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Executive summary

Within the framework of the CONDUITS project, Key Performance Indicators (KPIs) have been developed for four strategic themes of urban traffic management (traffic efficiency; traffic safety; pollution reduction; and social inclusion), with each theme consisting of individual sub-themes (e.g. mobility, reliability, operational efficiency and system condition as part of traffic efficiency). Operative definitions of the KPIs, along with detailed guidance on their use, have been provided in a comprehensive reference document (D3.5). In this, final, report, the KPIs are validated with the help of a number of case studies in four European cities (Paris, Rome, Tel Aviv and Munich), each assessing a different aspect of urban traffic management applications.

Two case studies are examined in the city of Paris: the implementation of systems granting priority to buses at signalised junctions on three bus lines (26, 91 and 96), and the construction of a new tram line (T3) on the “Boulevard des Maréchaux Sud” corridor. For both case studies, a before- and after-analysis is carried out in order to quantify the impacts of the two schemes in terms of mobility and traffic accidents. Using the appropriate KPIs fed by data from the city, it is found that the bus priority scheme resulted in clearly better public transport mobility for the three bus lines (lower travel times) and in marginally lower private transport mobility on the corresponding road stretches, thus indicating an improved overall mobility on the affected network parts. Similar results are obtained for the tram scheme, with improved overall mobility being recorded. As concerns the accidents assessment, it appears that the bus priority measures have been accompanied by a clear reduction in the casualty rate of deaths and slight injuries, but by a marginal increase in the rate of serious injuries, mainly involving pedestrians and cycles. The overall accidents rate, however, appears to remain constant. Similar trends are observed in the casualty rates of the tram scheme, where the slight injuries rates.

The reliability performance of the introduction of advanced traffic signalling strategies is evaluated in the Tel Aviv case study. Using congestion occurrence and duration data from the Ha’Shalom Expressway, it is found that the new signal programmes resulted in significantly improved reliability, additionally supported by travellers’ perceptions. Nevertheless, it is found through continuous monitoring that the index value has had a decreasing tendency, becoming stable within a year following the implementation of the

scheme.

A safety performance evaluation is conducted in a case study in the city of Munich, where the so-called direct safety impact of the installation of speed feedback dynamic message signs for a certain test period is measured through an appropriate KPI. It is found that the introduction of the signs resulted in a reduced speed warnings per vehicle value compared to before, indicating an improvement in safety during the test period. However, the value has returned to its previous level after the removal of the signs.

A different approach is adopted, finally, in the case study of the city of Rome, where a large-scale performance evaluation of the various techniques and ITS technologies that have been implemented within the framework of the Mobility Control Centre is conducted. Using travel times between representative zones throughout the city of Rome, defined as the area lying inside the “Grande Raccordo Anulare” (GRA) orbital motorway, as well as congestion occurrence and duration data, a general performance assessment is carried out in terms of mobility and reliability. The underlying conclusion of the former is that, as expected, private transport mobility is better than public transport mobility, with index values ranging at similar levels to the Paris case study. In the case of the latter, the city of Rome is found to have a very high reliability index, with very few congestion occurrences as a whole. This, however, may be attributed to the fact that the potentially unreliable and congested peak hours are compensated by the long uncongested off-peak (night time) hours, highlighting the need for a time-based reliability performance evaluation of the transport network.

Through the conduct of the case studies, it is concluded that the KPIs are easy to apply and require already available data, thus forming a very useful evaluation tool for assisting decision makers in the field of urban traffic management and ITS.

1 Introduction

The fact that cities today face a number of common problems when implementing traffic management measures, and particularly Intelligent Transport Systems (ITS), has been highlighted in the earlier stages of the CONDUITS project. It has also been realised that cities often find it difficult to objectively assess the effects of their decisions and make use of lessons learnt from urban traffic management examples elsewhere, as there is a methodological gap in terms of a widely-accepted performance evaluation framework [*1*].

It has been the primary objective of the CONDUITS project to bridge this gap by defining and testing a performance evaluation framework, consisting of a set of Key Performance Indicators (KPIs). The first part of this work, entailing the methodological definition, has recently been completed, with new KPIs having been developed for four themes of traffic management (traffic efficiency; traffic safety; pollution reduction; and social inclusion and land use). Operative definitions for the developed KPIs have been provided, with the outcomes of the development stage being comprehensively documented in the CONDUITS deliverable D 3.5 [*2*].

The present deliverable reports on the outcomes of the second part of the work, i.e. the testing and validation of the new performance evaluation framework. The objective is to apply the new KPIs to specific case studies of European cities, in order to demonstrate their usefulness and applicability. Focussing on the themes of traffic efficiency and traffic safety, a number of selected KPIs, five case studies in four European cities are conducted, namely in Paris, Tel Aviv, Munich and Rome.

In Paris, a performance evaluation for the case studies of the implementation of systems granting priority to buses at signalised junctions, and of the construction of a new tram line, is conducted. For both case studies, a before- and after-analysis is carried out in order to quantify the impacts of the two schemes in terms of mobility and traffic accidents. In Tel Aviv, the impact of the introduction of advanced traffic signalling strategies is assessed in terms of reliability. In Munich, the direct safety impact of the installation of speed feedback dynamic message signs for a certain test period is measured. Finally, in Rome a different approach is adopted, where a large-scale performance evaluation of the various techniques and ITS technologies that have been implemented within the framework of the Mobility

Control Centre is conducted in terms of mobility and reliability.

The report is structured as follows. Chapter 2 documents the procedure and results of the bus priority case study in Paris, while Chapter 3 has the same structure and presents the results of the second Paris case study, dealing with the construction of tram line T3. Chapter 4 then reports on the results of the reliability assessment in the Tel Aviv case study, Chapter 5 documents the findings of the safety assessment in Munich, and Chapter 6 describes the large-scale mobility and reliability assessment in the city of Rome. Finally, Chapter 7 summarises the conclusions of the report.

2 Paris: Bus priority on three bus lines

The first case study conducted involves the assessment of the implementation of a system granting priority to public transport vehicles at traffic signals on three bus lines in Paris. Assessment in terms of traffic efficiency and traffic safety is carried out. In the next section, a description of the scheme is first given, followed by an account of the assessment conducted and the results obtained.

2.1 Description of the scheme

In 2003 the Paris public transport authority ("Syndicat des transports d'Île-de-France (STIF)") investigated the potential application of a system granting priority to buses at traffic signals, which resulted in the compilation of a set of technical specifications to traffic managers. The investigation was followed up by a pilot experiment, during which bus priority was implemented at four intersections in the city of Paris, the encouraging results of which led to the decision of deploying the system on several bus lines. Installation work on lines 26, 91 and 96, the location of which within the inner city of Paris is shown in Figure 1, began in 2006.

Figure 1: Paris bus lines 26, 91 and 96 (Source: RATP)

The system employed was one of dynamic (on-demand) priority, whose concept of operation relies on radio transmissions at 5-second intervals, through which the bus communicates to the signal controller its current position and anticipated time of approach, as shown in Figure 2. The priority system is managed by a specialised computer (the "PC Véga"), whose architecture is shown in Figure 3.

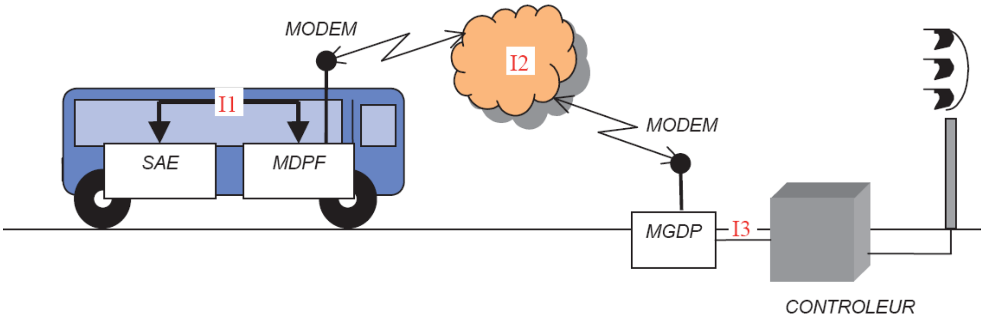

Figure 2: Bus priority operation

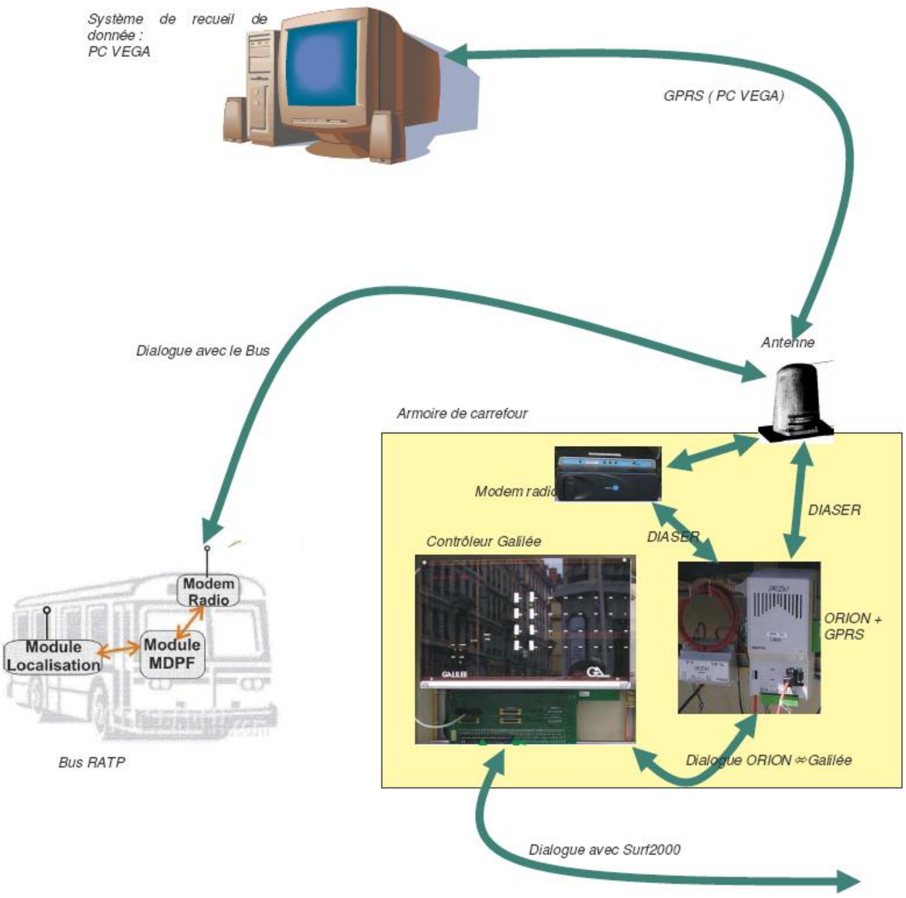

Figure 3: Bus priority system architecture

Approximately 150 signalised junctions were affected, involving a total cost of installation in excess of €3 million. It was anticipated that the application of the system on the three lines would result in an average travel time saving of the order of 30 seconds per passenger.

Given an average volume of 10 million passengers per year on each of the lines, the anticipated saving would correspond to a saving of one vehicle on each line for the bus operating company.

2.2 Performance evaluation – Traffic efficiency (Mobility)

For the assessment of the mobility of travellers as a result of the introduction of the priority measures each of the three bus lines has been broken up into four route segments of given length per direction, resulting in eight route segments per line and 24 route segments in total. Average peak-time bus travel times for each of the route segments have been measured over periods before and after the implementation of the priority, in order to identify travel time gains. Furthermore, a number of route segments of given length have been identified on the private transport network as being affected by the priority scheme (three for line 26, eight for line 91 and six for line 96, resulting in a total of 17), for which average vehicle traffic travel times were measured for the same periods before and after the implementation.

The mobility KPI, as defined in Equation (1) in [*2*], is used to perform an assessment of the overall impact of the scheme in terms of mobility on each of the lines, for public and private transport separately, taking equal weights for each of the route segments.

Table 1: Paris bus priority mobility assessment results

I_{MOB} (min/km)	Public transport			Private transport			Overall		
	Before	After	Change	Before	After	Change	Before	After	Change
Line 26	4.46	4.25	-4.82%	4.46	4.65	4.30%	4.46	4.37	-2.09%
Line 91	4.63	4.33	-6.55%	5.25	5.05	-3.89%	4.82	4.54	-5.68%
Line 96	5.03	4.67	-7.13%	2.71	3.02	11.55%	4.33	4.17	-3.63%
TOTAL	**4.71**	**4.42**	**-6.21%**	**4.21**	**4.26**	**1.14%**	**4.56**	**4.37**	**-4.17%**

The results of the mobility assessment are shown in Table 1. As can be seen, the priority measures appear to have resulted in a reduction of the public transport travel rate values (and hence in improved public transport mobility) for all three lines. Consequently, an overall decrease from 4.71 min/km to 4.42 min/km for public transport is recorded across the three lines, corresponding to an improvement (reduction) of 6.21% in public transport mobility. On the other hand, the priority measures seem to have negatively affected private transport mobility on lines 26 and 91, resulting in increased average travel rates, but not on line 91, for which slightly improved private transport mobility is recorded. Consequently, the overall private transport mobility has seen a marginal deterioration of 1.14%, expressed as a slight increase in the average travel rate from 4.21 to 4.26 min/km.

In order to determine the overall change in mobility, the weights w_{PV} = 0.3 and w_{PT} = 0.7 have been set, following consultation with a group of experts from the Municipality of Paris. As such, the overall mobility index is evaluated for the three lines separately, as well as for the three lines together, and the results are included in Table 1. As can be seen, an improvement (reduction) in the total mobility index on all the lines is found, corresponding to an average travel rate saving of 0.19 min/km, i.e. 4.17%.

2.3 Performance evaluation – Traffic safety (Accidents)

In the evaluation of the bus priority scheme in terms of accidents, only data from line 91 has been available, split in four segments per direction (i.e. a total of eight route segments). Namely, the numbers of casualties due to road traffic accidents over four-year periods before and after implementation of the priority scheme have been supplied, categorised according to severity (death, serious injury, slight injury) and road user type (pedestrian, cycle, 2-wheeler, 4-wheeler). In addition, average daily vehicle traffic flows have been obtained for the respective segments and periods.

The accidents KPI, as expressed by Equation (4) in [*2*], is used to perform a safety assessment of the priority system on line 91, for the different severity categories separately, taking equal weights for each of the route segments. Following a consultation with a group of experts from the Municipality of Paris, the weights for casualties of the different road user groups have been set to w_{cyc} = 0.25, w_{2w} = 0.2, w_{4w} = 0.15, and w_{ped} = 0.4 for cycles, 2-wheelers, 4-wheelers and pedestrians respectively.

Table 2: Safety assessment results for Paris bus line 91

I_{ACD} (casualties/million-veh)	Weights	Deaths		Serious injuries		Slight injuries		Overall	
		Before	After	Before	After	Before	After	Before	After
Cycles	0.25	0	0	0	2	3	5	0.02	0.05
2-wheelers	0.2	0	0	3	3	71	36	0.40	0.24
4-wheelers	0.15	2	0	0	1	27	20	0.32	0.12
Pedestrians	0.4	1	1	6	11	51	51	0.42	0.50
TOTAL	**1**	**0.07**	**0.04**	**0.31**	**0.63**	**4.10**	**3.57**	**0.30**	**0.28**

The results of the accidents assessment are shown in Table 2. As can be seen, the priority measures on bus line 91 appear to have resulted in marginally improved casualty rates for deaths, and in notably improved slight injuries rates; corresponding occurrences per million vehicles values seem to have dropped from 0.07 to 0.04 and from 4.1 to 3.57, respectively. However, it can also be seen that these findings are accompanied by a worse serious injuries rate, with the increased number of pedestrian and cycle serious injuries inducing a rise of the corresponding index value from 0.31 to 0.63 occurrences per million vehicles.

Compiling the three partial indices to determine the overall change in casualty levels (with the help of the experts the weights for the severity levels have been set to w_{death} = 0.85, w_{ser} = 0.1 and w_{sli} = 0.05 for deaths, serious injuries and slight injuries respectively) per road user category and overall, it can be seen that the accidents rates for cycles and pedestrians have risen, while the ones of 2- and 4-wheelers have dropped. As a result, the total accidents index has risen marginally, from 0.30 to 0.28 casualties per million vehicles.

2.4 Discussion

Given that the introduction of bus priority is a measure primarily aimed at improving public transport mobility, the results obtained from the mobility assessment are in line with what would be expected, i.e. better mobility for public transport without deterioration of private transport mobility, and consequently better overall mobility on all three bus lines. Accidents, on the other hand, appear to have stayed at fairly constant levels as a whole, with the increased index values of serious injuries and pedestrians being largely attributed to the fact that the smaller casualty occurrence numbers of those categories are weighted more heavily than the higher occurrence numbers of slight injuries.

It should be noted that the priority measures have also resulted in a drop in vehicle traffic volume along line 91, which may have further contributed to increases in accident index values. Nevertheless, the study highlights a potential “collateral damage” of the bus priority scheme, and it may be worth further investigating the circumstances of the pedestrian casualties in question.

3 Paris: Construction of a tram line

The second case study conducted is concerned with the assessment of the construction of a new tram line in Paris. As in the previous case study, assessment in terms of traffic efficiency and traffic safety is carried out, and following the same structure, a description of the scheme is first given, followed by an account of the assessment conducted and the results obtained.

3.1 Description of the scheme

The construction of a tram line on the “Boulevards des Maréchaux Sud” corridor in the southern part of the city of Paris (Figure 4) has been the objective of numerous studies, and prompted the complete redevelopment of the corridor, that is the redesign of the entire 40-metre wide urban expressway. The final study concluded on the implementation of the tram line on a separate track alongside vehicle traffic, with full priority at traffic signals. Feasibility studies were carried out since 2000, works started in 2003 and operation of the tram line T3 began on 16 December 2006.

Figure 4: Paris tram line T3 (source: RATP)

Apart from the complete redesign of the public space, one of the reasons for the introduction of the T3 tram line was to find a way to enhance public transport supply, which at the time was relying on a bus line with a frequency of 6 minutes. The entire project cost nearly €320 million.

The main objectives of the construction of the T3 line were: to address the increasing need for circumferential surface transport; to consolidate the link between the various existing transport modes in the area; to improve the local transport supply in the area and reinforce the link with the bordering municipalities; to revamp the urban streetscape of the “Boulevards des Maréchaux Sud” corridor; and to facilitate daily life (ensure progress and growth, organise commercial deliveries and residential parking, etc).

Focussing on the system granting priority at signalised intersections, its concept of operation relies on the detection of the tram vehicle before the intersection through magnetic loops and numerical counters, which enable the determination of the approximate time of arrival at the intersection. Hence, the signal controller optimises the phases of all vehicle streams of the junction, in order to provide a green phase to the tram upon its arrival. The objective of the priority system is to ensure a commercial speed of 20 km/h, a daily passenger throughput of 100,000, and a line frequency of 4 minutes.

3.2 Performance evaluation – Traffic efficiency (Mobility)

For the assessment of the mobility of travellers as a result of the construction of T3, each direction of the line is treated as a single segment, thus resulting in two route segments in total. Average peak-time tram travel times for each direction have been measured following the construction of the tram; however, no data are available for the pre-construction period, i.e. for the bus line that was replaced by T3, which means that public transport mobility can only be evaluated for the post-construction period. On the other hand, for the respective route segments on the private transport network affected by the tram line (two in total, i.e. one per direction), average vehicle traffic travel times were calculated from measured average speeds for periods before (2002) and after the construction (2007), thus making it possible to identify travel time gains/losses.

The mobility KPI, as defined in Equation (1) in [2], is used to perform an assessment of the overall impact of the tram line construction in terms of mobility, for public and private transport separately.

Table 3: Paris tram T3 mobility assessment results

I_{MOB} (min/km)	Public transport			Private transport			Overall		
	Before	After	Change	Before	After	Change	Before	After	Change
Line T3	-	3.54	-	2.90	4.06	39.94%	-	3.70	-

The results of the mobility assessment are shown in Table 3. As can be seen, the public transport mobility index is found to be 3.54 min/km, which is a lower value than the respective ones for the bus priority, investigated in Chapter 2. This is in line with what would be expected, i.e. that the tram with its own right of way provides better passenger mobility than buses. However, as no data are available for the before-case, it is not possible to assess the impact of the tram construction on public transport mobility.

The results also give values for private transport mobility. As can be seen, the construction of the tram has resulted in an increase of the respective KPI from 2.90 min/km to 4.06 min/km, corresponding to an augmentation (deterioration) of almost 40%. This is also expected, as the introduction of the tram track removed two lanes of traffic from the existing road, which reduced its traffic capacity and hence increased the travel times experienced by private transport travellers.

In order to determine the overall mobility, the weights w_{PV} = 0.3 and w_{PT} = 0.7 are again used, as in the case of the bus priority case study. As such, the overall mobility index is evaluated post-construction of the tram line, and is found to be 3.70 min/km. This value is, again, lower than the respective values for the buses, which is expected given the higher operational speed of the tram, despite the significant increase in private transport travel time. Nevertheless, the absence of data for the before-case of public transport prevents the calculation of the pre-construction overall mobility KPI, and as such, the investigation of its impact.

3.3 Performance evaluation – Traffic safety (Accidents)

In the evaluation of the tram construction in terms of accidents, data for the entire length of the line is available. The numbers of casualties due to road traffic accidents over nine-month periods before and after construction have been supplied, categorised according to severity (death, serious injury, slight injury) and road user type (pedestrian, cycle, 2-wheeler, 4-wheeler). In addition, average daily vehicle traffic flows have been obtained for the periods.

The accidents KPI, as expressed by Equation (4) in [*2*], is used to perform a safety assessment of the construction of tram line T3, for the different severity categories separately, taking equal weights for each of the route segments. Again, the same weights for casualties of the different road user groups as for the buses are used, i.e. w_{cyc} = 0.25, w_{2w} = 0.2, w_{4w} = 0.15, and w_{ped} = 0.4 for cycles, 2-wheelers, 4-wheelers and pedestrians respectively.

Table 4: Safety assessment results for Paris tram line T3

I_{ACD} (casualties/million-veh)	Weights	Deaths		Serious injuries		Slight injuries		Overall	
		Before	After	Before	After	Before	After	Before	After
Cycles	0.25	0	0	1	0	6	7	0.09	0.15
2-wheelers	0.2	0	0	5	7	67	54	0.83	1.46
4-wheelers	0.15	0	0	1	0	67	19	0.74	0.41
Pedestrians	0.4	1	0	5	1	32	14	0.63	0.34
TOTAL	**1**	**0.09**	**0.00**	**0.73**	**0.77**	**8.12**	**9.03**	**0.55**	**0.53**

The results of the accidents assessment are shown in Table 4. As can be seen, the construction of T3 appears to have resulted in a marginally improved casualty rate for deaths (given that no death is recorded after the construction, as opposed to one death observed before), which is, however, accompanied by worse serious and slight injuries rates, with slightly increased accident occurrences for 2-wheeler serious injuries and cyclist slight injuries. KPI values seem to have increased from 0.73 to 0.77 occurrences per million vehicles for serious injuries, and from 8.12 to 9.03 occurrences per million vehicles for serious injuries for slight injuries.

Compiling the three partial indices to determine the overall change in casualty levels (again the weights for the severity levels are set to w_{death} = 0.85, w_{ser} = 0.1 and w_{sli} = 0.05 for deaths, serious injuries and slight injuries respectively) per road user category and overall, it can be seen that the accidents rates for cycles and 2-wheelers have risen, while the ones of 4-wheelers and pedestrians have dropped. As a result, the total accidents index has dropped marginally, from 0.55 to 0.53 casualties per million vehicles.

3.4 Discussion

Given that the construction of a tram is primarily aimed at improving public transport mobility, the results obtained from the mobility assessment (through the available data) are in line with what would be expected, i.e. significantly better public transport mobility, with a deterioration of private transport mobility, and consequently good overall mobility on the tram line corridor (better than in the bus priority case study).

Accidents, on the other hand, appear to have stayed at fairly constant levels as a whole, though some substantial increases in the indices for slight injuries, pedestrians and 2-wheelers are recorded, despite overall drops in absolute accident numbers. It should be noted, though, is that the calculated accident rates for the after-case are accompanied by a significant decrease in traffic flow following the construction of the tram, due to the rearrangement of the public space and the reduction of the traffic capacity of the corridor. This explains why the generally observed drop in absolute accident occurrences is coupled with increases in the respective KPI values.

4 Tel Aviv: New signal strategies

The third case study involves the assessment of the implementation of new traffic signal control strategies in Tel Aviv. Assessment in terms of traffic efficiency is carried out, and in particular of reliability, and following the same structure as the previous case studies, a description of the scheme is first given, followed by an account of the assessment conducted and the results obtained.

4.1 Description of the scheme

The city of Tel Aviv is the nucleus of the largest metropolitan area of Israel and as such it is the main cultural and financial centre of the country. Most of the traffic in Tel Aviv originates from towns in the vicinity and outside the metropolitan area. The majority of this traffic enters the city during the morning peak period and leaves the city during the afternoon/evening peak period.

In order to preserve its predominant role as a major city, Tel Aviv strives to improve the quality of all transport modes and to reduce the congestion and environmental impacts of traffic. One of the major measures applied by the city is a recurrent update of its signal strategies library. Each year thousands of signal strategies updates are conducted, mostly aiming at resolving congestion and at implementing the municipal policy.

At the end of 2008 as a result of a congestion levels' analysis which took place at the Ha'shalom arterial (Figure 5), the city decided to update the afternoon peak period signal strategies along the entire arterial. The Ha'shalom arterial serves as the main entrance and exit route for travellers to and from the south-eastern cities. The extension of the Ha'shalom arterial stretches beyond the city of Tel Aviv and leads to Highway No. 4, one of the busiest highways in the state.

The results of the congestion analysis on the Ha'shlom arterial are presented in Figure 8, where the X-Axis denotes the time of day and the Y-Axis denotes the date. The plotted area in Figure 8 is the level of congestion, where blue dots represent saturated flow and red dots represent congestion. As can be observed in Figure 8, the congestion mostly occurs in the afternoon/evening peak. In the end of 2008 the municipality of Tel Aviv redesigned the signal strategies along the entire arterial according to the traffic Level of Service (LOS) of the arterial and the crossing streets. The new signal strategies were downloaded to the signal controllers at the beginning of February 2009.

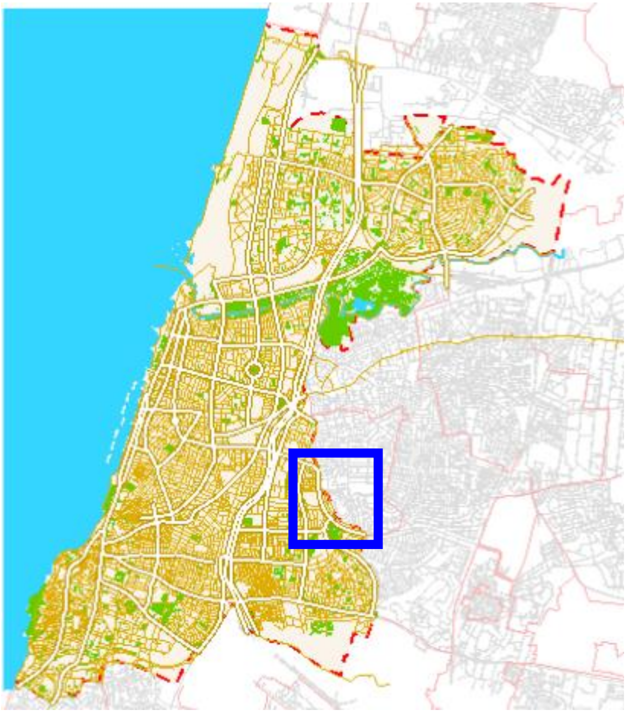

Figure 5: Tel Aviv map (Ha'shalom Arterial in the blue rectangle)

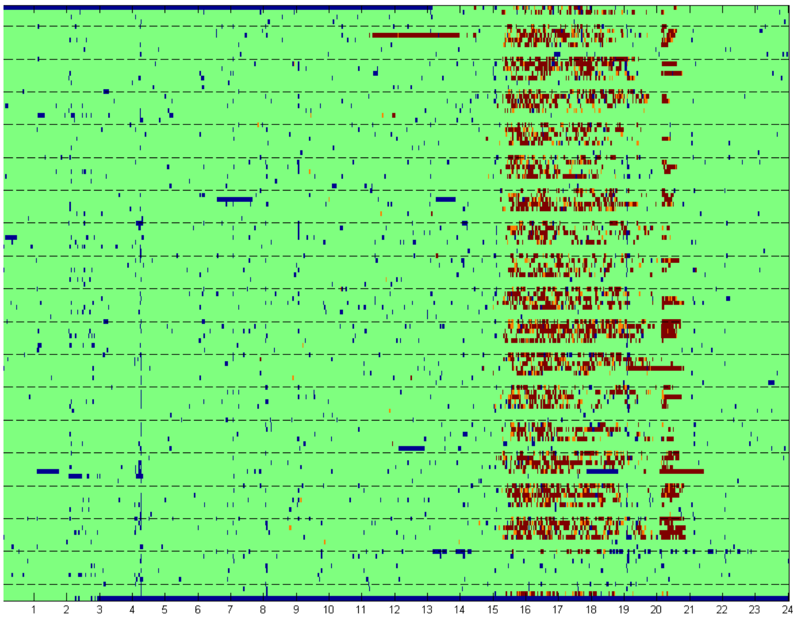

Figure 6: Congestion Analysis at Ha'shalom Arterial

4.2 Performance evaluation – Traffic efficiency (Reliability)

For the assessment of the traffic efficiency reliability as a result of the newly introduced signal strategies, the congestion duration was derived from the LOS algorithm integrated in the Tel Aviv traffic management System (AVIVIM). The LOS calculation of AVIVIM is based on detector measurements of volume and occupancy, retrieved from the signal controller at the end of each signal cycle. The AVIVIM LOS algorithm combines the detector data and the green splits in order to determine the existing LOS at each of the links in the network. The AVIVIM LOS calculation provides discrete results: free flow, saturated flow and congestion.

The reliability KPI, as defined in Equation (2) in [*2*], is used to perform an assessment of the overall impact of the new signal strategies in terms of mobility reliability. The Ha'shlom arterial serves very few bus, lines, thus the KPI is calculated only for the private traffic.

The w_l parameter in Equation (2) in [2] has been assigned according to the following logic:

- Inner links relative importance – the area is composed of a main arterial, a single crossing minor arterial and several crossing local roads. Links in the main and minor arterials were assigned with weights of 3 – 5 and local roads were assigned with weights of 2 – 4.
- Seasonal importance – the Ha'shalom arterial is subjected only to the general seasonal effects (i.e., weekends, school leave, etc.), as the example presented is in a single season of the year.
- Time importance – the day was split up into five segments: midnight to 5 AM, 6 AM to 10 AM, 11 AM to 1 PM, 2 PM to 7 PM and 8 PM to midnight. Such a fragmentation reflects the basic schedule of the traffic management centre in Tel Aviv. The links were divided into two categories: arterial/minor and inbound/outbound to the Central Business District (CBD). Links along the main arterial to both directions were given the weight 5 for four times of the day.
    - Links to the major/minor arterial:
        - Links leading to the CBD were assigned a weight of 3 during the afternoon peak.
        - Links leading out of the CBD were assigned with a value of 3 during the morning peak.
    - Links to the local roads:
        - Links leading to the CBD were assigned a weight of 4 in the morning peak, 2 in the afternoon peak and 3 in the rest of the time frames.
        - Links leading out of the CBD were assigned with a value of 2 in the

morning peak, 4 in the afternoon peak and 3 in the rest of the time frames.

The reliability KPI during the afternoon/evening peak period between 15:00 – 20:00 was calculated to be 0.8 in January 2009 and 0.9 in February 2009, representing an increase of nearly 10%.

4.3 Discussion

The increase in the mobility reliability as captured by the KPI was supported by the general perception of representative travellers in the arterial. Further analysis conducted later showed that the mobility reliability KPI remained at the same improved level for six months. By the end of 2009, the mobility reliability KPI dropped below 0.8 but with an increased throughput of 15%.

5 Munich: Speed feedback signs

In the case study of the city of Munich, a safety assessment of the introduction of dynamic speed feedback signs in two locations is carried out. Assessment in terms of direct safety impacts is carried out, and following the same structure, a description of the scheme is first given, followed by an account of the assessment conducted and the results obtained.

5.1 Description of the scheme

Dynamic feedback signs are widely used to provide drivers with information on their current driving behaviour. They aim at encouraging potential violators to obey to traffic regulations without applying hard measures of enforcement. There is a vast variety of applications targeting different aspects of driving behaviour, and the most common ones are related to respecting speed limits and providing either quantitative or qualitative information.

In the city of Munich feedback signs for speed limitations were tested for a defined period of time. The signs were installed at two locations near a school creating a significantly large number of children crossing the street at random spots. The speed limits at the two locations (Paosostrasse and Friedenspromenade) were 30 km/h and 50 km/h respectively.

The application was measuring the current speed of cars in both directions by the means of laser detectors integrated in the signs' bases. In case of a speed limit violation the signs gave the message "Slow down!" in red letters to the driver. If the speed limit was respected the signs showed "Thank you!" in green letters. Qualitative information was preferred over quantitative, as it has been observed that the display of the current speed value led to occurrences of "high scoring" during testing of such systems.

Through the sensors used for operating the signs, a sufficient database was provided to calculate the KPI for the direct safety impact. The data consisted of

- Time of a vehicle passing the location
- Speed of the vehicle

Both sets were provided separately for each street and each direction. The data were collected for a period of four weeks before the installation of the signs, during the complete testing period of four weeks and for four additional weeks after the removal of the signs.

5.2 Performance evaluation – Traffic safety (Direct impacts)

For the evaluation of the application the KPI presented in equation (7) in [*2*] is used. The information needed for the calculation consists of the daily traffic volume (DTV), the number of detected critical situations (CS) and a weighting factor w for each link.

For this case study the DTV could be calculated for an average day through by using the provided number of vehicles per day. Critical situations concerning the targeted system are the average speed limit violations per day. They could be extracted from the speed record of the vehicles passing the test site.

The weighting of the links is not an issue related with the ITS application and thus it cannot be calculated from the data provided. It is moreover a matter of the respective values and targets of the local policy. For this exemplary calculation, a weighting factor of 0.6 is used for the major road (speed limit 50 km/h) and 0.4 is given to the subordinate street (speed limit 30 km/h). Table 5 shows the results of the KPI calculation separately for each link and each direction.

Table 5: Traffic safety assessment results for each link

I_{DS} (actions/veh)	Before	During	After
Paosostrasse (eastbound)	0.45	0.26	0.37
Paosostrasse (westbound)	0.73	0.48	0.70
Friedenspromenade (northbound)	0.15	0.12	0.15
Friedenspromenade (southbound)	0.29	0.18	0.30

By using the individual link weights a combined indicator is also calculated for the entire field test, and the results are presented in Table 6.

Table 6: Traffic safety assessment results for all links

I_{DS} (actions/veh)	Before	During	After
Munich (Paosostrasse-Friedenspromenade)	0.37	0.24	0.35

5.3 Discussion

An analysis of the KPI results shows a general trend in the influence of driving behaviour through feedback signs. A certain safety level that pre-existed is significantly improved by the application in a short period of time. After the removal of the application safety levels decrease instantly but get stabilised in a better level than before the installation of the signs. This trend can be observed in the total KPI values as well as in most of the single link values.

A closer look at the individual results, however, reveals some differences in the performance of each link. The major road (Friedenspromenade) shows an anisotropic behaviour with safety levels northbound being much better but yet showing less improvement than the ones southbound. The reasons for that are somewhat speculative. They can however be a result of differences of the demand peaks in the two directions, one leaving less capacity for speeding up than the other.

The calculation and aggregation of the KPI results demonstrate the value of the KPI's scalability. Single effects like the anisotropy of a specific major road can become visible and if necessary be closely investigated by experts. Through the aggregation on a network-wide level such effects can blur out without falsifying the general trend which is of higher relevance for the political stakeholders.

6 Rome: General assessment

In the case study in the city of Rome, a large-scale performance evaluation of the various techniques and ITS technologies that have been implemented within the framework of the Mobility Control Centre is conducted. Focussing on the area lying inside the "Grande Raccordo Anulare" (GRA) orbital motorway, an assessment of traffic efficiency in terms of mobility and reliability is carried out, using the outputs of large macroscopic simulation models calibrated with real data.

6.1 Description of the scheme

Rome's Mobility Control Centre was implemented in 1999 on the occasion of the Jubilee 2000. Since then its functionalities and features have evolved and improved.

The main Mobility Control Centre's goals are:

- to gather and organise information concerning the mobility within the metropolitan area of Rome;
- to share this information with all the citizens, tourists and city users, giving them the tools to choose the best way to move around the city;
- and to control and regulate the mobility in order to progressively reduce road congestion and travel times, as well as to improve safety, quality of life, and environmental sustainability.

The general architecture of the Mobility Control Centre consists of an open-plan, modular and expandable structure, based on two control levels: the first level consisting of peripheral systems, which is managed intelligently by the second level consisting of the central supervisor.

The ITS systems operating at the first level support the regulation of urban traffic and contribute to the efficiency and sustainability of the movement of vehicles and people. The main systems in use are: sensors for measuring traffic flows and journey times; video-surveillance cameras; traffic signals; and electronic "access gates" for automatic access control to limited traffic zones and to reserved bus lanes.

6.2 Performance evaluation – Traffic efficiency (Mobility)

For the assessment of the mobility of travellers, the city of Rome is broken up into 18 zones, as shown in Figure 7, and data on the average travel time and distance between all zones on private and public transport is obtained. This results in 324 routes of known average travel time and length, which enables the calculation of the average travel rate (min/km) for each route and for both private and public transport. The mobility KPI presented in Equation (1) in [*2*], is used to perform an assessment of the mobility in the city of Rome, for private and public transport separately, taking equal weights for each of the routes.

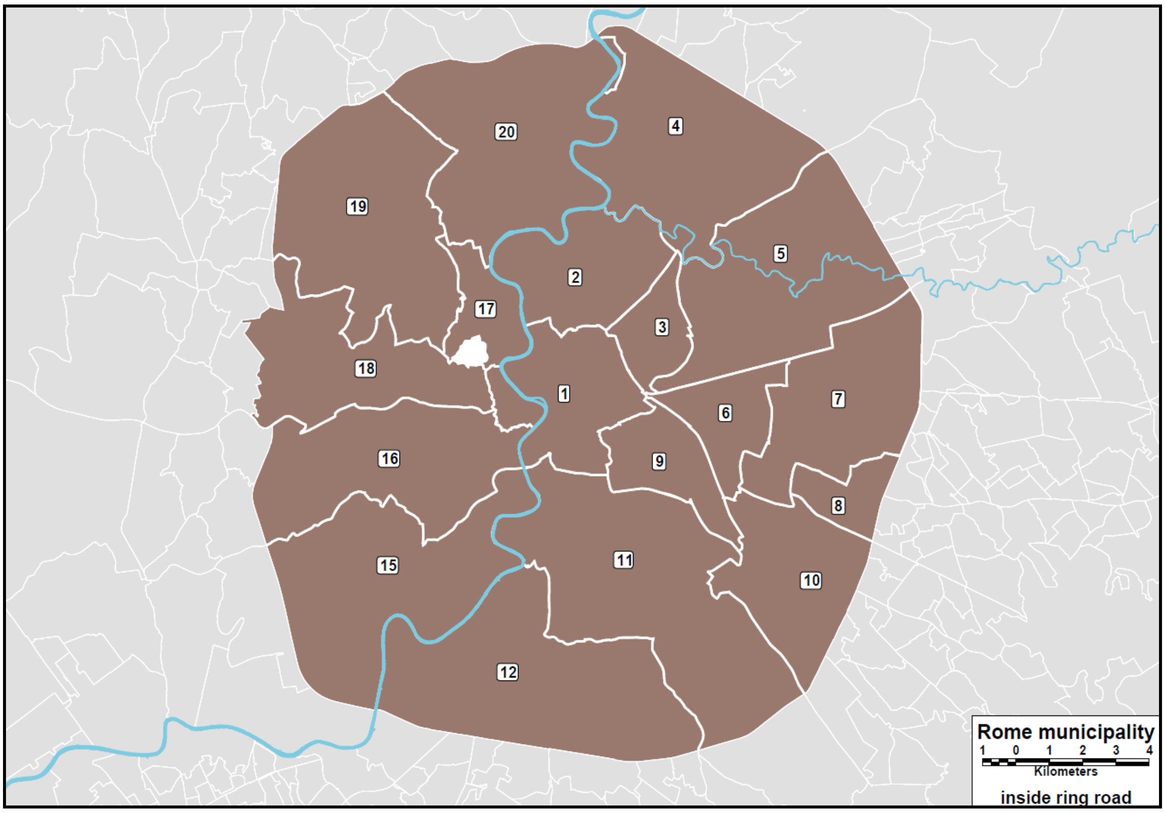

Figure 7: The 18 zones of the Rome study area (Source: Rome Mobility Agency)

The results of the assessment show that in Rome the average mobility of private transport over the 324 routes is better than that of public transport, with index values being 3.19 min/km for the former and 5.41 min/km for the latter. Based on the index values and setting the weights w_{PV} = 0.3 and w_{PT} = 0.7 following consultation with a group of experts from the Rome Mobility Agency, the overall mobility index for the city of Rome is calculated as 4.76 min/km. These findings are expected and give a representative overall image of the actual situation, as validated by the experts.

6.3 Performance evaluation – Traffic efficiency (Reliability)

In the assessment of reliability, congestion data on 45 representative routes across the road network of the city of Rome is used. This consists of the number of congestion incidents and their duration for a period of reference of one year, based on the definition of a congestion incident as the situation where the travel time on a route exceeds a certain threshold for 10 consecutive minutes. The threshold is, naturally, different for each route and depends on its length as well as on a number of other factors identified by the Rome Mobility Agency. A sample of the congestion data is shown in Figure 8.

ID Route	Name	Congestion threshold (minuts)	Occurrences	Average Duration (minuts)
10001	Sinagoga - Ara Pacis	16.8	167	50
10005	Ara Pacis - Porta Pia	20.4	14	17
10006	Porta Pia - Cinque Giornate	21.6	6	19
10007	Cinque Giornate - Trilussa	22.2	322	45
10008	Emporio - Sinagoga	8.4	149	40
10021	Ponte Mammolo - St. Tiburtina	20.4	23	35
10022	Olimpico - Maresciallo Giardino	19.8	3	23
10025	Olimpico - Salaria	25.8	12	18
10026	Salaria - St. Tiburtina	27.6	4	29
10027	Capannelle - Quadraro	18	6	20
10028	Quadraro - Cave	19.8	7	112
10030	Grottarossa - Olimpico	16.8	5	68
10031	Pio XI - P.le degli Eroi	12.6	128	59
10032	P.le degli Eroi - Olimpico	18	38	29
10033	Quadraro - Cave	14.4	5	22
10034	St. Tiburtina - Castrense	23.4	82	29
10035	St. Tiburtina - Porta Pia	15	13	90
10036	Colombo - Navigatori	13.2	5	34
10038	P.le Appio - Piramide	20.4	2	15
10040	Cecchignola - Colombo	19.8	2	263
10042	Agricoltura - Ponte Marconi	17.4	2	330
10043	Ponte Marconi - Piazza della Radio	9	20	118
10044	Agricoltura - Navigatori	21	3	50
10046	Aurelia (St. Aurelia) - P.za Carpegna	13.8	53	37
10047	P.za Carpegna - Porta Cavalleggeri	16.2	58	35
10048	Porta Cavalleggeri - Trilussa	9	3	30
10049	P.te Marconi - Majorana	12	11	85

We define one occurrence when the threshold (concerning every single route) has been exceeded for more than 10 consecutive minuts

totali

Ready

Figure 8: Congestion data for the city of Rome (Source: Rome Mobility Agency)

Applying the reliability KPI defined in Equation (2) in [*2*] and making the assumption that the routes are weighted equally, an index value of 0.9959 is obtained. This indicates a very high reliability across the network throughout the period of reference of one year, and is supported by the generally low number of congestion occurrences as a whole (1871 congestion incidents, with an average duration of approximately 57 minutes). This, however, may be attributed to the fact that the potentially unreliable and congested peak hours are compensated by the long uncongested off-peak (night time) hours.

6.4 Discussion

The main finding from this case study is that it is shown that the new traffic management and ITS KPIs are also appropriate for large-scale performance assessment, in addition to the evaluation of individual case studies. The mobility assessment results for the Greater Rome region are in line with what would be expected, namely better mobility for private transport than for public transport, with mobility index values of the same order of the ones in the two Paris case studies. As concerns the reliability assessment result, on the other hand, the obtained index value is, on one hand correct, based on the definition and occurrences of congestion around the network, but is, on the other hand, not representative of the situation at critical times (peak). The result, hence, shows that the mobility index is appropriate, but highlights the need for a time-based reliability performance evaluation (e.g. only at peak times) of the transport network.

7 Conclusions

Following the methodological definition of the new performance evaluation framework for urban traffic management and ITS, developed in the previous stages of the CONDUITS project, this report described the validation procedure for the new KPIs, which was carried out with the help of five case studies in four European cities (Paris, Rome, Tel Aviv and Munich), each assessing a different aspect of urban traffic management applications.

The evaluation of the KPIs with the help of the five real-world case studies demonstrated the usability and accuracy of the new performance evaluation framework. The calculation output was found to generally reflect major phenomena in the traffic conditions of the respective city, as confirmed by the local transport experts used in each case study, but as opposed to previous work, the output is single values and charts rather than manifold assessments. Furthermore the validation of the KPIs demonstrated their scalability, since they were applied successfully in small parts of networks (e.g. the case studies of Paris) as well as in large caption areas (e.g. the general assessment for Rome).

The KPIs are immediately usable by local authorities, as they utilise common and available data. This instance was not only confirmed through the application with data from four different cities, but also by means of direct consultation with other local authorities through the CONDUITS City Pool.

Nevertheless, it is recognised that the implementation of the KPIs requires the consideration of several dimensions in order to become an effective tool of decision-making in the field of traffic management and ITS, and therefore work in this direction continues. The next steps will thus concentrate on applying the KPIs to more case studies of different characteristics, so as to continue their validation and parameter fine-tuning. Further work will also focus on the testing and validation of the KPIs for pollution and social inclusion, as well as on the development of new measures and indices.

References

[*1*] Zavitsas, K., Kaparias, I., and Bell, M. G. H. *Transport problems in cities - CONDUITS Deliverable 1.1*. 2010.

[*2*] Kaparias, I., Bell, M. G. H., Eden, N., Gal-Tzur, A., Komar, O., Prato, C. G., Tartakovsky, L., Aronov, B., Zvirin, Y., Gerstenberger, M., Tsakarestos, A., Nocera, S., and Busch, F. *Key Performance Indicators for traffic management and Intelligent Transport Systems - CONDUITS Deliverable 3.5*. 2011.