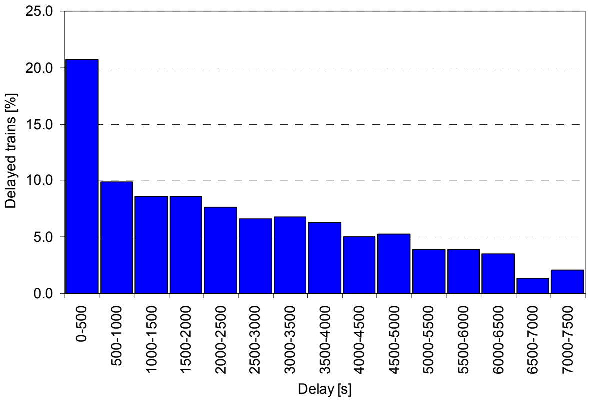

Fig. 14 Delay histogram (loco failures – Case B)

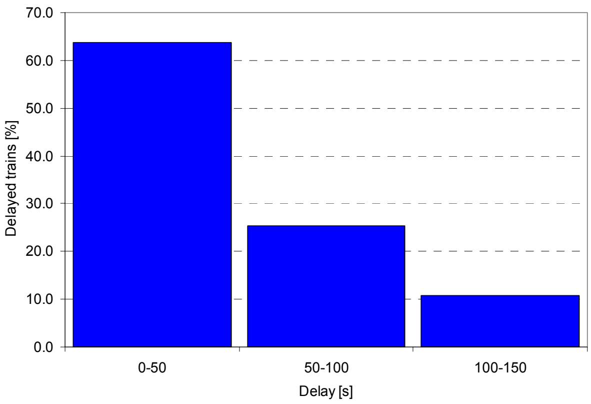

Fig. 15 Delay histogram (ESS+AT failures – Case B)

Tab. 5 Post processing measures (Case B)

Measure	Value [s]	
	Delayed trains	All trains
Mean delay	510	39.2
Std deviation σ_m	18	1.4
90% SC limits	510 ± 29	39.2 ± 2.3
95% SC limits	510 ± 35	39.2 ± 2.8

Tab. 6 Post processing measures (delayed trains – Case B)

Measure	Value [s]	
	ESS+AT failures	Loco failures
Mean delay	43.9	2529
Std deviation σ_m	0.7	63
90% SC limits	43.9 ± 1.2	2529 ± 104
95% SC limits	43.9 ± 1.4	2529 ± 125

Fig. 16 shows the behaviour of the delay Cumulative Distribution Functions for the whole set of the observed trains (Case B). The curve characterised by a continuous line has been directly derived from the simulation results, while the curve characterised by a dashed line has been plotted by approximating the delay histogram with an exponential distribution, through the mean value of Tab. 5.
Fig. 17 and Fig. 18 show the conditional Service Dependability (Case B), plotted taking into account just the delays due to loco failures and ESS+AT failures respectively. Once again, the dashed line has been plotted by approximating the relevant delay histogram with an exponential distribution, through the mean values of Tab. 6.
The effectiveness of relationship (6) has been successfully tested for Case B too, once computed the parameters of the analytical expression by means of the simulation outcomes. The final results are presented in Fig. 19, where Service Dependability behaviour already presented in Fig. 16 (continuous line) is depicted, but the dashed line has been now plotted by utilising (6).

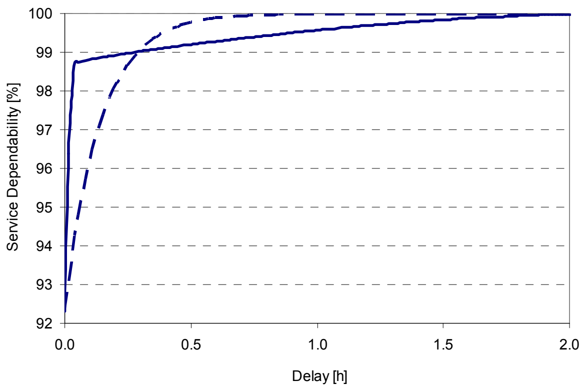

Fig. 16 *SD* behaviour (Case B)

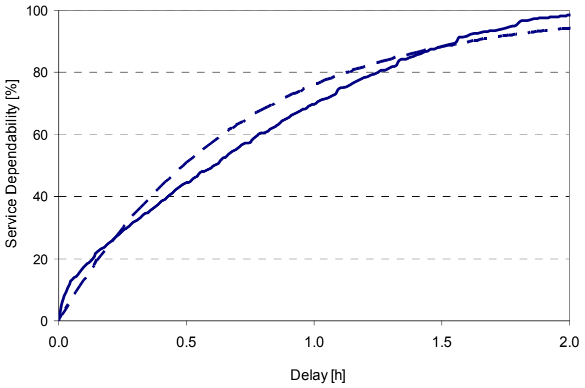

Fig. 17 Conditional *SD* behaviour
(loco failures – Case B)

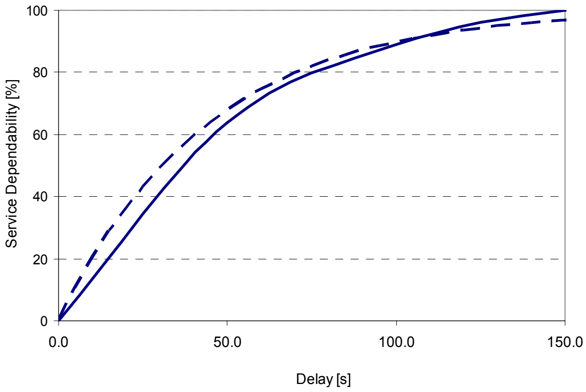

Fig. 18 Conditional *SD* behaviour
(ESS+AT failures – Case B)

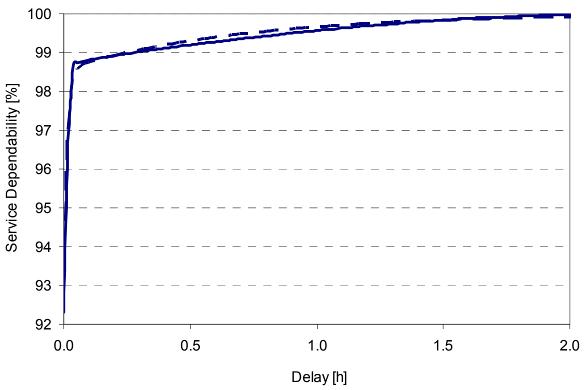

Fig. 19 *SD* behaviour (Case B)

Stated that the adopted fleet size revealed sufficient to avoid lost runs or delayed departures, that is to say the observed delays are caused by components failure only, it is important to remark the impact of maintenance policies on the service quality. By comparing the results related to the whole set of runs, it turns out a not negligible increase of the train mean delay and a decrease of the Service Dependability for Case B, due to the reduction of the frequency of preventive maintenance operations on the loco mechanical equipment.

To complete the information about the maintenance related input data of the simulation, a Mean Time To Repair equal to 8 h has been assumed for the loco electrical and electronic components, while the loco mechanical equipment and the components of the feeding system have been characterised by a Mean Time To Repair equal to 50 h. At last, for each basic component of the system, the relevant Time To Repair has been supposed exponentially distributed.

5 Conclusions

The results of the impact analysis presented in this paper clearly show the effectiveness of the procedure proposed and based on the adoption of an innovative simulation tool developed by the authors. Such a procedure allows to effectively analyse and solve different problems concerning railway and metro systems. In particular, the main function the tool has been designed for is to provide the user with a set of indicators related to the quality of the service in real operating conditions, and able to support the choice of the optimal solution (as far as, for instance, traffic management rules, maintenance strategies and fleet consist are concerned) during the design phase of a railway or metro system or the choice of the most effective corrective actions to be implemented, when required, in an existing system. Such support is realized by providing an estimate of the impact on the system performances of components failures, traffic management policies, fleet management and maintenance strategies. The added value of such an impact estimate is twofold: on one hand it is *customer* oriented, as it allows to identify the influence of a particular choice on the quality perceived by the final users (passengers), on the other hand it is *decision maker* oriented, as it provides all the information to achieve the needed quality targets taking under control the life cycle cost of the system.

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