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Travel time in case of accident prediction model

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Abstract

The aim of this paper is to estimate the travel time along a motorway section, both in undisturbed condition and taking into account a perturbation due to an accident. The estimated travel time is calculated adding the travel time under normal traffic conditions, the time used settling the accident area and the time needed to dissolve the queue. To be applied the model requires the knowledge of accident characteristics, the traffic flow at the accident time and the value of the reduced capacity during the accident management. The model refers to traffic conditions and accident management procedures typical of motorways.

Keywords: travel time prediction; accident duration; accident management systems; BPR curves calibration; prediction model

1. Introduction

Many developments are taking place in the area of Intelligent Transportation Systems (ITS) for traffic management purposes. Many of the current ITS applications are aimed at improving accessibility, giving information to the drivers through Variable Message Sign (VMS) about traffic conditions and services available along their itinerary (applications called with the generalized word "infomobility").Usually the travel time to specific destination is communicated to the drivers using an integrated system which statistically calculates the

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travel-time between two given localities by measuring the transit time of the vehicles at both the origin and destination sections and evaluating the travel-time by difference. The reliability of the system depends on the distance between the monitored sections and on the absence of disturbing factors on the road. It is an "a posteriori" system, based on the past performance of the infrastructure, thus unable to predict the expected performance of the road in the near future. In case of an accident or other local unexpected perturbations totally or partially blocking the road, the downstream monitoring section will not register any vehicle passage until the first blocked vehicle is newly able to start moving after queuing. In the meanwhile the system is not able to update the last calculated value of the travel time, thus, resulting unreliable in these occasions.

A predictive approach is necessary in these cases, to keep the users informed also during the accident resolution period. A research project was performed to this purpose, aimed to develop an analytical model able to estimate the travel-time the users are going to experience when travelling in a motorway section where, at a certain moment, a perturbation event occurs, taking care of the time needed to restore the undisturbed traffic flow conditions. The project is part of the SIMOB project, funded by the Tuscany Region (IT), and integrates the results obtained in an applied research funded by Autostrade per l'Italia Company. It is conceived to be integrated in the general model developed in SIMOB seeking the shortest path within an origin and a destination [1].

The developed system represents a new road management instrument, aimed at evaluating an user-oriented quality indicator, directly understandable by drivers once transmitted and allowing them to decide about the eventual alternative route to keep.

2. Description of the modeled system

The travel-time in case of accident predictive model was developed to describe the traffic flowing in a motorway environment within two control sections: one upstream and one downstream the analyzed section where the perturbing event can occur (see Fig 1.). The motorway cross section includes two or more traffic lanes with or without an emergency lane. The access to the motorway are controlled in correspondence of intermediate interchanges.
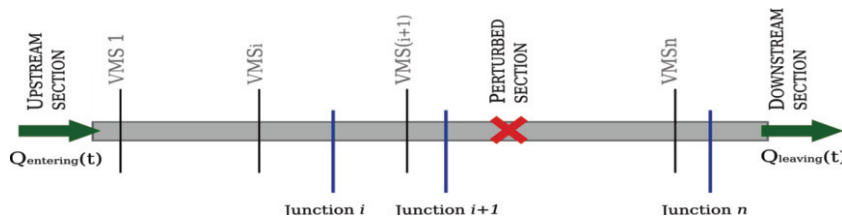

Fig 1. The motorway system scheme

The vehicles flowing in the system are measured and identified at the two ends of the analyzed motorway stretch; at each interchange the incoming and outgoing traffic is also measured. The traffic flow is considered variable in time. The effective travel time experienced by each vehicle is monitored calculating the difference between the entrance and the exit time in the modeled system.

The information to the users are provided by means of variable message signs (VMS) placed at the beginning of the analyzed section and upstream each interchange. The VMSs are intended to provide the user with the travel time required to travel from each VMS location to the exit downstream section.

The section where the perturbing event can occur, partially or completely blocking the traffic flow, can be located anywhere within the analyzed stretch.

3. Travel-time in case of accident

In case of an accident completely blocking a motorway section, the actual travel time experienced by the motorway users can be described as shown in Fig 2., in which the data registered in a real motorway situation, referred to an accident occurred on December 18, 2007 at 2:30 pm, are shown.

The x-axis reports the time at which a platoon of vehicles within a 5 minutes time frame enters in the system and the y-axis shows the average travel time experienced by the same vehicle platoon to leave the controlled system. The vehicles entering in the system in the time frame 12.30 am – 1:30 pm experience a travel time of 60 – 70 minutes, which is the undisturbed travel time required, in the period considered, to travel along the 86 km long motorway section which Fig 2. refers to. The vehicles entered in the system after 1:40 pm, instead, experience a much higher travel time (about 100 – 110 minutes) due to the occurrence of the accident at a distance of about 65 km from the system entrance section; the accident blocked the motorway from 2:30 pm to about 3:20 pm as shown by the blue and green vertical lines in Fig 2..

All vehicles entered after 1:40 pm queued. The gap between the entrance time of the first car stuck in the queue and the event is the time needed to reach the accident point from the entrance section. The maximum travel-time is given by the sum of the undisturbed travel-time and the time during which the motorway was blocked by the accident. The travel-time grow rate depends on the traffic volume registered by the sensors upstream and the percentage of heavy-goods vehicles. The vehicles entered in the system after the accident occurrence (2:30 pm) experienced a travel-time higher than normal but less than the maximum value due to the fact that after reaching the queue tail, they spent queuing only about 30 minutes, after which the accident was solved and the queue started dissolving.

Fig 2. emphasizes the fact that the actual procedure used to report the expected travel-time on the VMS, based on the a-posteriori evaluation of travel-time experienced by the vehicle exiting the system, is not usable in case on an accident. A model able to predict the increased travel-time as soon as the accident occurs is therefore required to overcome this difficulty.
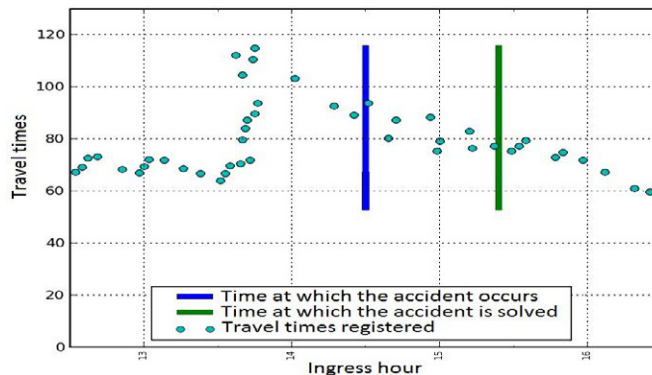

Fig 2. Travel times registered on December 18, 2007 during an accident occurred at 2:30 p.m.

4. Structure of the travel-time prediction model

The total travel time in case of accident (Tt_{pert}) can be computed by means of the following equation:

$$Tt_{pert} = Tt + \Delta Tp \tag{1}$$

where Tt is the travel-time under normal traffic conditions, depending on road-geometry, day-time and traffic flow, and ΔTp is the time spent queuing, which is given by the sum of two terms:

$$\Delta Tp = Tar + Tqp \tag{2}$$

where *Tar* is the time necessary to solve the accident, i.e. the time needed to set the accident area free from vehicles and other obstacle, and *Tqp* is the extra time spent queuing after the accident resolution.

Each of the terms in Equation 1 and 2 are given by a different model:

- *Tt*: is given by a model based on the BPR (Bureau of Public Roads) [2][3][4] curves developed for the motorway section considered and represents the "usual" travel time without perturbations in the flow. This model allows to expose on the VMSs the travel time expected in the road section considered under normal traffic conditions, in replacement of the system currently in use. The system may evolve into a system of real-time calibration of the new model based on the comparison of the estimated travel time and the time really employed by users to cover the road section;

- *ΔTp*: is given by a model accounting for the different possible strategies to manage the residual capacity of the infrastructure at the accident location, depending on the severity of the accident and the conditions in which it occurs. The strategies may foresee the total closure of the carriageway (residual capacity null), the partial closure with traffic on a single lane (right or overtaking lane), the closure of only the emergency lane or a combination of several situations implemented in succession (for example: complete closure followed by a partial closure before restoration of normal flow conditions). The *ΔTp* model consists of two parts:
    - The accident time resolution model, to evaluate the term *Tar* [5];
    - The "Clessidra" model for *Tqp* evalutation [6].

To develop the Tt_{pert} prediction model the construction of several integrated data bases was necessary:

- *ADDB* (Accident Duration Data Base): collection of data regarding the resolution time of accidents occurred within the analyzed motorway section in the period January 2002 - December 2006. The *ADDB* was built to organize the accidents data to allow their easy accessibility for consultations, changes, updates and analysis;

- *DB_flow*: data base of vehicular flow, speed and traffic composition in the same motorway system and the same time frame in which the accidents data were collected;

- *DB_Tt*: collected travel time data of light and heavy vehicles registered in the considered motorway system;

- *DB_accidents*: collection of management strategies of the accidents occurred within the considered motorway system and time frame;

- *DB_weather*: weather data collected by stations located along the route in order to correlate the travel times to the specific weather conditions under which the motorway system has been run through.

- The flowchart of the activities developed to setup the Tt_{pert} prediction model is shown in Fig 3..
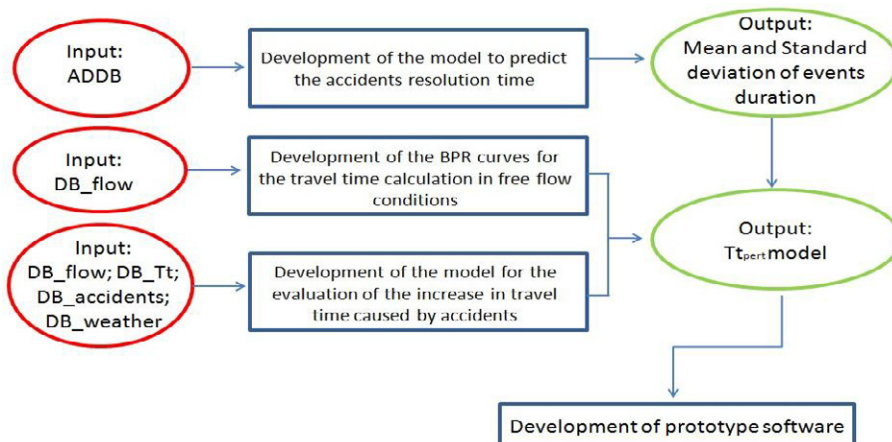

Fig 3. Flowchart of activities to develop the prediction model of the travel time in case of accidents

5. Travel-time under normal traffic conditions (*Tt*)

By analyzing the variation of the travel-time in 60 of the observed days during which no accident or perturbing event occurred, it resulted that the light and heavy vehicles average travel-time varies between 50 and 60 minutes during daytime, while during the night the average is higher than 60 minutes (Fig 4.). The difference is highly correlated to the percentage of heavy vehicles, which varies during the daytime.
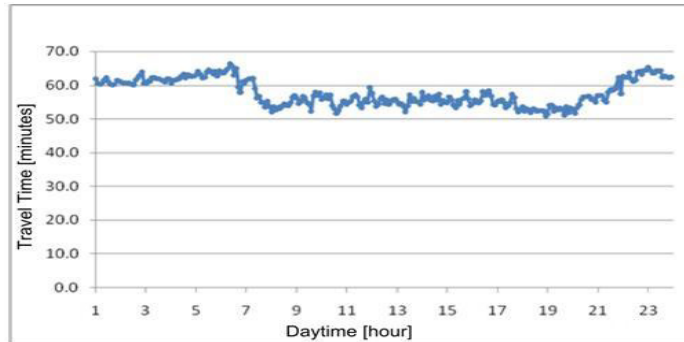

Fig 4. the Travel-time under normal traffic condition in the southbound carriageway of the analyzed motorway system (the example is about a single day)

To calibrate the volume-delay diagram as a function of the vehicles' mix, represented by cars and light trucks percentage (*%LV*), the general congestion function proposed by the Bureau of Public Roads (BPR) has been chosen, describing the average speed on a link as a function of the traffic flow and the percentage of cars and light trucks (*%LV*):

$$v = f(q, \%LV, \alpha, \beta, v_0) \tag{3}$$

The three parameters α, β, v_0 of the BPR function in Equation 3 were determined by dividing the traffic surveys in clusters, defined by the percentage of cars (least squares method): the three parameters have shown an highly linear dependence on the *%LV*: for the free-flow speed v_0 the regression coefficient R^2 is 0.98 (Fig 5.). Hence, the calibration process has been reduced to a linear problem, where the parameters α, β, v_0 can be described by linear functions of the percentage of cars and light trucks.
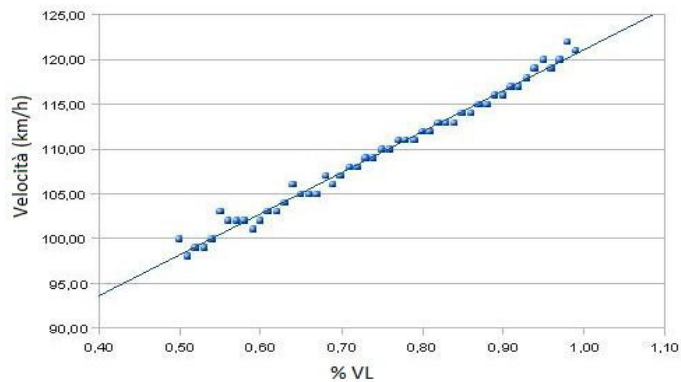

Fig 5. Free-flow speed regression (Northbound surveys) function of %LV

The calibration values resulting from this process are given in Table 1 for North and South bound directions.

Table 1. the results of the calibration process of the BPR curves

Northbound	α (%LV)	0.16
	β(%LV)	0.99
	v_0 (%LV)	75.3
Southbound	α (%LV)	-0.16
	β(%LV)	2.73
	v_0 (%LV)	71.4

6. Accident resolution time (*Tar*)

The total time spent from the instant in which an accident occurs to the complete re-opening of the road, is called "Accident Resolution Time" (*Tar*) and varies according to the nature of the accident and the infrastructural environment [7]. The developed prediction model evaluates the time necessary for the rescue teams to reach the accident location, to rescue the involved peoples, to remove the vehicles and to restore the normal traffic flow. The model was developed analyzing the duration time of the accidents occurred in a 5 year time period on the reference motorway, included in the Data Base *ADDB* constructed for the research scopes. The model was set up according to the CART (Classification And Regression Tree) statistical procedure [5].

The influencing variables considered by the model include the accident type (high time consuming or not), the type of the involved vehicles (heavy goods or light vehicles), the accident severity (causing deaths, injured peoples or only damages to vehicles) and the time at which the accident occurs (night or daytime).

The time durations estimated by the developed model are affected by a high variability due to the many different situations which can occur at each accident site. Nevertheless the model allow to differentiate if the occurred event will require more or less time to be recovered based on the first basic information arriving at the Traffic Control Room (TCR) from the accident site. The TCR will have the possibility to choose the *Tar* value to be included in the Tt_{pert} model taking care of a certain level of probability that the travel time displayed value could be exceeded or not.

The developed model reliability will increase if the *ADDB* on which the model operates will be continuously updated with the new accident data occurring along the motorway network considered. The continuous enrichment of the *ADDB* will also allow an off line periodic analysis of the data to evaluate if new descriptive variables should be included in the classification tree to increase its representativeness.

7. Extra time spent queuing (*Tqp*)

When a traffic perturbing event occurs causing a capacity reduction, it is frequent to record a queue upstream the event occurrence location. The time necessary to overcome the traffic anomaly was analyzed under the hypothesis that the vehicles have no alternative path to take and a queue grows up before the resuming of normal traffic conditions.

The developed model, called *Modello Clessidra* (hourglass model) [6] follows the approach of the macroscopic flow theory and describes the phenomenon in a deterministic way. The name of the model recall the fact that the hourglass gives the time spent by a grain of sand (queueing vehicle) to reach the bottleneck starting (accident location) from the top bulb (tail of the queue); the time to pass through the bottleneck is a function of how many grains have to pass through the bottleneck (how many vehicle are present in the queue) and by the sand flow passing through the bottleneck per unit of time (road residual capacity at the accident location).

The developed model analytically solves just the stated problem. allowing to evaluate the time spent in queue by the i-th vehicle (*Tqp)* knowing the number of vehicles queued before it and the value of residual capacity of the road at the point where event occurred [6].

8. The travel time prediction model (Tt_{pert})

Once the number of vehicle travelling along the road upstream x_a and the educed capacity (q_p) at section x_a are know, the general model can be made explicit based on the hypothesis that the accident in section x_a cause anyhow a queue (see Fig 9.) The capacity of the road downstream x_a evolves with time and it can be equal to zero, when the motorway is completely blocked, can have a value q_p, minor than q_c (the road capacity in critical conditions), when a reduced number of traffic lanes is available at the crash location. After the accident resolution, the traffic flow will perform at capacity (q_c) up to the moment when the vehicle queue dissolves and the traffic flow resumes its normal value q_l in normal traffic conditions.

In Fig 6., the subscript a refers to the time of the accident, the subscript p to the partial re-opening and the subscript l to the total re-opening of the motorway at section x_a.

For instance, if the accident management strategy provides for two phases (a total close-up of the road up to the time t_p (Equation 4) and a partial re-opening after t_p before the final opening t_l (Equation 5)), the general model takes the following forms:

$$\Delta T_p(t) = \frac{x_2 - x_1}{v_1} + t_p - t_a + \frac{N_t(t)}{q_p} - t \quad if \quad N_t(t) \le N_p \tag{4}$$

$$\Delta T_p(t) = \frac{x_a - x_1}{v_1} + t_1 - t_a + \frac{N_t(t) + N_p}{q_p} + \frac{x_2 - x_a}{v_c} - t \quad if \quad N_t(t) > N_p \tag{5}$$

where, besides the terms already known:

- $\Delta T_p(t)$: sum of *Tar* and *Tqp* at the generic time t;
- x_1 and x_2: upstream and downstream control sections, being $(x_2\text{-}x_1)$ the length of the examined motorway section;
- x_a: accident location, being $(x_a\text{-}x_1)$ the motorway length upstream the accident and $(x_a\text{-}x_1)$ the length downstream the accident;
- vl: average speed in normal traffic condition;
- vc: critical speed of vehicles leaving the accident section x_a after the re-opening but before normal conditions are restored definitely;
- t_a: time at which the accident occurs;
- t_l: time at which the accident is completely solved;
- t_r: time at which cars entering in the system don't experience the effects of the accident after the queue dissolving;
- $N_t(t)$: number of vehicles entering in the system between t_a and t;
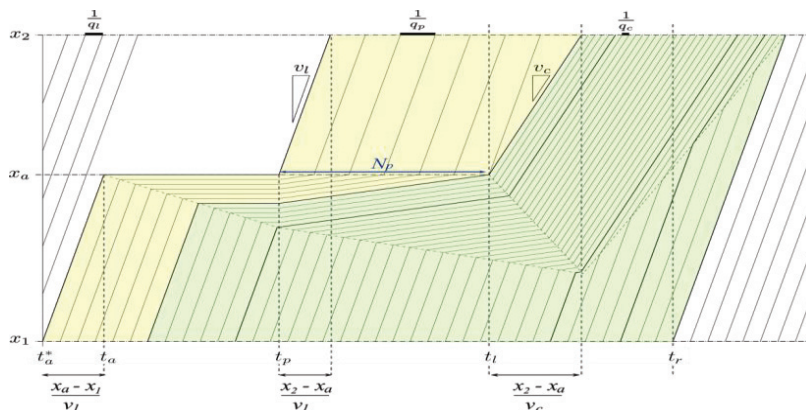- N_p: amount of vehicles which can drive through during the partial re-opening.

Fig 6. The explicit formulation of the model.

The gap between t_a and t_l is exactly *Tar*, while the other terms are the explicit formulation of the Clessidra model. The formulation distinguishes between the situation of cars entering in the system and travelling downstream x_a when the section is totally or partially closed (yellow area in Fig 6. and Equation 4) and cars travelling in critical condition, after the total reopening of the section: their travel-time is still affected by the former bottleneck, which caused the critical flowing condition (green area in Fig 6. and Equation 5).

The implementation of the model hence requires the knowledge of q_p (reduced capacity of the road in the accident location) and q_c (critical capacity of the accident section after the total re-opening). These values are generally unknown because they depend on several factors which can hardly be modelled: among these factors, for q_p the police controlled vehicle flow or the reduced lane width can be named, while q_c depends, for example, on the number of trucks in the queue, the environment where the accident happens (tunnel or open road) or the longitudinal slope of the motorway at the crash location.

In the studied cases, the values weren't available: hence, for the application of the developed model, they were deduced by comparing the predicted travel-time with the measured values, minimizing the root mean square of the variance of their difference.

Among all the accidents in the database, 12 have been chosen for the evaluation of q_p and q_c and the results are shown in Table 2.

Table 2. Characteristics of the 12 accidents evaluated and results.

Id	crash class	location	direction	total lanes	daytime	qc [veh/h]	qp [veh/h]	msr
101	2	tunnel	northb.	2	13:12	2330	1570	3.04
148	3	open road	southb.	2	11:55	2660	1520	5.3
153	3	open road	northb.	2	17:08	3290	2520	3.67
157	3	open road	southb.	2	16:24	3130	1010	4.22
165	3	open road	southb.	2	16:09	2570	950	54.57
189	3	tunnel	southb.	2	15:48	2480	890	35.84
187	3	open road	southb.	2	12:43	1940	1930	10.68
62	3	open road	northb.	2	11:59	2660	2650	16.16
17	3	tunnel	southb.	2	06:59	3490	1910	28.23
109	3	tunnel	northb.	2	15:06	2770	2290	30.05
111	3	tunnel	northb.	2	15:30	3310	2170	16.61
181	3	tunnel	southb.	2	09:44	2150	1890	8.37

Data in Table 2 show that, as expected, the process gives back highly variable q_c and q_p values. Fig 7. shows three examples of result obtained; in each diagram:

- on the x-axis the time when the car has entered in the system is displayed; the total observed period has been divided in steps of 5 minutes ($x=20$ means that the car has entered in the system at minute 100 after the first observation moment);
- on the y-axis the total travel-time is displayed in minutes;
- the blue line displays the measured data;
- the red line shows the prediction model result;
- the green band shows the +/- 3 minutes period with reference to the predicted travel-time;
- the blue vertical thick line represents the moment of the event at time t_a;
- the green vertical thick line represents the moment of the re-opening of the road at time t_l;
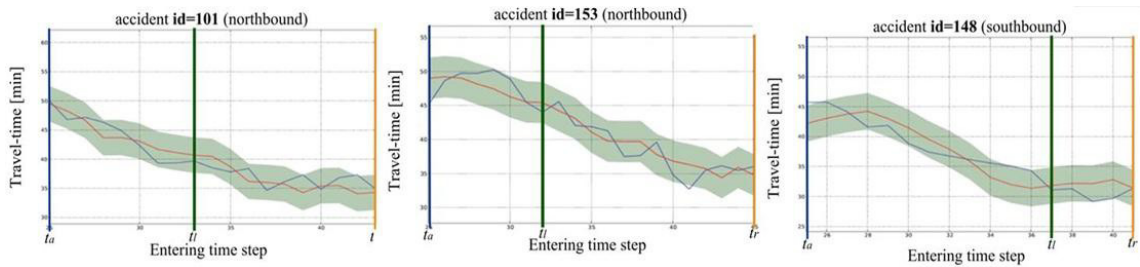- the orange vertical thick line represents the time when the normal traffic conditions are restored, at time t_r.

Fig 7. Results evaluated for three accidents.

The predicted travel times are contained in all analyzed cases within the ±3 minutes time range of the actual values. The evaluation is less accurate in the first 5-10 minutes after the event occurrence, due to the lack of precise information about the accident managing strategy adopted in this period. Results shown in Fig 7. prove that, if the residual capacity is known, the model is able to closely predict the travel-time also taking into account the time delay due to an accident.

9. Communication of travel time to drivers on VMS

The result of the model gives the chance of displaying real-time information to drivers about the expected travel-time along a given motorway section in case of an accident.

This system has been tested in a pilot case (accident id=157), using 3 variable message signs located upstream the section where the event has occurred (km 251 of the motorway): the exact VMS location are at km 206, km 221.9 and km 236.
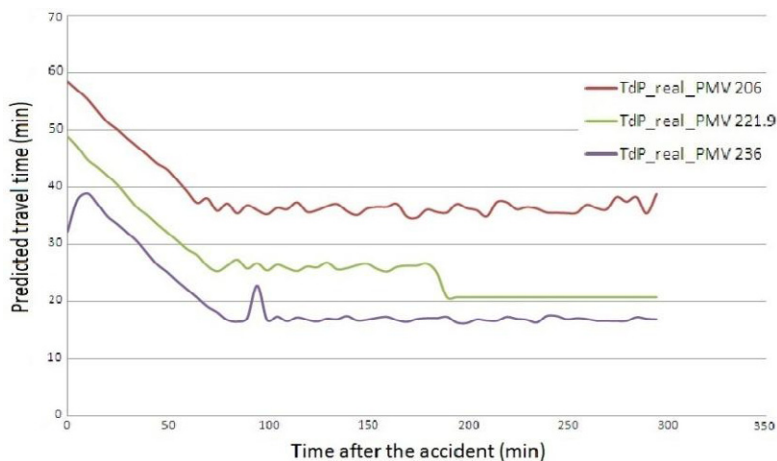

Fig 8. Predicted travel times displayed on VMSs upstream the crash location.

The predicted travel-times which the Tt_{pert} model could allow to display on the cited three panels are shown in Fig. 8. The max values shown at t=0 (time at which the crash occurs) represent the travel times that the vehicles passing at each VMS location at the moment in which the crash occurs at km 251 will experience. The greatest value is displayed on the VMS most far away from the crash location, and lowest value on the nearest VMS. The vehicles under the VMS at km 236 (the nearest) will be the first vehicles which will be in the queue upstream the crash location, and they have to wait the total accident resolution time *Tar* before they will start again moving.

The travel times displayed after $t = 0$ are lower because vehicles adding themselves to the already formed queue will have to wait a time period less then *Tar*.

The effects of the accident on the travel time prediction is clear and the displayed travel time trend is very similar to the measured values shown, for instance, in Fig 2.

10. Conclusions

The developed model provides an estimate of the travel-time that the users are going to experience when travelling in a motorway section where, at a certain moment, a perturbation event occurs, taking into account the time needed to restore the undisturbed traffic flow conditions. The developed model allows to predict both the travel-time under normal traffic condition, thus allowing to substitute the at present available "a-posteriori" systems, and the travel-time in presence of an accident.

To operate the developed prediction model the following data and systems are necessary:

- The number of vehicle flowing within the considered motorway system these data can be obtained from the traffic counting stations usually along the itinerary and at each interchange;
- the BPR curves, calibrated for the motorway considered;
- the value of the residual capacity at the accident location, both during the accident management period (q_p) and after its resolution, when the infrastructure operates at capacity (q_c). These values usually are not available; the accident management procedures has to include the measurement of q_p and q_c during the accident resolution time to allow the developed travel-time prediction system to operate;
- an accident resolution time prediction model similar to the one developed for the infrastructure considered for the project, based on a CART statistical model.

According to the motorway section used to develop and calibrate the model, the goodness of the travel-time in case of accident predictions could be high. This allows to consider the possibility to introduce the system in the user information procedures adopted for traffic management, displaying on a real-time basis the expected travel-time on the VMSs available along the road. The user benefits provided by the knowledge of the expected travel-time in case of accident occurring along the traveled itinerary are clearly very high.

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