A decision support system based on transport modelling for events management in Public Transport Networks

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Abstract. This paper presents a modeling approach developed within the MOTUS project, designed to provide a standardized and solid intervention proposal to face events and disruption on a public transport network. This modeling approach resulted into a tool capable of identify in a formalized way the nodes and links where to broadcast info-mobility information through ITS systems, to lead the users to the best alternative solutions. The tool is exploited to make the decision process less dependent on the expert judgment (that still plays a vital role) and human factors, to allow the service provider to respond in a faster and clear way to the possible disruptions both through info-mobility and the strengthening of the offer on the involved routes. Therefore, this paper describes how the modeling approach is applied, how the resulting tool can be exploited and finally provides an example on the city of Milan, simulating the closure of one of the main lines and reporting the results provided by the presented model and the developed tool.

Keywords: Disruption Management, Transport Modelling, ITS, Decision Support System, Public Transport, Emergency Management

1 Introduction

The continuous development of collective transport networks in metropolis, along with the application of demand management policies aimed at discouraging the individual motorized mobility, led in the last years to a continuous increase in the use of collective means, both for systematic and for occasional travels. This trend has significant direct and indirect benefits at collective level. For this virtuous process to continue in the near future, the Local Public Transport (hereinafter LPT) system shall provide high efficiency standards to satisfy users and their needs as far as possible, e.g. by providing them with a regular and punctual service.

Over the years the companies managing LPT systems therefore developed operating procedures and solutions to increase the regularity and effectiveness of the service under ordinary service conditions; for example, satellite location systems for vehicles and real-time user information systems. Even though these solutions, as well as other technological innovations, allowed to increase the competitiveness of LPT with respect to private transport under standard service conditions, several criticalities still concern the management of emergencies caused by relevant disruptive events. Inconveniences prove particularly significant in case of service interruption on a main urban line, e.g. a railway or subway section, under consideration of the high number of users they affect.

In this context, a macro-model agile enough to evaluate different interventions and a tool to automatically produce the needed info-mobility strategies were developed to manage the events causing the interruption or the reduction of an LPT service. In fact, the designed model aims at identifying and proposing both interventions on the transport supply (dimensioning of the replacement service, increase in the number of means on the lines near the event, etc.), and strategic indications to manage the demand, which means providing users with focused, timely and effective information so they can choose more appropriate routes and means. The main contribution of the MOTUS project, as reported in this paper, was exactly to formalize the operating procedures and how they are defined during these disrupting events, so to eliminate or at least reduce the weight of human factors on the managing process. The tool developed within MOTUS is, in fact, flexible enough to be transferred and applied to other urban transport networks, as it will be showed in the following.

The modeling approach proposed and the corresponding tool for the analysis and management of collective transport under disrupted service conditions follows these steps:

- construction of a simulation model describing the collective transport system and simulating its operation under both standard and disrupted conditions;
- implementation of an analysis and intervention procedure to manage emergencies by enhancing the offer system in case of disruption. Threshold for different relevant indicators were identified so that the service provider would retain control over the adopted strategies while still enjoying the benefits of a semi-automated simulation process;
- implementation of a procedure and definition of the tool to identify strategic network nodes where users should be provided with useful information, in case of disruption, for them to spread out to new itineraries based on the optimum configuration given by the model.

2 State of the art

At operational level, the management of events causing interruptions, slowdowns, or more general consequences on a LPT network typically relies on the competence and experience of operators and functionaries of an operating center. The model and its tool, as described in this paper, refer to problems that are widely analyzed in the scientific literature and concern disruption management and user information management.

Within disruption management, a recent paper ([1] Sun et al., 2016) provides an interesting model to identify and characterize disruptions by analyzing users' behavior which, for the purposes of the model, is divided into three categories: missed passengers, detoured passengers, and delayed passengers. The model, which is applied to the metropolitan network of Beijing, allows to quantify the effects of a disruption in terms of journey time and delay.

Disruption management was also historically analyzed in detail in railways, a field offering a wide literature in particular on the timetable rescheduling problem. For example, the most recent papers on the subject focus on the development of methods and models in cases when the management of the transport supply is committed to different objectives: passengers' satisfaction, control of operational costs and of variations to the original time schedule [2], minimization of delays and cancellations [3]. Again in railways, the paper by [4] identifies and effectively highlights the three variables railway schedule, staff and rolling stock management to intervene in organizational terms to minimize inconveniences in case of disruption, thus developing a model that can enhance the configuration of the variables with few iterations.

A frequently used approach in disruption management, in the emergency planning, refers to the analysis of the vulnerability of transport networks by means of techniques, theories and models deriving from the theory of graphs. A wide overview and dissertation on this subject is given by Mattsson e Jenelius [5] in their work collecting the most recent researches on the subject, while a current application is presented for example in paper [6], which analyses the robustness of the subway network of Beijing based on the complex network theory.

Among other interesting recent works on disruption management [7], which presents a model developed in CPLEX to manage a disruption affecting the LPT of Vienna, and [8], which develops a model tested on the subway network of Naples to define the optimum intervention strategy in case of disruption on railway and metropolitan networks, also considering stochastic variations of train performances and delays.

Useful references for the model that is implemented and described in this paper are also researches and publications referring to methods, models and theories on the management of private transport networks. In particular, ([9] Russo and Vitetta, 2004), ([10] Velonà and Vitetta, 2004), ([11] Russo, 2001), ([12] Studer et al., 2007) and ([13] Studer, Marchionni and Ponti, 2009).

Other useful references for the management of passenger rerouting is [14], which addresses the problem of congested train stations along a subway line having boarding/alighting difficulty due to large volumes of boarding/alighting commuters, and [15], which proposes a novel probabilistic methodology to estimate the bus dwell time taking into account the interactions among buses, arrival passengers, and surrounding traffic.

The effective and ready management of user information in case of disruption is an efficient tool to limit inconveniences. On this subject, a useful reference is the paper by O. Cats e E. Jenelius [16] that analyses the mitigating effect that real-time information may have on the impacts of disruptions in LPT. In order to define strategic links and nodes of a network where users are to be informed, criteria such as the number of users, their needs and the actual possibilities of the network manager are taken into consideration. Other useful published papers that analyses the topic of user information in detail are [17], which analyzes the benefits obtainable by informing travellers of integrated public transport options using real time accurate information, and [18], which investigates customers' desired quality of IMTI (Integrated Multimodal Travel Information) provision in public transport. Both papers are based on surveys carried on public transport users in the city of Melbourne and in Holland respectively. They allow to understand the great importance given by users on the information they receive during their journey, above all in case of disruptions which force them to change their habits.

Finally, [19] proposes the design and development of a real time mobility information system concerning public transportation in the city of Milan, conceived in synergy with the methodology and the tool presented in this paper: however [19] is mainly aimed at developing a travel planner that can suggest personalized travel solutions for individual users involved in a disruption.

3 The macro-simulation model and the disruption management tools

The management of emergency situations on an integrated network of collective public transport is a task requiring, for every metropolitan context and in peace time, the development of defined procedures, which must be as far as possible standardized and shared between the several subjects that are to operate in case of relevant events. However, in some contexts or situations, the decisions may only be taken when an event occurs, based on criteria defined by the staff on duty and on their experience. The consequent interventions, although focused on solving the disruption, do not consider the global condition of the network and can hardly comply with criteria of resource optimization and minimization of inconveniences.

A greater effectiveness of emergency management can be obtained by engineering the procedures to follow in case of disruption. The aim of the presented modeling approach is to offer intervention solutions complying both with a precise criterion of optimization of the available resources and with the minimization of overall time-wasters at collective level, i.e. all network users.

The implemented model consists of different phases to carry out sequentially. The first stage is a double simulation that allows a comparison of users' flow on the various sections of the network between the Baseline Scenario (mobility as usual) and the Disruption Scenario. By evaluating the results of the first comparison, the model utilizer (generally a control room operator) may define the main parameters governing the following steps of the model. In the successive step, the model determines the necessary enhancements of the offer system during the disruption. In the last phase another comparative simulation is carried out between the Baseline Scenario and the Intervention Scenario (defined as the Disruption Scenario with the addition of the implemented enhancements); on the basis of this comparison the model determines the content and the location of the information to be provided to users.

The main contribution developed during the MOTUS project is represented by the intermediate and the last phase: in fact the designed model is not limited to the simulation of the transport network considering the disrupted segments, but actually grants the service provider with the routes to be strengthen and the needed transport means on the basis of some service thresholds, and determines the necessary information to communicate to users. Fig. 1 provides and overview of the process through a flowchart, detailing when in the process the developed tools exploit the simulation outputs.

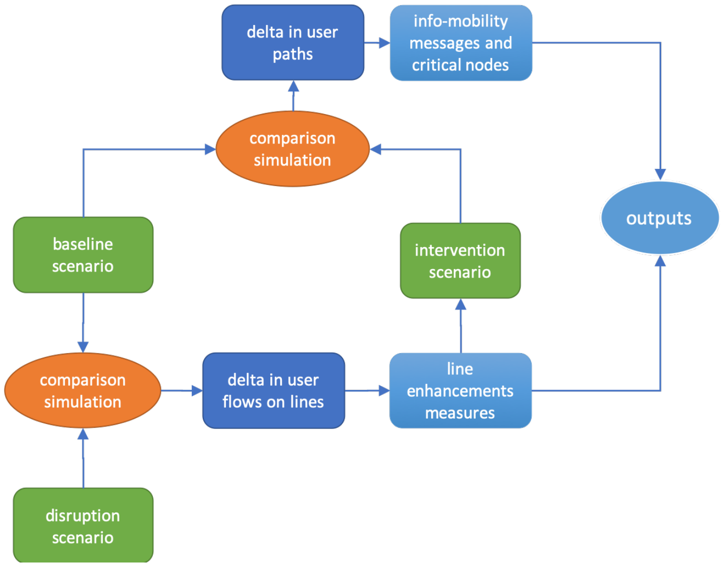

Fig. 1. Model flowchart.

Simulations aside, this paper also describes the info-mobility and intervention tools, both designed through the Cube software environment and its programming language. Cube is a modeling platform that covers all aspects related to transportation planning, engineering, and land-use. A brief example of the coding of the model is shown in Fig.2. Through these tools, the control room operator is able to automatically obtain both the lines to be strengthened, the number of additional vehicles and the messages to be broadcasted at each node.

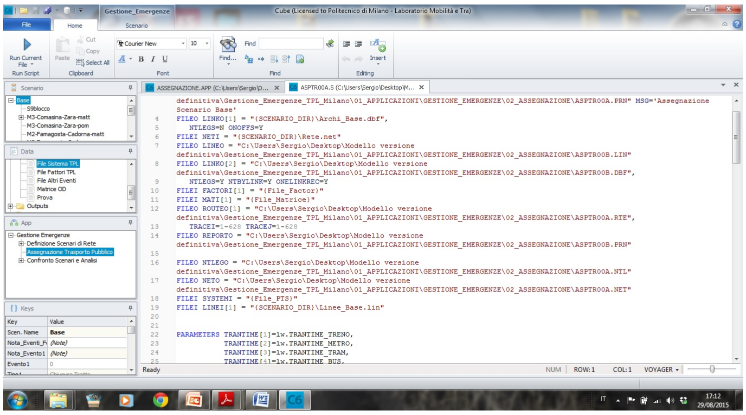

Fig. 2. Extract of the tool script.

3.1 First simulation: normal state of the network (Baseline Scenario)

This first phase does not differ much from macro-simulations as found in literature but it is necessary to frame the state of the network and define a benchmark against which compare the effects of the disruption and the goodness of the adopted interventions (on which the info-mobility tool defines the messages to be broadcasted and where to broadcast them). Still, it is worth to highlight that the model was calibrated with a focus on the LPT routes on the basis of the travel times; the ones obtained through the model during the application to the Milan case study were compared with the ones provided by ATM (the transport company managing the public transport lines in Milan).

Moreover, the model adopts the hyperpaths algorithm; the process is based on proper parameters and consists in two main phases: the identification of hyperpaths and the calculation of the probability to choose each route. In the first phase of hyperpaths identification, the model identifies a discrete set of possible routes for each origin-destination pair. Theoretically, this process may generate an infinite number of hyperpaths. In order to avoid this, the following approach is applied:

- for each origin-destination pair the minimum-cost hyperpath is identified;
- further possible hyperpaths are found that have a lower cost than a limit value that is specifically defined;
- at last, identified routes are eliminated if they show a number of interchanges that is higher than a specified value.

In the second phase of the process of calculation of routes, the probability to choose each route is defined.

3.2 Second simulation: Disruption Scenario and scenarios comparison

The above-mentioned process of assignment, carried out for the normal (non-disrupted) state of the network, is replicated for the disrupted condition of the network. The events of disruption are given to the model as inputs files (through .csv files for surface lines and through a dashboard specifically developed for high capacity lines like subways) containing all the disrupted lines, the involved direction, the involved nodes and the kind of event (closure of line segment or closure of a station).

The two simulations (Baseline Scenario and Disruption Scenario) are compared to highlight the different distribution of passenger flows along the network. As a first output at the end of this simulation phase, the model generates, for each LPT line, a list containing the flow/capacity value for each link of the line in both scenarios (in Fig. 3 is reported an extract referred to the M3 subway line of Milan).

A	B	DIST	VOL_1	FMCAPACITY	RAPP_V_C_1	VOL_2	FMCAPACITY	RAPP_V_C_2
30085	30082	1.68	2970.91	38640	0.08	2970.39	38640	0.08
30082	30077	0.79	8872.67	38640	0.23	8906.93	38640	0.23
30077	30072	0.67	10194.74	38640	0.26	10226.72	38640	0.26
30072	30068	0.37	11275.17	38640	0.29	11305.45	38640	0.29
30068	30063	0.86	12580.43	38640	0.33	12610.67	38640	0.33
30063	30057	0.82	13311.24	38640	0.34	13491.28	38640	0.35
30057	30050	0.66	14100.54	38640	0.36	14334.69	38640	0.37
30050	30041	0.78	14123.91	38640	0.37	14417.02	38640	0.37
30041	30042	0.43	14677.51	38640	0.38	15852.8	38640	0.41
30042	30046	0.69	9018.12	38640	0.23	12897.44	38640	0.33
30046	30048	0.55	8300.84	38640	0.21	12184.87	38640	0.32

Fig. 3. Flow/capacity ratio in Baseline Scenario (1) and Disrupted Scenario (2) for each link of M3 subway line of Milan. Link with maximum flow/capacity ratio is highlighted.

In addition, the model determines the average variation along the line and the maximum change (which occurs on the section that is mostly affected by the disruption). For example, in Fig. 4 are shown flow/capacity changes (in absolute and percentage) for the lines of the Milan LPT network that have positive variations of these values.

NOME_LINEA	RAPP_MED_1	RAPP_MED_2	D_RAPP_MED	P_RAPP_MED	RAPP_MAX_1	RAPP_MAX_2	D_RAPP_MAX	P_RAPP_MAX
TRAM33	0.14	0.24	0.1	71.43	0.31	0.65	0.34	109.68
TRAM7	0.06	0.08	0.02	33.33	0.16	0.23	0.07	43.75
Bus48	0.1	0.13	0.03	30	0.2	0.26	0.06	30
Bus37	0.19	0.25	0.06	31.58	0.58	0.74	0.16	27.59
M1	0.26	0.3	0.04	15.38	0.57	0.72	0.15	26.32
TRAM2	0.34	0.4	0.06	17.65	0.86	1.03	0.17	19.77
TRAM14	0.37	0.38	0.01	2.7	0.72	0.86	0.14	19.44
TRAM3	0.25	0.3	0.05	20	0.67	0.8	0.13	19.4
TRAM15	0.21	0.24	0.03	14.29	0.56	0.66	0.1	17.86
Bus965	0.49	0.55	0.06	12.24	1.4	1.64	0.24	17.14
M3	0.16	0.18	0.02	12.5	0.38	0.44	0.06	15.79
TRAM23	0.25	0.28	0.03	12	0.55	0.63	0.08	14.55
Bus79	0.06	0.05	-0.01	-16.67	0.14	0.16	0.02	14.29
Bus713	0.08	0.09	0.01	12.5	0.22	0.25	0.03	13.64
BUS190	0.1	0.1	0	0	0.22	0.25	0.03	13.64
S11	0.89	0.94	0.05	5.62	2.14	2.43	0.29	13.55
Bus70	0.08	0.08	0	0	0.26	0.29	0.03	11.54

Fig. 4. Average (med) and maximum (max) flow/capacity variation in absolute value (d) and percentage (p) for some Milan LPT lines. Line with maximum percentage increase is highlighted.

The analysis of the results given, in terms of extent of the variations on the several lines, allows to quantify the effects of the disruption on the public transport system, and the priorities of any intervention.

3.3 Intervention tool: strengthening of the service and Intervention Scenario

In order to define the strengthening of the service to be implemented, some criticality thresholds related to flow/capacity values are defined, beyond which a line can be defined as critical. In particular, a generic line *l* is considered critical if the following three conditions are meet:

- the absolute value $R^{D}_{l\,MAX}$ for the *l*-th line of the maximum flow/capacity ratio in the Disruption Scenario exceeds a predetermined threshold $\bar{R}_{min}$:

$$R^{D}_{l\,MAX} > \bar{R}_{min} \tag{1}$$

- the percentage increase $\Delta P_{l\,MAX}$ for the *l*-th line of the maximum flow/capacity ratio between the Baseline Scenario and the Disruption Scenario is greater than a predetermined threshold $\bar{P}_{min}$:

$$\Delta P_{l\,MAX} > \bar{P}_{min} \tag{2}$$

- the ratio between the linear extension of the *l*-th line sections characterized by critical conditions (as defined by the previous two points) $l_{CRIT\,l}$ and the total line length L_l is greater than a predetermined threshold $\bar{E}_{min}$:

$$\frac{l_{CRIT\,l}}{L_l} > \bar{E}_{min} \tag{3}$$

The first two conditions refer to single line links. The simultaneous exceeding of threshold (1) and threshold (2) makes the line link critical. If the number of critical links is such as to affect a percentage extension of the total line route that is higher than the threshold (3), the line itself will be considered as critical and therefore in need of enhancement.

The setting of the thresholds values depends on the overall capacity of the LPT operator to cope with offer enhancements and can therefore be calibrated by simulating a set of possible disruptions on the network.

In particular, condition (1) allows to define an absolute threshold lower limit; ideally, the value of $\bar{R}_{min}$ should be set at 1 or even less than 1 if to ensure a greater level of comfort. Contrariwise, in case of a network normally very congested, during emergency conditions the flow/capacity ratio can exceed the value of 1 on several links and several lines. In this case, considering the limits of the resources available (means and people), and requiring intervention priorities to be defined, it is possible to set the $\bar{R}_{min}$ threshold even above the unit value, by calibrating it on a value that is considered appropriate by the LPT network operator.

The fulfilment of condition (2) guarantees that only those links, and potentially the lines, where crowding considerably increases because of the disruptive event will be considered as critical. Lines that are already overcrowded in standard conditions are therefore excluded. A decrease in crowding on these sections should hopefully be obtained in the long term, but it is not relevant for the aims of the emergency management which this model is implemented for.

Condition (3) sets a limit on the extension of the criticality along a LPT line to make it require an enhancement: service enhancements are only planned on a line that is considered as critical based on conditions (1) and (2), if it involves a higher percentage of the total route than the set threshold.

The developed tool allows the dynamic definition of threshold values requiring service enhancements or not. As a function of the single case study, of the significance of the disruptive event and of the availability of mitigating resources, it is therefore possible to vary these thresholds to effectively react to the emergency. If the real-time model is used to manage emergencies, the need to quickly set appropriate values requires an adequate sensitivity in use on the part of operators. Intervention scenarios can nevertheless be prepared in peace time, possibly making iterations with several values and opting for those which most satisfy the operational needs of the transport company. Still in the following case study, the values adopted for the MOTUS project and the city of Milan will be reported.

For the lines defined as critical according to the procedure described above, the model will suggest enhancements. The model is designed in a way that, through the comparison of the Baseline and of the Disruption scenarios, by exploiting the defined thresholds the interventions are automatically obtained. In fact, this phase of the model generates the list of interventions to implement in order to mitigate the effects of the disruptive event. For critical lines, the number of additional means required is defined; the enhancement will be such as to bring the crowding condition on the line below the threshold value $\bar{R}_{min}$ that initially determined the condition of criticality.

Once the lines to enhance according to the above-mentioned algorithm are defined, the graph of the network is updated with the planned enhancements. The successive simulation consists in the assignment of the demand to the graph modified from the supply side, and the result is the final users' optimum distribution on the network, named Intervention Scenario.

The management of the emergency shall aim at letting users spread out according to the optimum configuration defined by the assignment of the Intervention Scenario, thanks to the information they received along the route as defined by the model itself.

The information, as well as the strategic nodes where it is to be provided, are defined by means of algorithms based on the comparison between the flows assigned in the Intervention Scenario and the flows of the non-disrupted Base Scenario.

Fig. 5 shows the result of the process of comparison. LPT lines sections where, in case of disrupted service, users should be redirected and consequently flows will increase are highlighted in green. Conversely, lines where users will decrease are highlighted in red. Lines to reroute users can therefore also be found at qualitative level.

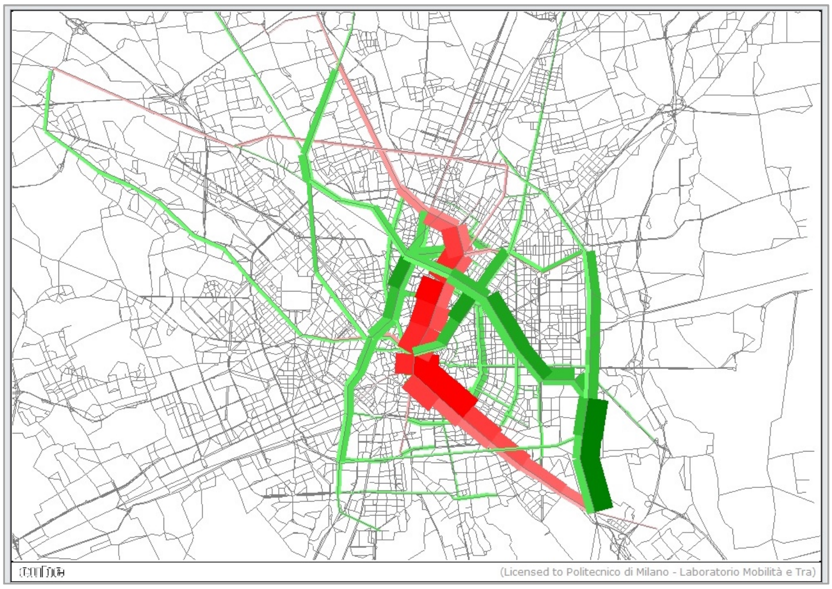

Fig. 5. Comparison between volumes assigned in the Baseline Scenario and in the Intervention Scenario in the city of Milan, downstream offer enhancements.

3.4 Info-mobility tool: definition of information to be provided to users

Based on the analysis of the way the flows distribution varies with respect to the undisrupted Baseline Scenario, the info-mobility tool will generate a word-processed report containing a list of the aggregate information to provide users with, as well as of the strategic network nodes where it shall be given. This kind of information aims at addressing users' flows towards the best alternative route by means of information that is as simple and immediate as possible.

The implemented algorithm is based on the evaluation of variations (between Baseline and Intervention scenario), both absolute and in percentage, of the users' flow on the different links of the network. The set of links on which it is necessary to provide information is determined on the basis of two simultaneous conditions:

- the absolute increase or decrease ΔF_{il} in the flow of users on each *i*-th link of the *l*-th line between the Baseline Scenario and the Intervention Scenario is greater than a predetermined threshold $\bar{F}_{min}$:

$$|\Delta F_{il}| > \bar{F}_{min} \quad (4)$$

- the percentage increase or decrease $\Delta F_{\% il}$ in the flow of users on each *i*-th link of the *l*-th line between the Baseline Scenario and the Intervention Scenario is greater than a predetermined threshold $\bar{F}_{\%\,min}$:

$$|\Delta F_{\% il}| > \bar{F}_{\%\,min} \quad (5)$$

Focusing on the set of links identified by the above described conditions, a subsequent condition is placed on the starting and final nodes of the links themselves, in order to definitively identify which are the essential points of the network where to provide information to users (directing them towards their ideal alternative path): the absolute increase or decrease in the numbers of users getting on (ΔON_{ni}) and getting off (ΔOFF_{ni}) at the n-th node of the i-th link between the Baseline Scenario and the Intervention Scenario is greater than the previously determined threshold $\bar{F}_{min}$:

$$|\Delta ON_{ni}| > \bar{F}_{min} \quad (6)$$

$$|\Delta OFF_{ni}| > \bar{F}_{min} \quad (7)$$

As with the evaluation of enhancements, the thresholds determining the significance of a variation in terms of information diffusion are also defined as input by the evaluator using a specific user interface developed with the tool.

The developed model can specify the text of the information as well as its space location, i.e. its stop-node where the message is to be transmitted. Moreover, the needed information are prioritized on the basis of the number of reached users for each node. The duration of the simulation process is limited so that information is given quickly to prepare staff and means for an enhancement of the service.

4 The Case Study

The developed model and tool were then applied to the Milan city to evaluate different scenarios in which one or more sections of the underground lines can be interrupted; as an example, a specific case is presented below, in which a section of the M3 subway line is interrupted between the stations of Sondrio and Porta Romana, as showed in Fig.6.

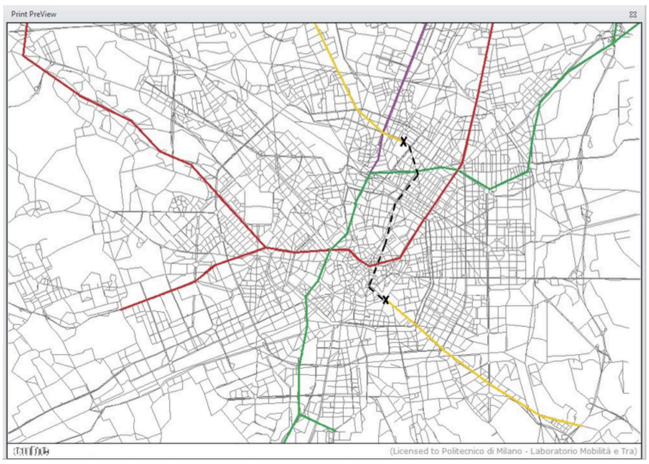

Fig. 6. Section closure on the subway M3 line between Sondrio and Porta Romana.

The simulations were carried out considering the morning peak-hour, 7 stations were made unavailable due to said closure. Again, it should be highlighted that the results that will be reported in the following were obtained in a semi-automated and formalized way. The value of the developed modeling tool presented in this paper lies, in fact, in the easiness and responsiveness of the model that allows the service provider to obtain both the interventions and the crucial points where to broadcast the info-mobility information. Therefore, it should be clear to the reader that the following results could be obtain for any other disruption of the public transport network, in short times and through a user-friendly tool.

For the Milan case study, and in particular for the specific scenario presented, the values of the thresholds introduced in chapter 3 and used in input for the model are detailed in Table 1.

Table 1. – Value of threshold used in the Milan case study.

Threshold	*Brief description*	*Value*
$\bar{R}_{min}$	flow/capacity ratio	0.8
$\bar{P}_{min}$	percentage increase of flow/capacity ratio	15%
$\bar{E}_{min}$	extension of criticalities along the line	20%
$\bar{F}_{\%\,min}$	percentage increase or decrease of passengers' flow on links	20%
$\bar{F}_{min}$	Absolute increase or decrease of flow on links and of passengers getting on/off at stops	200 (metro,train) 100 (bus, tram)

It should be clear that, when talking about increase and decrease it is meant a comparison between the Baseline Scenario and the Disruption/Intervention Scenarios.

The intervention tool of the model, based on the first three thresholds of Table 1, suggests for the case study in question the enhancement of one bus line (line 222 with 3 additional vehicles) and three train lines (one more run for each of them) in their urban section.

The last two thresholds are conversely important for the info-mobility tool: in fact, through these values the tool decides what are the nodes worth of involving in the broadcasting of the information, as showed in fig. 4. To use the delta in volume at nodes guarantees that the messages are broadcasted only where and when needed.

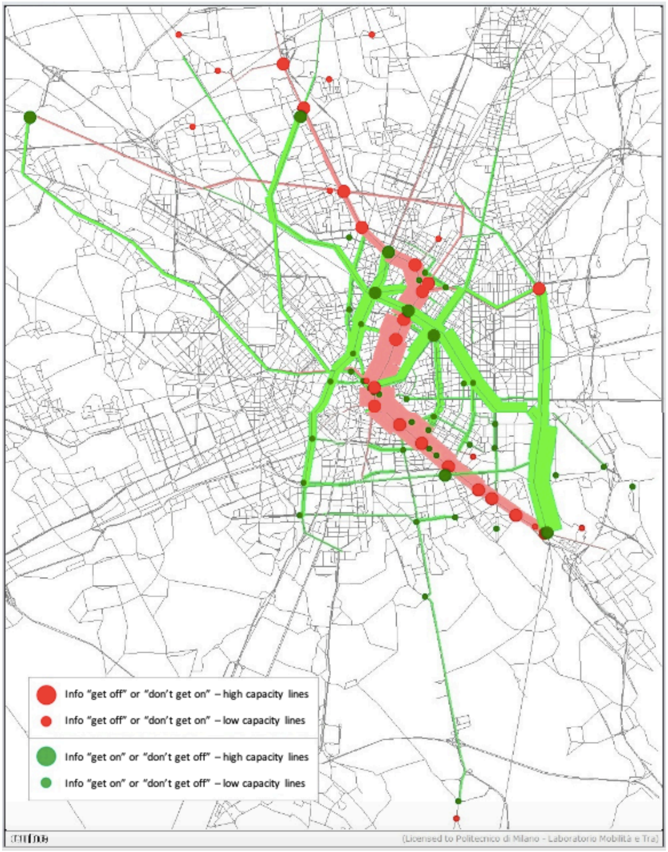

Fig. 5. Output of the info-mobility tool: localization of network points where to provide information to users.

Again, the information tool of the model gives an output that includes both the nodes where to broadcast the information and the set of information itself; an extract of this list of information is shown in Table 2.

Table 2. Extract of info-mobility messages to be provided to users, as given by the tool

STOP/NODE (LINE)	***POINT OF BROADCASTING***	***INFO-MOBILITY MESSAGE***
MACIACHINI M3	Surface lines (on-board)	*Don't get off tram line 4 but continue to Lanza M2 - Cairoli M1*
	Within the metro station and at the surface transit stops	*Don't get on line M3*
		Take the tram line *4 up to Lanza M2 - Cairoli M3*
ZARA M3	Metro (on-board)	Exit the M3 line
		Don't get off line M5 but continue to Garibaldi FS

	Within the metro station and at the surface transit stops	*Don't get on line M3*
		Take line M5 and continue to Garibaldi FS
SONDRIO M3	Metro (on-board)	*Get off line M3*
	Surface lines (on-board)	*Don't get off bus line 43 but continue to Gioia M2 - Turati M3*
	Within the metro station and at the surface transit stops	*Don't get on line M3*
		Take bus line 43 and continue to Gioia M2 - Turati M3
		Take bus line 90 and continue to Centrale M2-M3 - Caiazzo M2 - Loreto M2-M3
		Take bus line 92 and continue to Centrale M2-M3 - Caiazzo M2 - Lodi M3
CENTRALE M2-M3	Within the metro station and at the surface transit stops	*Don't get on line M3*
		Take tram line 5
		Take tram line 9 and continue to P.ta Romana M3 - P.ta Lodovica - P.ta Genova M2
		Take bus line 92 and continue to Sondrio M3 - Zara M3-M5
…		

Both the nodes of broadcasting and the messages as defined above are given back by the developed model, based on the functional thresholds as defined by the service provider. This allows the public transport service provider to test different events and situations in a flexible and replicable way, without consuming time and efforts. In the same way, the model gives back also the means of transportation and their location to be deployed to restore the service level under the defined thresholds, as will be showed in the following. It should be highlighted that the info-mobility messages are already including the alternative routes and vehicles. Again, should the number of additional vehicles be too high as an effort, the service provider can access the tool and act on the level of service to tune the suggested solutions. Finally, even though in this case study no additional vehicle is suggested for the train line, the line is considered in the tool and can be strengthened as well.

5 Conclusions

Aim of the paper was to describe the developed model and highlight how, through the programmed tools, it grants to service providers and public transport companies both the possibilities of planning ahead for certain disrupted scenarios and of reacting promptly and in a formalized way to unforeseen events. Through the description of the case study it was shown how the tool calculates the best strengthening actions and routes and also identifies the crucial nodes and the information to be broadcasted.

The main highlights are focused on the methodological part; though, it is described through the paper how the model is designed to grant control to the evaluators, through thresholds definition and a flexible simulation activity based on the comparison with the baseline state of the network. The simulation phase of the model doesn't differ much from a macro-model analysis, so a certain degree of simplicity was maintained in its description; however the developed tools are based on the outputs of this simulation activity (specifically on the scenario comparisons) and were designed in a way that presents the results as coherent and co-existent with the results of the simulations themselves.

Therefore, the paper tries to describe and report both the methodological approach and the resulting tools in order to promote as best-practice this formalized analysis of public transport networks responding to disruptive events, both planned and unforeseen. It is acknowledged both in industry and in literature that public transport will see growing both its importance and the resulting challenges in future cities and metropolis such as Milan, therefore the paper tries to contribute with the tools to improve the resilience and the operational performance of the public transport system.

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