Performance evaluation of urban traffic management and ITS: The Rome case study

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1 Introduction

In order to cope with their growing traffic problems, cities throughout the world deploy Intelligent Transport System (ITS) applications in various fields of urban networks. The decision making process for the installation of ITS is a dialogue between the political instance of the municipalities and the planners. The strategic concept and the detailed planning are undertaken by transportation experts in the respective planning authorities and is based on a vast variety of measurements and evaluations (Reed et al., 1993). The decision for funding the systems however is taken on a political level and is based on the consideration of expected benefits, economic aspects but also public debates and controversies. It is obvious that this dialogue within an inhomogeneous group of stakeholders needs a common basis for the consideration of benefits of ITS as a counterpart to the often obvious costs.

In order to deliver this common basis of discussion, a transparent methodology to calculate and present the benefits of ITS has to be elaborated. This methodology should support the decision making process in several aspects:

- to identify best practice applications already operational in similar cases in other cities;
- to decide on the installation of the system on a technical and a political level;

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- to monitor the performance of the deployed application over a longer period of time;
- to weigh the investment and operational cost compared to the benefits of the system.

Several solutions to this problem were proposed within the EU FP7 project CONDUITS (2009 - 2011). They included the elaboration of a set of Key Performance Indicators (KPI) targeting different categories of ITS and providing a single, measurable value for their benefit.

The following paper gives an overview of the definition process for the KPI, explains their function and gives an example for the calculation of the KPI based on real-life data provided by the city of Rome.

2 Key Performance Indicators

2.1 Defining a set of KPI for urban ITS

Transportation plans and projects have goals and objectives from which performance measures are derived. Data requirements should be defined and analytical methods should be chosen with the intention of generating performance measures and applying them in a process of evaluation of the alternatives, decision-making support and ongoing monitoring. Such processes are mostly conducted by using several measures in order to reduce the inherited bias of basing decisions on a single measure. An alternative for that is based on composite synthesis indices, which combines several measures into a single index allowing drill-down and slicing the composite index.

A Key Performance Indicator is a composite index, consisting of different measurable indices and reflecting the performance of a system according to its pre-defined goals. The KPI is not necessarily required to have physical dimensions and its magnitude can vary between different application areas. The development of the values compared to past periods however delivers an easy and comprehensible idea of the systems performance. One common example for a Key Performance Indicator is the Consumer Confidence Index (CCI).

The definition of a KPI is subject to different boundary conditions:

- goals and objectives of the targeted system;
- already applied evaluation procedures;

- data availability;
- social role or position of the addressee supposed to use the information provided.

Figure 1 shows the placement of the KPI calculation within the conventional, performance-index-based evaluation of the system's outcome.

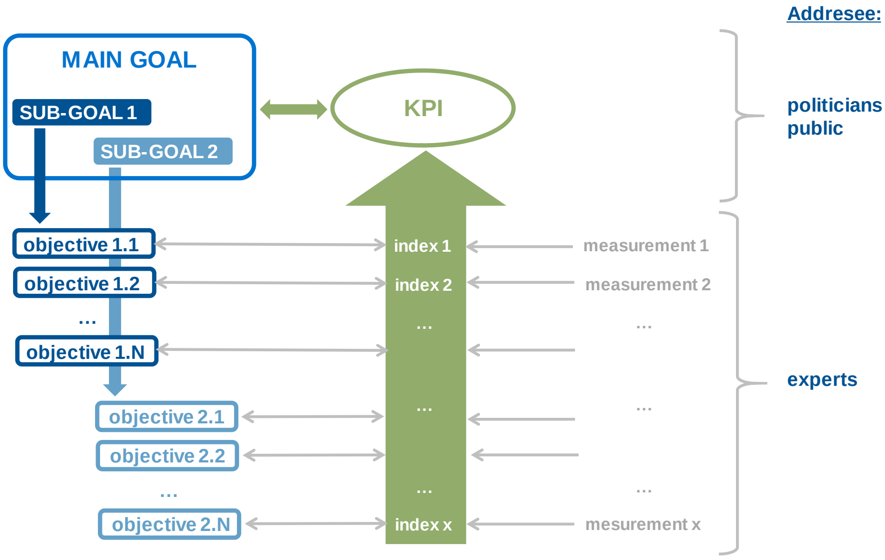

Figure 1: Evaluation of indexes and KPI

It is here important to underline that the KPI-based evaluation does not aim to replace the detailed evaluation procedures undertaken from the planning authorities and addressing transportation experts. It rather integrates it, processing the results of this evaluation to generate a less complex output addressing other target groups such as politicians and the open public.

2.2 Requirements and Categories of KPI

The KPI defined in the CONDUITS project aim to be applicable in a wide variety of cities and for manifold ITS-applications. Therefore a close cooperation between researchers and municipalities was necessary in the development phase. Within the project a pool of fifteen cities was set up and involved in the process from the very beginning with the main task of stating the initial requirements for the KPI in terms of their aspired role within the decision making process, to comment and steer their definition in terms and their usability for the public authorities and finally to provide data from realistic case studies for the final calculation and validation of the KPI set.

NCHRP report 446 discusses in details the requirements on performance measure. The most important ones are::

1. Measurability:
   The KPI must be easily calculated with data already available at the municipalities and shall not require additional measurements;
2. Clarity:
   The KPI must be comprehensible and simple to communicate to non-experts such as the open public and policy makers but also be usable in a first instance for professionals;
3. Controllability:
   The public authorities must be able to adjust the KPI to their specific needs and according to their respective values. The KPI must be usable for different modes, different sizes of geographical areas, different times of the day/year. Additionally a weighting between elements (modes, network parts, times of day) of higher and lower significance must be possible.

The developed set of KPI was structured in four major categories, each one containing two or more indicators (Figure 2).

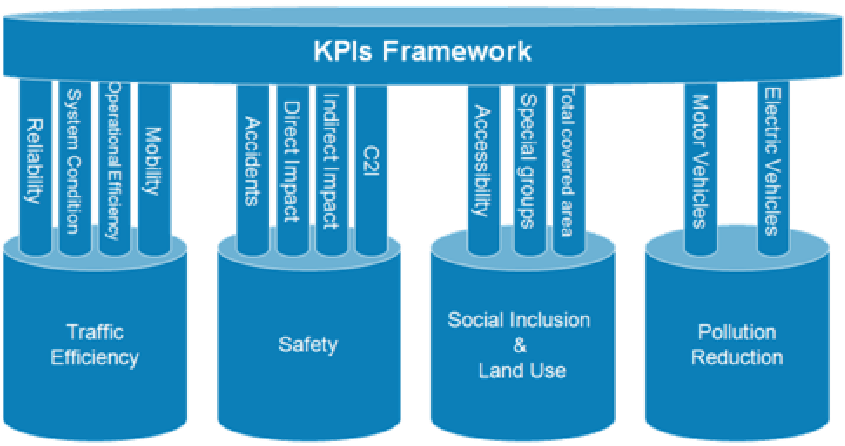

Figure 2: The KPI-framework developed in CONDUITS, source: Kaparias et al. (2011)

The categories of Traffic Efficiency and Pollution Reduction are original fields of urban ITS and thus have a number of applications targeting directly their improvement.

The field of Traffic Safety includes some applications that influence safety impacts directly, and many others that actually aim at improving efficiency or emissions but have a secondary effect - positive or negative - on traffic safety.

Finally, the fields of Social Inclusion and Land Use were considered. ITS may play an important role in social inclusion, even if they lack mass-applications due to the limited target group. Land Use is a slow-going process, mainly influenced by general development factors. In this case indicators to approximate single effects of ITS were developed.

In the final part of the project, the KPI for Traffic Efficiency, Pollution Reduction and Traffic Safety were calculated and validated using data provided from the city pool.

3 Evaluating Traffic Efficiency

The term traffic efficiency may cover a variety of aspects. For the purposes of the present study, traffic efficiency is constituted by the following four sub-categories: mobility; reliability; operational efficiency; and system condition and performance.

Mobility is defined as the ability of a transport system to provide access to jobs, recreation, shopping, intermodal transfer points, and other land uses, which is one of its primary purposes. Measuring the performance of mobility is hence an important part of quantifying the performance of the system in terms of traffic efficiency as a whole. Mobility measures should reflect the ability of people and goods to reach different destinations using different modes. Moreover, measures of mobility should capture the density of transport service within a given area and express the user's perspective. Mobility is mainly concerned with the travel time on the road and public transport networks.

Reliability is another important function of transport systems, which expresses the ease of mobility. Reliability is an essential component of traffic efficiency and should thus also be measured. Reliability measures should reflect the ease or difficulty of people and goods to plan their trip-based activities. Since reliability is concerned with travel time variability, speed, system usage and system capacity, many reliability measures will come from the perspective of the suppliers of the modes and the infrastructure.

Operational efficiency refers to the good organisation of resources to produce an acceptable level of transport output and is, as such, an important constituent of traffic efficiency. The quantification of the performance of operational efficiency is of particular interest to the suppliers of transport services, and measures evaluate the competency of systems from a financial, operational, time and user's perspective. The most frequently used measures are trip time, congestion-related attributes, mode shares, transfer times at connecting facilities and public transport cost performance. As specified with regard to reliability measures, congestion-related attributes and trip times are typically estimated with travel models, mode shares are collected through surveys, and connecting times and distances at transfer facilities can be collected with field data or user surveys.

Finally, system condition and performance refers to the physical condition of the transport infrastructure and equipment, which is seen as a vital directive by most practitioners. System condition and performance measures can focus on the condition of the system itself (e.g. roadways with deficient ride quality) or on the efficiency of transport programmes (e.g. cost to maintain roadways). The most common measures relate to roadway and bridge conditions and age, as well as maintenance by their management organisations.

Each traffic efficiency performance measure presented in the previous section necessitates an operative definition as far as measurement unit and levels of implementation are concerned. The following sections present the KPI for Mobility and Reliability that are of relevance for the Rome case-study.

3.1 KPI for Mobility

A mobility KPI can be composed of different elements but essentially consists of the average travel time to different destinations in the highway and public transport networks expressed in time units, normalised by the distance to the destinations, and weighted by importance according to the goals and objectives of the application under consideration. The mobility index, I_{MOB}, may thus be formulated as follows:

$$I_{MOB} = w_{PV} \cdot \frac{1}{|R_{PV}|} \cdot \sum_{r \in R_{PV}}^{|R_{PV}|} \frac{ATT_{PV}^{r}}{D_r} + w_{PT} \cdot \frac{1}{|R_{PT}|} \cdot \sum_{r \in R_{PT}}^{|R_{PT}|} \frac{ATT_{PT}^{r}}{D_r} \quad (1)$$

where:

R_{PV}: set of monitored routes on the private transport network

R_{PT}: set of monitored routes on the public transport network

r: a route among the monitored routes in R_{PV} and R_{PT};

ATT^r_{PV}: average travel time for route r on the private transport network

ATT^r_{PT}: average travel time route r on the public transport network

D_r: length of route r

w_{PV}: represents the weight of the travel time on the road network

w_{PT}: denotes the weight of the travel time in public transport

The spatial concern of the analysis influences the selection of origins and destinations and the determination of the route sets R_{PV} and R_{PT}. The spatial scale is mostly determined by the type of authority, as national and regional authorities are likely to have different needs than local authorities, and are therefore likely to monitor different routes.

In equation (1) the ratio ATT/D is calculated separately for each of the routes of the sets R_{PV} and R_{PT}, and then summed. The reason why two separate sets are used is to enable the application of different weighting factors for private and public transport, as opposed to the case where these would be weighted equally. Within the average travel time assessment these weighting factors are assigned values from 0 to 1, with their target sum set to 1.

Moreover, the I_{MOB} KPI depends on the selection of the actual paths connecting the OD pairs. The paths selected influence travel time and accordingly the index, but logical considerations of the minimal travel time path in congested conditions across different projects or different time points allows a fair comparison of mobility conditions. The minimum travel time path guarantees the evaluation of mobility as a necessity, since travellers who do not choose the shortest path could be defined to have a different objective. The congested conditions ensure the "worst case scenario" condition of major interest, as free-flow conditions imply good mobility regardless of the implemented project or plan.

It should be noted that the units of I_{MOB} KPI are "travel time per km", and that the dimensionless weights w_{PV} and w_{PT} have to be determined through expert evaluation, as better specified at the end of section 3.2.

3.2 KPI for Reliability

Congestion may be defined as an increase in travel time (or reduction of speed) above a threshold or could be calculated based on available algorithms in the literature based on data gathered from detectors, signal program information and static topological layout.

The congestion index which represents reliability could be calculated in different ways according to the acceptable methods of each transport agency. In order to allow a normalised benchmarking, the congestion or reliability KPI is to be normalised so that the result remains within pre-defined limits, i.e. 0-1.

The reliability index, I_{REL}, calculated for links and for modes, may be defined as follows:

$$I_{REL} = \frac{\sum_{l \in L}^{|L|} \left(w_{PT} \cdot \sum_{pt \in PT}^{|PT|} w_l \cdot \frac{CT_{pt}^{l}}{T_{wl}} + w_{PV} \cdot \sum_{pv \in PV}^{|PV|} w_l \cdot \frac{CT_{pv}^{l}}{T_{wl}} \right)}{\sum_{l \in L}^{|L|} \left(w_{PT} \cdot \sum_{pt \in PT}^{|PT|} w_l + w_{PV} \cdot \sum_{pv \in PV}^{|PV|} w_l \right)} \qquad (2)$$

CT^{l}_{x}: congestion duration on link l in the "x" network, where $x=pt \in PT$ for public transport and $x=pv \in PV$ for the road network

w_l: relative importance of link l

w_{PT}: represents the weight of public transport

w_{PV}: represents the weight of private transport

T_{wl}: represents the period in which congestion is monitored and to which w_l is attributed

The reliability index is computed over all the monitored links as the total congestion ratio on public and private transport.

The weights w_{PT} and w_{PV} have to be defined with a continuous value between 0 and 1 and they are required to add up to 1; their value should reflect the importance of the mode, and as a result, they are usually city-wide weights.

The weight w_l should be defined according to the following points:

- The length of the link;
- Inner links relative importance – the weight of a link should reflect its general importance compared to other links (arterials are often more important than the local roads);
- Seasonal importance – the weight of a link should reflect its changing importance during the year (links near recreation areas are to be assigned with higher weights during holidays and weekends rather than on weekdays);
- Time importance – the weight of a link should reflect its changing importance during the day (a link that leads to the city is more important during the morning peak and of less importance during the evening peak).

In order to calculate the weights required in almost all of the indices, an expert-based method is suggested as a methodological approach able to achieve a two-fold purpose: (i) providing a methodology to construct a performance measure that may be tailored to any transport plan or program, and (ii) providing a methodology that may be transferred across projects, provided that suitable experts are selected. The selected expert-based technique is the Delphi method which is considered a valid method for judgmental forecasting (Tolley, 2001)..

4 Application

To demonstrate the operation and applicability of the performance evaluation framework, the KPIs defined above are applied to a case study in 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. 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.

4.1 Mobility assessment

For the assessment of the mobility of travellers, the city of Rome is broken up into 18 zones, as shown in Figure 3, 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 Section 3.1, 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.

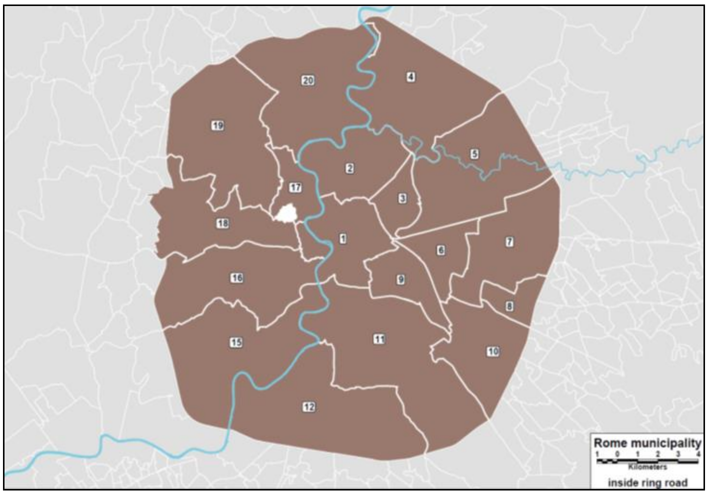

Figure 3: The 18 zones of the Rome study area, source: Rome Mobility Agency

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, hence demonstrating the correctness of the KPI.

4.2 Reliability assessment

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 4.

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

Figure 4: Congestion data for the city of Rome, source: Rome Mobility Agency

Applying the reliability KPI defined in Section 3.2 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, highlighting the need for a time-based reliability performance evaluation of the transport network.

4.3 Usability of the KPI

The results of this example from the city of Rome instantly state the question of their usability. In first instance a single value stands alone as general assessment of mobility or reliability. The value of this calculation lies within the scalability and the applicability of the KPI.

The scalability allows the local authority to calculate the indicator for smaller parts of the network and for single modes or ITS applications. Through the comparison with the city-wide average the contribution of single elements to the overall effect can be evaluated. Furthermore elements with a high deviation from the average can be identified as a subject for further improvement.

The applicability of the KPI allows the authorities to re-calculate the value in a row of many subsequent years in order to evaluate the performance development in time. The introduction of new ITS-applications can thus be closely monitored, first through the before/after comparison but also by monitoring the months following the systems introduction, investigating its amortisation and eventual rebound effects.

The applicability also allows comparisons with other cities -mostly ones in search for suitable applications who already have an assessed “before-state” in their networks.

5 Conclusions and Outlook

The evaluation of the KPI framework with the help of some other realistic case studies (calibrations for the cities of Paris, Tel Aviv and Munich have been developed) proved the usability and accuracy of the indicator set.

Local transportation experts (Municipality of Tel Aviv-Yafo, 2005) confirmed that the KPI calculation output really reflects the main traffic conditions of the respective cities. In the case presented here, however, everything was expressed through the use of a single value and a single chart in place of a variety of manifold assessments.

Furthermore, KPI proved 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 presented in this paper).

The KPI can be generally used immediately by local authorities since they base on common and available data. This instance was not only confirmed by the application with data from around five different cities but also after a survey among the fifteen members of the city pool.

Finally it can be stated that the KPI can support a robust decision making process for the application of ITS. This fact was confirmed by the acute interest in the outcome of the project from the side of the public authorities as well as from the side of the ITS industry.

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