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An Innovative Methodology for Managing Service Disruptions on Regional Rail Lines

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Abstract. Regional rail transport, albeit a major element in public mobility, is frequently affected by great vulnerability to system failure. Hence it is worth developing suitable procedures to manage rail disruption appropriately. In the particular case of breakdowns, the latter may be managed by means of shunter locomotives or empty rail convoys if the faulty convoy is able to travel in non-autonomous conditions. Obviously, the use of rescue vehicles on the line generates a disturbance with related reductions in service quality. Against this backdrop, this paper has two main aims. First, we investigate the possibility of adopting some unconventional rescue strategies based on the use of operating rail convoys or maintenance vehicles, and propose a methodology, based on a micro-simulation approach, for accurately modelling interactions among all rail system components so as to optimise management in emergency contexts. The second aim is to identify suitable intervention strategies which provide the right balance between the swiftness of rescue operations and the disturbance inflicted upon rail services during failure management. Finally, the method is applied to the 'Naples-Sorrento' regional rail line in southern Italy in order to show the utility and feasibility of the suggested approach.

Keywords: Regional railways; micro-simulation approach; travel demand estimation; disruption management, rescue vehicles.

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Introduction

Effective management of rail transport systems is of great importance to reduce negative externalities from private car use such as air and noise pollution, accidents and congestion. Although in recent years the automotive sector has moved several steps towards the use of technologies for improving driving safety and efficiency (Bifulco *et al*. 2015; Pariota *et al*. 2015), rail transport is intrinsically characterised by a low environmental impact, a high degree of safety and automation, and limited land use in relation to the large transport capacity provided. Moreover, the use of exclusive facilities, constrained driving and the signalling system allow rail/metro systems to achieve lower unit costs per seat-km (i.e. vehicular capacity multiplied by travel distances) or per passenger-km (i.e. travel demand multiplied by travel distances) with respect to other transportation systems, obviously in the case of the same load factors.

However, rail systems are highly vulnerable because of their complexity due to the large number of interactions between the components involved (infrastructure, signalling system, rolling stock and timetable). The vulnerability of a transport system can be defined as the propensity for service performance to degrade once an incident occurs. An overview of concepts of vulnerability and resilience in transportation can be found in Mattsson, Jenelius (2015) and Reggiani *et al*. (2015). Recently, Cats *et al*. (2016) integrated vulnerability and disruption exposure analysis into network risk assessment. The specular feature to vulnerability is system robustness, which represents the ability to react appropriately to a perturbation by mitigating the consequences and avoiding the propagation of the related harmful effects.

The issue of re-establishing ordinary service conditions after a breakdown occurs is the so-called rescheduling problem. As shown by Veelenturf *et al*. (2016), due to its complexity, the rescheduling problem is generally split into different phases that are solved in sequence and concern, respectively, timetable, rolling stock and crew.

Our proposal addresses the first phase, i.e. timetable rescheduling, and we thus analyse the robustness of the system to absorb delays by avoiding their propagation (see, for instance, Goverde 2005; Cacchiani, Toth 2012).

Rescheduling problems may concern services with different territorial coverage (e.g. urban, regional or national services), different kinds of breakdown (e.g. disturbance or disruption) and different points of view (e.g. costs incurred by railway undertakings, passenger generalised costs or environmental impacts).

First, as regards network territorial coverage, Gao *et al*. (2016) proposed an optimization method, in the case of a metro system, based on a skip-stop pattern whose aim is to minimise total travel time and the number of passengers waiting in stations by considering the capacity constraint of convoys. By contrast, Adenso-Diaz *et al*. (1999)

proposed an on-line rescheduling model in the case of a regional network, based on exploring a solution space by means of a backtracking algorithm. Optimisation methods based on this search algorithm are also investigated by the recent literature (see, for instance, Chen *et al*. 2017). Moreover, Kecman *et al*. (2013) illustrated different macroscopic models for addressing disruptions in the case of large networks. In particular, the paper analysed the trade-off between computational time and solution quality on various disturbed traffic conditions and tested the proposed approach on the Dutch national railway network.

Secondly, according to the severity of failure, we may distinguish between disturbance and disruption: as shown by Cacchiani *et al*. (2014), disturbances are generally considered as small perturbations influencing the system, while disruptions indicate large external incidents which can lead to the cancellation of train runs within the timetable or even the interruption of whole services. Clearly, the greater the severity of failure, the greater the impact of the corrective measures adopted. For example, Dollevoet *et al*. (2012) dealt with the problem of connection and re-routing of passengers in the case of a delay occurrence, while more severe perturbations are tackled by Corman *et al*. (2010a) and Ghaemi *et al*. (2016). The former considers a serious disruption where some block sections have a reduced maximum speed together with others which are totally unavailable for traffic, while the latter presents a macroscopic rescheduling model to compute the disruption timetable for a complete blockage with the focus on short-turning trains.

Finally, regarding the perspectives analysed, D'Acierno *et al.* (2016) described different measures of fault resolution by adopting two different formulations for the objective function to be minimised, so as to consider a dual point of view: user generalised costs and the economic convenience for the rail enterprise of each solution. Furthermore, Corman *et al*. (2011a) introduced an innovative optimisation framework for rescheduling rail services in the case of perturbations, considering trains with different classes of priority to include the needs of different stakeholders. Moreover, Umiliacchi *et al*. (2016) dealt with the delay management problem by introducing also an energy-saving perspective.

A large number of contributions model the rescheduling process by means of the Alternative Graph model proposed by Mascis, Pacciarelli (2002). In D'Ariano *et al*. (2008a), the alternative graph model was implemented in *ROMA* (Railway traffic Optimization by Means of Alternative Graphs), a decision support tool for dealing with delays and other alterations of the planned timetable, which is based on an advanced optimisation algorithm. By contrast, in D'Ariano *et al*. (2008b) some timetabling constraints are relaxed in the *ROMA* tool to produce flexible timetables, which are preferable to rigid ones: they offer more freedom to solve conflicts and increase punctuality. Moreover, Quaglietta *et al*. (2013) combined *ROMA* with the microscopic simulation software *EGTRAIN* to assess the stability of rescheduling measures against the stochastic propagation of the disturbance, making a comparison between the optimal intervention strategies within different time horizons.

Furthermore, rescheduling models have been proposed, based on modelling frameworks which may be both micro (see, for instance, Corman *et al*. 2011b; Chu, Oetting 2013) and macro (see, for instance, Narayanaswami, Rangaraj 2013; Louwerse, Huisman 2014).

Finally, it is worth noting that, due to the intrinsic complexity of the rescheduling problem and the huge number of feasible solutions in real contexts, apart from a few contributions which are able to solve it by means of an exhaustive approach (see, for instance, D'Acierno *et al*. 2016), most applications are based on implementing metaheuristic algorithms such as tabu search (see, for instance, Corman *et al.* 2010b), simulating annealing (see, for instance, Burkolter 2005), neighbourhood search (see, for instance, Botte *et al.* 2017) and some greedy approaches (see, for instance, Semet, Schoenauer 2005; Tornquist 2012).

Although various kinds of breakdown can occur, in this paper we focus on a failure which makes the faulty convoy able to travel in non-autonomous conditions. In this case, appropriate measures should be taken to enable recovery by hauling the train to be rescued. However, according to current Italian regulations (see, for instance, EAV 2015a, 2015b), the faulty train may be towed (or, with special precautions, pushed) by means of a shunter locomotive or a similar empty convoy. Obviously, the use of additional (i.e. rescue) vehicles on the line may generate a disturbance with related reductions in service quality.

In this context, our proposal is to evaluate the possibility of implementing some unconventional rescue strategies based on the use of operating rail convoys or bimodal rail-road maintenance vehicles (such as locotractors, diggers or catenary maintenance vehicles). Obviously, it is necessary to propose a system of models able to evaluate performance in terms of rescue swiftness and disturbance incurred by the rail service in order to identify the optimal intervention strategy among conventional and unconventional proposals.

The paper is organised as follows. In the following sections, the proposed methodology is illustrated by describing the unconventional intervention strategies analysed and the simulation framework implemented. Then, in order to demonstrate its effectiveness, the proposed approach is applied in the case of a real regional line in southern Italy. Finally, conclusions and research prospects are summarised.

The proposed methodology

Currently, emergency management is carried out through the implementation of specific codified procedures which define responsibilities, tasks and actions. In the context of a regional railway, possible disruptions may concern, for instance, fire on board trains, derailments, collisions between trains, pedestrian hits, power supply failures, signalling system breakdowns and mechanical problems. Our analysis focuses on breakdowns which allow a rail convoy to travel non-autonomously, such as the case of failure of the on-board traction system. In this context, it is necessary to use an additional vehicle to tow the faulty vehicles and free the line. However, for safety reasons, the towing vehicle must not have passengers on board. In this context, current Italian regulations (see EAV 2015a, 2015b) require the use of shunter locomotives, generally diesel vehicles positioned at depots or workshops or rail convoys which are empty (i.e. without passengers) usually located at depots or terminals. Since the location of the rescue vehicles (depot, workshop or terminal) may be quite far from the intervention site, a considerable time may well elapse between the request for intervention, reaching the intervention site (generally by travelling along the disrupted line), coupling operations, removal and housing of the faulty vehicles.

Our proposal consists in considering two kinds of unconventional strategies where the term '*unconventional*' concerns the fact that, under current Italian regulations, they are not considered feasible.

The first strategy consists in adopting bimodal rail-road vehicles generally used for maintenance such as locotractors, diggers or catenary maintenance vehicles. These vehicles, generally adopted for different purposes, equipped with a coupling device may have a limited towing capacity. Hence, the main limit of this proposal is the low speed on the line during the hauling of the faulty train. On the other hand, the main advantage would be the ability to reach the intervention site quickly by travelling on ordinary asphalt roads and/or locating maintenance vehicles at intermediate stations. Moreover, such vehicles have low purchase costs.

The second class of strategies consists in adopting operating rail convoys (i.e. with passengers on board) as rescue vehicles. Obviously, in this case, it would first be necessary to unload all passengers onto a station platform, then reach the faulty convoy, couple it and tow it to a maintenance track. Finally, any waiting passengers would need to be reached and their trips restarted. Obviously, if available, the waiting passengers may be recovered by another rail convoy. The main disadvantage of this strategy is that the unloading and loading of passengers may considerably increase user disservice perception. However, its strength consists in the speed of intervention and the limited disturbance due to the non-use of additional rescue vehicles.

However, in order to verify the goodness of the strategies proposed, we suggest the use of a system of models able to evaluate effects of (conventional and unconventional) intervention strategies for each feasible breakdown so as to provide a *decision support system* (DSS) for dispatchers. The following section provides analytical details of the above DSS which may be formulated as an optimisation problem whose solution could provide useful information to rail service managers.

The last issue to be implemented, if one or more unconventional strategies were to appear more efficient than their conventional counterparts, is the amendment of rail regulations. Obviously, this is merely a matter of form since all safety requirements (such as the absence of passengers on board) would be satisfied and the only additional requirement would be the qualification of drivers of maintenance vehicles.

Simulating impacts on rail services

The problem of determining the optimal intervention strategy in the case of rail system failure can be formulated as a multi-dimensional constrained optimisation problem as follows (D'Acierno *et al.* 2016):

$$\hat{\boldsymbol{y}} = \arg\min_{\boldsymbol{y}\in \boldsymbol{Sy}} Z(\boldsymbol{y}, \boldsymbol{ut}, \boldsymbol{uf}, \boldsymbol{rtm}, \boldsymbol{in}, \boldsymbol{rs}, \boldsymbol{rc}) \tag{1}$$

subject to:

$$[\boldsymbol{ut}, \boldsymbol{uf}, \boldsymbol{rtm}, \boldsymbol{rc}] = \Lambda(\boldsymbol{y}, \boldsymbol{in}, \boldsymbol{rs}, \boldsymbol{ss}, \boldsymbol{ptm}, \boldsymbol{td}) \tag{2}$$

with:

$$[\boldsymbol{in}, \boldsymbol{rs}, \boldsymbol{ss}] = \boldsymbol{FM}\left(\boldsymbol{fc}, \boldsymbol{in}^0, \boldsymbol{rs}^0, \boldsymbol{ss}^0\right), \tag{3}$$

where: $\boldsymbol{y}$ – the vector describing intervention strategy to be implemented; $\hat{\boldsymbol{y}}$ – the optimal value of $\boldsymbol{y}$; $\boldsymbol{Sy}$ – the feasibility set of $\boldsymbol{y}$; $Z(\cdot)$ – the objective function to be minimised; $\boldsymbol{ut}$ – the vector of user travel and waiting times; $\boldsymbol{uf}$ – the vector of user flows; $\boldsymbol{rtm}$ – the vector describing the real timetable of the rail service; $\boldsymbol{in}$ – the vector describing the infrastructure conditions in the failure context analysed; $\boldsymbol{rs}$ – the vector describing the rolling stock conditions in the failure context; $\boldsymbol{rc}$ – the vector of residual capacities of the rail convoys; $\Lambda(\cdot)$ – the simulation function which provides inputs for the calculation of objective function Z; $\boldsymbol{ptm}$ – the vector describing the planned timetable; $\boldsymbol{td}$ – the vector of travel demand; $\boldsymbol{ss}$ – the vector describing the signalling system conditions in the failure context; $\boldsymbol{FM}$ – the failure model function which provides infrastructure, rolling stock and signalling system conditions in the failure context; $\boldsymbol{fc}$ – the vector describing the failure context; $\boldsymbol{in}^0$ – the vector describing the infrastructure conditions in unperturbed conditions; $\boldsymbol{rs}^0$ – the vector describing the rolling stock conditions in unperturbed conditions; $\boldsymbol{ss}^0$ – the vector describing the signalling system conditions in unperturbed conditions.

Equation (2) represents the consistency constraint between transportation system performance and travel demand flows, whose formulation requires the interaction of four models (see D'Acierno *et al.* 2013):

- a *service simulation model*, which provides the real timetable of the rail system (***rtm***) depending on the intervention strategy implemented (***y***), rail infrastructures (***in***), rolling stock (***rs***), signalling system (***ss***), planned timetable (***ptm***) and user flows (***uf***);
- a *supply simulation model*, which provides performance of all transportation systems in the analysed area (***tsp***) depending on user flows (***uf***);
- a *pre-platform demand model*, which provides user platform flows (***upf***) depending on performance of all transportation systems in the analysed area (***tsp***) and travel demand (***td***);
- an *on-platform demand model*, which provides user flows (***uf***), user times (***ut***) and residual capacity of convoys (***rc***) depending on user platform flows (***upf***), the real timetable (***rtm***) and the rolling stock conditions (***rs***).

Equation (3) expresses the analytical formulation of a failure model which provides, for each feasible breakdown context (***fc***), the related reductions in infrastructure (***in***), rolling stock (***rs***) and signalling system (***ss***) performance. This model is based on the adoption of *RAMS* techniques, where the term *RAMS* is the acronym for *Reliability* (i.e. the ability of a system to perform a specific function), *Availability* (i.e. the ability of a system to be kept in a functioning state), *Maintainability* (i.e. the simplicity with which the product or system can be repaired or maintained) and *Safety* (i.e. the requirement not to harm people, the environment, or any other assets during the life cycle of the system). Details on *RAMS* techniques can be found in CENELEC (1999).

Since our proposal is to identify the optimal intervention strategy which minimises user discomfort in the event of rail system breakdowns, we propose to adopt an objective function which expresses the total generalised cost of rail system users, that is a weighted sum of times and monetary costs. Hence, the objective function $Z(\cdot)$ may be expressed as:

$$Z(\cdot) = \beta_{VOT} \cdot (T_w + T_t) + M_c \tag{4}$$

with:

$$T_w = \sum_s \sum_p \sum_r \beta_w \cdot tw_{s,p}^r(\boldsymbol{ut}) \cdot fw_{s,p}^r(\boldsymbol{uf}) \tag{5}$$

$$T_t = \sum_l \sum_r \beta_{ob}(\boldsymbol{uf}) \cdot tt_l^r(\boldsymbol{ut}) \cdot ft_l^r(\boldsymbol{uf}) \tag{6}$$

$$M_c = \sum_o \sum_d \sum_k c_{o,d}^k \cdot fp_{o,d}^k(\boldsymbol{uf}) \cdot \left(1 - er_{o,d}^k\right), \tag{7}$$

where: β_{VOT} – a parameter which expresses the monetary value of time in terms of *€/h*; T_w – the total user waiting time whose formulation is provided by (5); T_w – the total user travel time whose formulation is provided by (6); M_c – the total user monetary cost whose formulation is provided by (7); β_w – a parameter which describes user perception of the time spent waiting for trains; $tw_{s,p}^r(\cdot)$ – the average waiting time between run $(r-1)$ and run *r* at station *s* and on platform *p*; $fw_{s,p}^r(\cdot)$ – the number of passengers waiting for run *r* at station *s* and on platform *p*; $\beta_{ob}(\cdot)$ – a parameter which describes user perception of the time spent on board the train which depends on the crowding level (as shown by MVA Consultancy (2008)); $tt_l^r(\cdot)$ – the travel time of run *r* on link *l*; $ft_l^r(\cdot)$ – the number of passengers who are on board run *r* and on link *l*; $c_{o,d}^k$ – the monetary cost of ticket type *k* which allows travel from the starting station *o* to the arrival station *d*; $fp_{o,d}^k(\cdot)$ – the number of passengers who travel from station *o* to station *d* by using ticket type *k*; $er_{o,d}^k$ – the evasion rate (i.e. the percentage of non-paying passengers) of ticket type *k* in the case of trips from station *o* to station *d*.

Since the strategies considered do not provide for variations in fare schemes or evasion rates, with the assumptions that no user leaves the rail system to reach his/her destination on a different transport mode and fare schemes do not change in time, term M_c is invariant and may therefore be omitted in the objective function formulation.

Application to a real regional line

In order to demonstrate the feasibility of the proposed approach, we applied the suggested methodology to the case of a real regional line, the Naples-Sorrento line in southern Italy operated by the *Ente Autonomo Volturno* (EAV) enterprise. It covers 35 stations and is 41.5 km long. The line extends from the regional capital Naples to the Sorrento peninsula, where the town of Sorrento represents the terminus. The winter timetable comprises 66 runs per day and has a twice-hourly service frequency. The convoys operating on the line can reach a maximum speed of 90 km/h. However, the short distance between two consecutive stations rarely allows trains to achieve this speed.

The infrastructural layout of the line consists of two different parts (see Fig. 1): the first is a double-track line between Porta Nolana station in Naples and Moregine; the second is single-track between Moregine and Sorrento, which may constitute a bottleneck for rail operations.

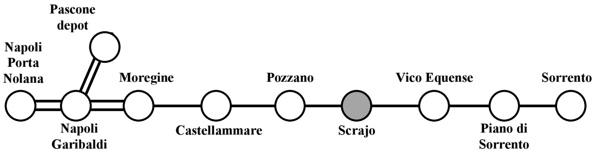

Fig. 1. Naples-Sorrento line diagram

The proposed application consists in simulating a certain train failure and the comparison between different re-scheduling strategies in terms of passenger generalised costs. Since our aim was to stress the system as seriously as possible, the simulated failure was purposely located in the longest single-track section between the stations of Castellammare and Sorrento. In terms of characteristics, the failure involved the on-board traction system and made the faulty convoy able to travel in non-autonomous conditions. It was necessary to put appropriate measures in place to tow the faulty train to a special location in order to re-establish ordinary service conditions as rapidly as possible.

In this context, it is worth pointing out that since the aim of our application was to assess optimal intervention strategies, without claiming to deal with the random nature of failures and related issues, both for the localisation and the kind of the breakdown analysed, no stochastic analysis was carried out. We hypothesised that, during the morning peak hour, a train running from Sorrento to Naples (which represents the most loaded direction in terms of passenger flows) breaks down and is forced to stop at Scrajo station, where all on-board passengers have to alight. Since, importantly, this station between Pozzano and Vico Equense has no points, it was also necessary to address the issue of picking up passengers who were unloaded from the faulty train.

In order to react appropriately to this disruption, different rescheduling scenarios were developed. They may be grouped according to the category of vehicles used for the rescue. Obviously, the proposed strategies are based on the available rolling stock of the EAV enterprise. In particular:

- *Scenario 1.1*, based on the use of a diesel locomotive with a power of 260 kW, located at the Pascone depot. The diesel vehicle is driven to Scrajo where it couples to the faulty train and, after changing direction, tows it to Castellammare. Rescheduling is then required to pick up passengers who were unloaded from the faulty train at Scrajo;
- *Scenario 1.2*, similar to scenario 2.1 but based on the use of a diesel locomotive with a lower power (i.e. 74 kW);
- *Scenario 2*, based on the use of a train not operating when the failure occurs: one of the empty convoys available at Sorrento (i.e. a convoy which has completed its run from Naples to Sorrento and is ready to start its service in the opposite direction according to the planned timetable) is driven to Scrajo where couples to the faulty train and, after changing direction, tows it to Vico Equense. Rescheduling is then required to pick up passengers who were unloaded from the faulty train at Scrajo;
- *Scenario 3.1*, based on using two electric locotractors (i.e. maintenance vehicles) located at Castellammare. The vehicles are driven to Scrajo where they couple to the faulty train and, after changing direction, return to Castellammare station where the faulty train is recovered. Rescheduling is then required to pick up passengers who were unloaded from the faulty train at Scrajo;
- *Scenario 3.2,* similar to scenario 3.1 but, in this case, the locotractors are initially located at Vico Equense;
- *Scenario 4.1*, based on the use of a train operating in the opposite direction with respect to the faulty convoy (i.e. from Naples to Sorrento) which has already gone past Scrajo (i.e. the station where the faulty convoy has stopped) when the failure occurs. The operating train interrupts its ordinary service at Piano di Sorrento station, where unloads passengers. It then changes direction and proceeds empty to Scrajo for coupling to the faulty train, which is finally towed to Vico Equense in order to be recovered. In this case, an additional issue needs to be addressed. Indeed, the required rescheduling is two-

fold: in favour of users waiting at Scraio (i.e. passengers who were on board the faulty vehicle) and Piano di Sorrento (i.e. passengers who were on board the rescue vehicle). Passengers waiting at Piano di Sorrento station are picked up by a different train from the one which unloaded them before;

- *Scenario 4.2*, similar to scenario 4.1 but, in this case, passengers waiting at Piano di Sorrento are picked up by the same train which unloaded them before;
- *Scenario 5.1*, similar to scenario 4.1 but, in this case, the rescue convoy has not yet gone past Scrajo. Therefore, it interrupts its ordinary service at Pozzano, where it unloads passengers, and proceeds empty to Scrajo for coupling to the faulty train. The coupled vehicle changes direction and finally the faulty train is recovered at Castellammare station;
- *Scenario 5.2*, as in scenario 5.1 but, in this case, passengers waiting at Pozzano are picked up by the same train which unloaded them before;
- *Scenario 6*, based on the use of a train operating in the same direction as the faulty convoy (i.e. from Sorrento to Naples) and which precedes it. Therefore, the operating train interrupts its ordinary service at Vico Equense, where it unloads passengers, and proceeds empty to Scrajo for coupling to the faulty train. The coupled vehicle then changes direction and the faulty train is finally towed to Vico Equense in order to be recovered. At this point, the rescue vehicle may restart its ordinary itinerary from Vico Equense to Naples, clearly under a properly rescheduled timetable.

From the above description, it is clear that the pre-configuration phase of all the rescheduling strategies required a sub-optimisation action which properly considered the features of the timetable and the infrastructural layout of the line.

As already shown, the first three strategies (i.e. from 1.1 to 2) are termed *ordinary* because they are allowed under the current regulations. They involve shunter locomotives or non-operating trains. By contrast, the other strategies (i.e. from 3.1 to 6) are termed *unconventional* because they involve vehicles which are currently not allowed to be used for rescue services. The application aims to investigate their technical feasibility in order to raise awareness among legislative authorities and make the use of these vehicles permitted, so as to improve service quality and passenger satisfaction during the failure management phase.

Table 1. User generalised costs for each scenario analysed

Scenario	User generalised costs [€]
1.1	340,116
1.2	317,855
2	336,659
3.1	355,061
3.2	375,753
4.1	345,727
4.2	313,805
5.1	275,010
5.2	274,887
6	322,489

By means of the proposed optimisation framework, the user generalised costs are computed for each intervention strategy as shown in Table 1.

Simulation results show that optimal intervention strategies are those based on the use of operating trains (i.e. with passengers on board) for rescue services, thanks to their towing capability and maximum achievable speeds. Moreover, the fact that such convoys are able to provide a service for passengers, immediately after completing rescue operations, makes them a most appropriate choice, with respect to non-operating trains, in order to minimise user discomfort. By contrast, the intervention strategies which provide the highest user generalised cost are those based on the use of electric locotractors. Indeed, contrasting with a low purchase price, together with the possibility of being located at strategic points of the line and also travelling on ordinary asphalt roads (in order to minimise the time required to reach the faulty train), they offer a very limited towing capability. This results in high disturbance to ordinary rail services and produces great inconvenience for passengers.

Conclusion and research prospects

In this paper, we proposed a methodology for determining optimal intervention strategies in the case of disruptions in a regional rail context. Our aim was to provide a decision support system for optimising the emergency management phase so as to minimise passenger discomfort when a breakdown occurs. By means of a micro-simulation optimisation framework, we compared the conventional and unconventional rescheduling strategies in terms of user generalised costs. Hence, beside the actions based on the use of vehicles allowed to be used for rescue services under current regulations, we investigated the technological feasibility of strategies which make use of other kinds of vehicles (i.e. electric locotractors and operating trains).

The application in the case of a real rail line shows that optimal rescheduling measures are those based on the use of operating trains. The reason is related to their high towing capability, thanks to which they are able to minimise the time required for managing the disruption and hence the delays and other perturbations to the planned timetable. As shown, the main drawback of such strategies concerns the issue of loading and unloading which may result in considerable discomfort for passengers. However, the simulation outcome showed that passenger waiting times on platforms, when they alight from the faulty train, are lower than the delays incurred if they remain on board and the system is restored by means of a diesel locomotive or an empty but distant rail convoy.

Nevertheless, the alteration of passenger perception remains. For this reason, it is fundamental to provide some info-mobility strategies for informing users regarding the development of emergency conditions. The last issue to be addressed concerns amendments to current regulations so as to make operating trains available for rescue services. However, as already shown, given the high level of complexity and automation achieved in all transportation fields, these unconventional measures are not of a safety concern, either for users and non-users of the system, and therefore this represents a mere formality.

With regard to future research, we propose to apply the suggested methodology to other network contexts and with different levels of travel demand, in order to investigate the stability of the optimisation intervention strategies with respect to passenger flows. Finally, in order to make the simulation much more realistic, it would be very effective to introduce the random nature of train performance into the modelling framework.

Disclosure statement

Authors declare that they have no competing financial, professional, or personal interests from other parties.

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