Automatic conflict detection and resolution in metrorail systems: evaluation approach for MARCO EU project

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Abstract

The European Union (EU) is promoting, within Telematics Application Programme, several Research and Development (R&D) projects, devoted to Transport Sector, containing high profile telematics technology applied to planning and operational tasks. In particular, MARCO, acronym of Multilevel Advanced Railways Conflict resolution and Operation control, concerns the development of telematics tools for traffic conflict management: the project purpose is to develop a set of tools, algorithms and technologies for the Conflict Detection and Resolution (CDR) in a wide range of real time applications within railways and metros networks. In order to assess MARCO functionality in metrorail applications, a CDR demonstrator will be developed and installed in Milan Underground at Sesto terminus, and subsequently tested and evaluated during traffic real operations through suitable procedures. In this paper the authors present a proposal for evaluating, on the basis of objective indicators, the performances of the above mentioned demonstrator, taking into account both a comparison between historical field data and actual operations, and a comparison between actual operations and simulated operations (without MARCO) in presence of the same traffic conditions.

1 Introduction

In the Fourth Framework R&D Programme, the Telematics Applications Programme (TAP) has to promote the competitiveness of European

industry, to improve the efficiency of services of public interest, and to stimulate job creation through the development of new telematics systems and services. At the beginning of the programme, Europeans yearly spent over 500 billion ECU on transport, and the economic losses associated with traffic delays and accidents were estimated at 150 billion ECU annually. Then, new solutions were needed to reduce the high levels of accidents, congestion and pollution caused by today's ever increasing traffic volumes. Tangible benefits are expected, through the application of telematics systems, on indicators such as quality of service, travel times, number of accidents, regularity of public transport, pollution. In particular, MARCO project, which is involved in *Task 3.27 - Control Centres* of the Telematics Workprogramme, has to develop a telematics based support environment in rail and metrorail control centres to enhance systems efficiency through a better regulation of traffic operation. This improvement will be realised by means of advanced software tools, which will be introduced in modern Traffic Management Systems (TMSs), in order to manage and solve perturbed traffic conditions.
In this paper the authors present the evaluation activities carried out during the project development and define some performance measures, which could be utilised in metro verification site in order to assess if the initial project objectives are reached.

2 Overview of the project

Several factors affect traffic regularity and the resulting delays vary from a few seconds to several hours. Such perturbed traffic conditions are usually managed by human operators (dispatchers) but, as traffic complexity increases, an advanced software system could be very useful in order to help the dispatcher in the decision process or to perform automatically conflict solution [1]. Referring to a multi-layered Supervision System for Traffic Control, the project will improve Conflict Resolution Sub-systems (CRSs) for:

- Global Area Network (GAN) level, which includes many High Traffic Areas.
- High Traffic Area (HTA) level, which includes complex junctions, stations and lines.
- Underground level, developed for its most complex operational situation (end line).

The project, which started at the beginning of 1996, involves several partners coming from metro and railway administrations, industries and universities and it is co-ordinated by *ABB Daimler-Benz Transportation (Adtranz Italy)*. Starting from the knowledge of the procedures for

conflict detection and resolution utilised within the existing traffic Management Control Centres, the project has identified, at first, the methods used by the dispatchers and the possible benefits due to the introduction of a computerised system, formalising the results in the User Requirements and Constraint Definition documents.
The second phase of the project has developed the Functional Analysis and the System Architecture.
During the third phase, the algorithms development and their assessment have been carried out in order to highlight the most promising optimisation techniques to be utilised in the traffic detection and resolution process.
The major emphasis in the Fourth Framework is on verifying the benefits of telematics applications for solving real-world problems. To this aim a set of demonstrators (prototypes) will be developed, both in real and simulated environments. The demonstrators functionality in the presence of typical conflicts, distinguished by levels of disposition as shown in Table 1, will be verified.

Table 1 - Typical conflicts

Type of conflict	*HTA Junction*	*GAN*	*HTA Line*	*Metro*
Train headway conflict (track usage)	✓		✓	✓
Train meeting conflicts			✓	
Train passing conflicts	✓		✓	
Locked tracks	✓	✓	✓	
Fouling of gauge		✓		
Route conflicts (in interlocking system)	✓		✓	✓
Platform (berth) conflicts	✓			
Train connection	✓	✓		
Re-routing conflicts		✓		
Local load peak conflicts on a line		✓	✓	
Local load peak conflicts in a junction	✓	✓		
Impact of conflicts in neighboured railways		✓		
Conflicts with additionally inserted trains		✓	✓	
Roster conflicts		✓		
Convergence conflicts	✓			

In the following Table 2 MARCO experimental sites are shown.

Table 2 - Verification sites

Verification Site	*MARCO Level*
Milan Metro - Sesto Terminus (Italy)	Underground
FS Milan Junction (Italy)	HTA
VR Huopalahti Junction (Finland)	HTA
NMBS/DB Connection (Belgium)	GAN

In order to assure that the project, during all its life, is well managed and each step is coherent with the others, a specific task, Evaluation, has been developed in parallel with the project.

3 The role of verification and evaluation

The verification process aims to finally provide realistic guidance to the way the experimental scheme will operate and be used in normal, full-scale application, to determine its user and wider acceptability, to inform potential investors of commercial performance and market potential, and authorities of the wider social effects, costs and benefits [2], [3].
In MARCO, the relationships and information exchanged during verification among different workpackages are shown in Figure 1: developers have to build the demonstrators, integrating the subsystems previously developed in order to meet the requirements stated by the users, verification activities have to test the operating performance of each application and to make the application acceptable by end users, and evaluation has to determine the value of the application in comparison with alternative applications and/or with a reference case, analysing results of related experiments and deriving recommendations for decision makers.
The responsible partner of the evaluation activities, developed in MARCO, is the *Dipartimento di Ingegneria Elettrica - Università degli Studi di Genova* (*UGDIE*), which is not directly involved in any system development phase in order to guarantee a high level of independence.
The evaluation objectives are:

- to assess that MARCO application successfully solves the problem of conflict detection/resolution in a wide range of real time applications within railways and metros network;
- to guarantee the quality aspects of the project development.

The Evaluation Plan, developed by the Consortium, has formalised some verification objectives, summarised in the following bullet list, which

have to be taken into account during the verification activity on the basis of associated indicators:

- capability of detection;
- capability of resolution;
- improvement of traffic regularity;
- MMI with control features for all resolution measures;
- display capability for network layout, load status and train data.

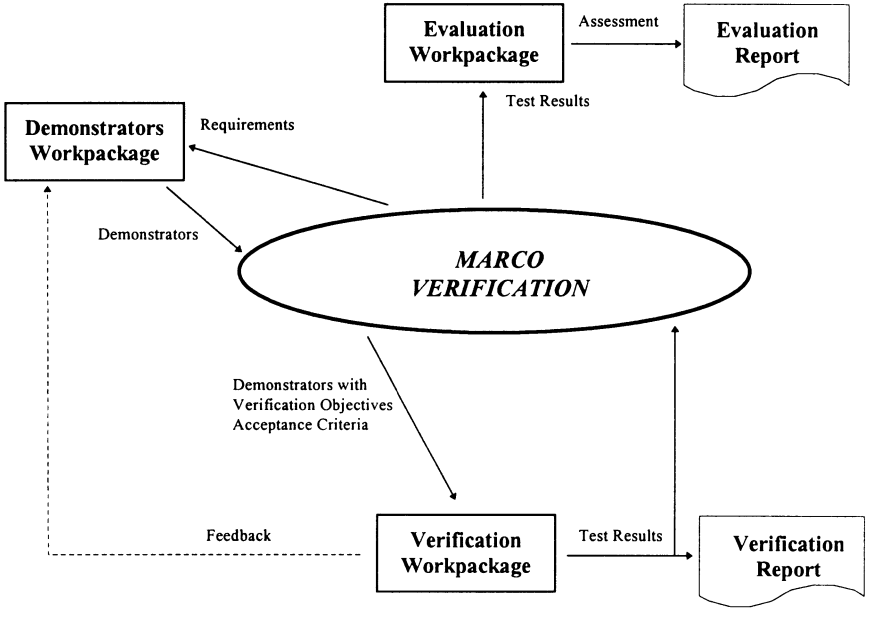


Figure 1 - Relationships during verification

The final goal of the verification activities is to make available a set of results allowing the evaluation team to analyse the traffic performances on the basis of suitable predefined indexes before and after MARCO during an adequate time period, which depends on the nature of the controlled area.

It is worth noting that all the objectives have not to be assessed in each verification site, and for this reason it is mandatory to define in detail the purpose of each demonstrator in terms of the objectives to be verified.

In particular, as far as Milan Metro demonstrator is concerned, the impact due to the introduction of MARCO tools on traffic regularity has to be analysed and the improvement assessed.

3.1 Milan Metro Demonstrator

Milan Metro demonstrator will run on site, but an evaluation activity simply based on the comparison between field test and a data collection, *a priori* defined, may not lead to a satisfactory assessment of the performances. In fact, in the real operation of the demonstrator, the disturbances comes from the stochastic behaviour of the traffic and cannot be controlled at all (i.e. it is not possible to repeat the same identical condition within different experiments). For this reason a laboratory evaluation of the demonstrator should be provided, before performing the field test, allowing to:

- test the demonstrator before field operation;
- assess the demonstrator performance in presence of well defined and repeatable events.

By this way the assessment of the Milan Metro demonstrator will have two contribution: laboratory - simulated assessment and field test assessment.

During the field testing, the demonstrator will be located in the terminus of Sesto. The final user of the demonstrator is the dispatcher who has in charge the interlocking command console of Sesto terminus and has basically a *read only interaction* with the demonstrator, which gives him:

- an updated suggestion of the commands to be executed by means of the interlocking console;
- a short term forecast of the next arrivals to the terminus;
- a short term forecast of the behaviour of the terminus, as a consequence of the application of the above commands.

The commands are described as a *timed list* of part routings to be executed, while the forecast is described as a prediction of trains arrival and departure times. By an operational point of view, the dispatcher is free to follow or not the timed commands sequence suggested by the demonstrator. If the dispatcher does not correctly follow the suggestion of the system, the forecast is no longer valid.

The basic aim of Milan Metro demonstrator is to suggest to the dispatcher a regulation policy of the terminus allowing to obtain:

- on schedule departure timing, even if arrival timing are not regular (if arrival irregularity is not too big and may be fully recovered by terminus operation capability);
- a smooth recovery of the departure irregularity, in the case of strong perturbations of arrival times.

The evaluation of the demonstrator will be carried out by analysing the improvement of traffic regularity inside the terminus area, measured by means of adequate performance indicators, as suggested by the authors in the next paragraph.

4 Performance indicators for Milan Metro

In this paragraph the performance indexes which may be utilised for the evaluation of Milan Metro demonstrator are described.

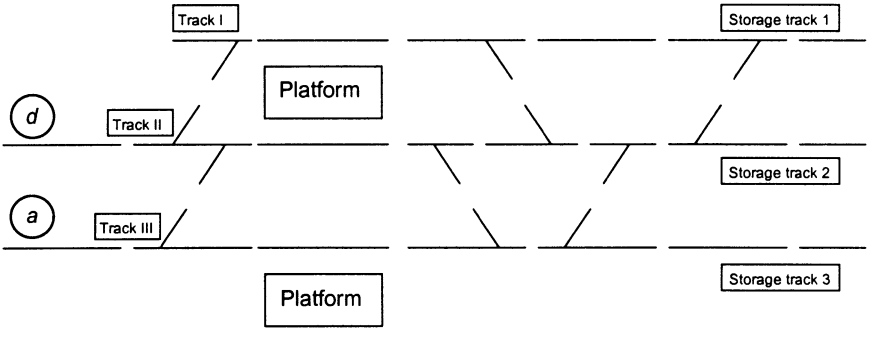


Figure 2 - Sesto terminus layout (*a* = arrival, *d* = departure)

According to the physical layout of Sesto terminus, depicted in Figure 2, and to the objectives of the demonstrator, defined in the previous paragraph, the following two indexes have been taken into account:

- delay index - departure;
- headway index.

Such indexes, which if suitably customised may be utilised for both railway and metro systems, allow the estimation of *service quality* as far as operating characteristics are concerned. They coincide with the ones proposed by UITP, but their analytical expressions have been suitably revised in order to be applied in different scenarios.
For a generic index X, the relationships for the measure of the average value X_m, of the RMS value X_{RMS} and of the standard deviation σ_X are presented; in particular, the last one gives probabilistic information about a population starting from a measure performed on a limited number of elements, being about 68% the probability that X assumes a value in the range $(X_m - \sigma_X, X_m + \sigma_X)$ if X is supposed normally distributed.

4.1 Delay index *D* (departure)

The delay index D is defined as:

$$D = t_{dep_real} - t_{dep_sch} \quad (1)$$

where:

t_{dep_real} = real departure time, measured in point *d* of Figure 2
t_{dep_sch} = scheduled departure time

The average value D_m is:

$$D_m = \frac{1}{n}\sum_{k=1}^{n} D_k \tag{2}$$

The RMS value D_{RMS} is:

$$D_{RMS} = \sqrt{\frac{1}{n}\sum_{k=1}^{n} D_k^2} \tag{3}$$

The standard deviation σ_D is:

$$\sigma_D = \sqrt{\frac{1}{n-1}\left(\sum_{k=1}^{n} D_k^2 - nD_m^2\right)} = \sqrt{\frac{n}{n-1}\left(D_{RMS}^2 - D_m^2\right)} \tag{4}$$

where:
D_k = departure delay index for *k-th* train
n = number of observed trains

4.2 Headway index *f*

The headway index *f* is defined as:

$$f = h_{real} - h_{sch} \tag{5}$$

where:
h_{real} = real headway
h_{sch} = scheduled headway

The average value f_m is:

$$f_m = \frac{1}{n}\sum_{k=1}^{n} f_k \tag{6}$$

The RMS value f_{RMS} is:

$$f_{RMS} = \sqrt{\frac{1}{n}\sum_{k=1}^{n} f_k^2} \tag{7}$$

The standard deviation σ_f is:

$$\sigma_f = \sqrt{\frac{1}{n-1}\left(\sum_{k=1}^{n} f_k^2 - nf_m^2\right)} = \sqrt{\frac{n}{n-1}\left(f_{RMS}^2 - f_m^2\right)} \tag{8}$$

where:

f_k = headway variation for *k-th* train
n = number of observed trains

In order to perform the impact analysis on traffic regularity in Milan Metro due to the introduction of MARCO, a collection activity of historical data has been carried out, taking into account the following conditions:

- winter timetable (September-October);
- peak evening hours (17.00 - 18.50);

which represent both the analogous period when the field test will be executed and the time interval when the traffic disturbances may be highly probable.
In particular, the data collection is related to the following events:

- arrival at the terminus;
- departure from the terminus.

The first class of data deals with the definition of disturbance typology (frequency and duration), while the second one is useful to characterise the previously mentioned indicators before the introduction of MARCO tools. Moreover, they allow a better knowledge of the arrival delay pattern (for algorithms refinement purposes) as well as the actual terminus regulation policy.
The sample size required to be significant will be dimensioned later by experimental way. At present a good starting point may be a sample of 300 trains passing through the terminus (about 10 days of peak hour operation).
The values of *historical* performance indexes will be calculated and analysed by means of adequate statistical methods in order to make possible a comparison with the analogous indexes, similarly collected during the test activity of MARCO demonstrator.
The final release of the performance indexes to be utilised for the evaluation of Milan Metro application will be further refined, taking into account the final version of the optimisation strategy implemented in the demonstrator.

5 Conclusions

In this paper the authors have presented the evaluation framework of EU Telematics project MARCO. In particular, starting from the general objectives proposed by the project, they have highlighted the evaluation activity which will be carried out in the Milan Metro verification site, where a demonstrator will be implemented and executed utilising the data coming from the field operation. To this aim the set of indicators,

which will be probably utilized for impact analysis on traffic performance of the terminus, have been proposed.
In the next months the development of the demonstrator will be completed and the verification phase will start. Moreover, thanks to the promising results of the current project, a new EU Telematics project, COMBINE, is next to start. This new project, still managed by *Adtranz Italy* and evaluated by *UGDIE*, will deal with the conflict detection and resolution problems in metrorail applications in presence of moving block based signalling systems.

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