Using key performance indicators for multi-criteria traffic management strategic decisions

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Abstract

In recent research work (FP7 CONDUITS) a performance evaluation framework for traffic management and Intelligent Transport Systems was developed. The new framework consists of a set of Key Performance Indicators (KPIs) for the strategic themes of traffic efficiency, safety, pollution reduction and social inclusion, and the last stages of the project saw its validation through its application to four case studies. Following up from this work, this paper presents the extension of the framework for use as a prediction tool enabling urban transport authorities to assess the impacts of relevant policies and technologies before implementing them. The first stage of the extension focused on pollution reduction, and a novel decision-support tool (CONDUITS_DST) integrating the respective KPI with micro-simulation modelling was developed. Case studies executed in Brussels and Zurich demonstrated the usability and viability of the tool. This paper takes the development one step further and reports on the extension of the approach, which moves from single-criterion to a multi-criteria decision support tool through the inclusion of the KPI on traffic efficiency, again based on micro-simulation modelling outputs.

Keywords:

Performance Indicators, Intelligent Transportation Systems, Multi-Criteria, Simulation, Emissions, Traffic efficiency

Introduction

Cities today share common transport problems and objectives with respect to mobility management, and put great focus on Intelligent Transport Systems (ITS). The market offers decision makers a variety of ITS solutions, from which they are required to choose the most suitable and effective ones. Making this choice is a non-trivial task, especially given that transport problems are multi-dimensional by nature. Hence, a performance evaluation framework that addresses the various dimensions of transport problems while at the same time reflecting the perspectives and priorities of decision-makers is required (Zavitsas et al, 2011).

Performance evaluation framework

An evaluation framework for urban traffic management and ITS was developed as a result of the European Commission funded CONDUITS project. Key Performance Indicators (KPIs) were formulated, taking into account a wide range of requirements, such as the need for them to be easily understandable, impartial and scalable. The development process adopted a hierarchical approach, where traffic management as a whole was decomposed into the four strategic themes of traffic efficiency, traffic safety, pollution reduction and social inclusion, and where each theme was decomposed according to its relevant dimensions (e.g. the traffic efficiency KPI aggregates performance measures relating to various transport modes, various types of routes within the network etc.) (Kaparias et al, 2011). The developed KPIs were subsequently validated through the conduct of case studies in the cities of Paris, Rome, Tel Aviv and Munich (Tsakarestos et al, 2011; Kaparias et al, 2012). Through the conduct of the case studies, it was concluded that the KPIs are easy to apply and require already available data, either collected in the field or generated by a modelling tool, thus forming a very useful evaluation tool not only for operational decision-making but mostly for strategic decision-making. Sponsored by Kapsch TrafficCom, on-going research work on integrating the KPIs with micro-simulation modelling has created a prediction tool for traffic management and ITS, called CONDUITS-DST. At the current stage, two out of the four CONDUITS KPI categories have been integrated: the pollution generated by the transport modes in the form of greenhouse gas emissions, and the traffic efficiency, expressed through measures such as travel time and network reliability.

Predictive evaluation framework

The procedure followed for predicting the potential impact of new traffic management and ITS applications combines real life measurements on one hand, and the simulation of alternative scenarios on the other. One of the most common transport modelling tools used for pre-deployment analysis is the PTV VISSIM micro-simulator. This tool has the ability to estimate the likely impacts of ITS measures on mobility patterns and, as a consequence, the traffic-generated emissions. While the first stage of the CONDUITS_DST focused on the integration of the pollution KPI based on the traffic-generated emissions, the current development stage goes from a single-dimensional analysis enablement, to a multi-dimension by incorporating the CONDUITS traffic-related KPI's. In order to accomplish that, new definitions were made in order to allow an easier comparison on the one hand and with seeds aggregated results on the other. By establishing these new definitions, a linkage between the pollution reduction and the traffic efficiency is achieved.

CONDUITS_DST Components

The structure of the tool which integrates the CONDUITS KPIs with the micro-simulation tool is described by Figure 1.

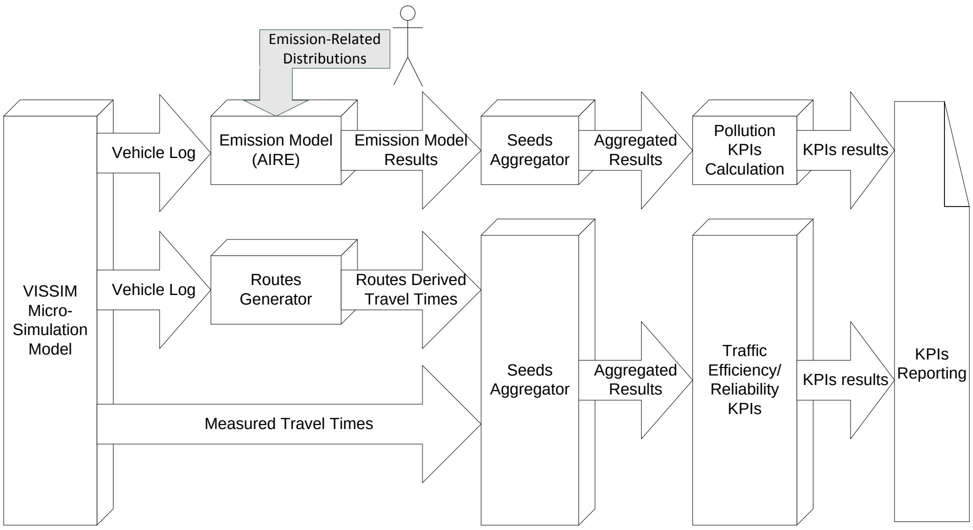

Figure 1: Structure of the prediction tool

The CONDUITS KPIs are the main components of the CONDUITS DST. These KPIs are based on requirements specified in earlier stages of the CONDUITS project (Kaparias et al, 2011). Three of the CONDUITS KPIs have been integrated in the tool: The pollution reduction (1), mobility (2) and the traffic reliability (3). These are presented next.

$$(1)\quad I_P = \frac{\sum_{vt\in VT}^{|VT|}\sum_{et\in ET}^{|ET|} W_{vt}\cdot W_{et}\cdot Q_{vt,et}}{\sum_{vt\in VT}^{|VT|}\sum_{et\in ET}^{|ET|} W_{vt}\cdot W_{et}}$$

Where:

VT – Vehicle type
ET – Emission type
W_{vt} *– Vehicle type weighting factor*
W_{et} *– Emission type weighting factor*
$Q_{vt,et}$ *– The average ET quantity by travel distance and number of cars per VT*

$$(2)\quad I_{MOB} = \frac{\sum_{vt\in VT}^{|VT|} W_{vt}\cdot \frac{1}{|R_{vt}|}\cdot \sum_{r\in R_{VT}}^{|R_{vt}|} \frac{ATT_{vt}^{r}}{D_r}}{\sum_{vt\in VT}^{|VT|} W_{vt}}$$

Where:

R_{VT}: set of monitored routes for the VT
r: a route *among* the monitored routes in R_{VT}
ATT^{r}_{vt}: average travel time for route r for vt
D_r: length of route r

$$(3)\quad I_{REL} = \frac{\sum_{l\in L}^{|L|}\sum_{vt\in VT}^{|VT|} W_{vt}\cdot W_l\cdot \frac{CT_{vt}^{l}}{T_{wl}}}{\sum_{l\in L}^{|L|}\sum_{vt\in VT}^{|VT|} W_{vt}\cdot W_l}$$

Where
CT^{l}_{x}: congestion duration on link/route *l* for VT
W_l: relative importance of link/route *l*
T_{wl}: represents the period in which congestion is monitored and to which *wl* is attributed

Predictive KPIs aim to present the impact of measures planned to be deployed according to evaluated scenarios but the simulation outputs are presented for a given seed or execution. Also, the VISSIM natural outputs do not directly meet the KPIs' requirements. To bridge the gap, two main components were developed: (1) Seeds aggregator which accumulates the results of the different seeds in order to generate a single KPI for the scenario, and (2) Routes generator, which utilises the same emissions required measurements, to generate the list of routes travelled in the scenario, thus relating the travel times instead from to actual routes instead of origin-destination pairs. Deriving the routes is possible by using the detailed VISSIM vehicle log file which is used also for the emissions calculations module (Eden et al, 2012). This however is considered to be a time consuming task.

Routes Generator

The VISSIM vehicle record file includes information of each of the vehicles that exists in the network at any given time. The file is ordered by the second of the time step.

The fact that VISSIM generates a finite number of vehicles for a single simulation run and the vehicle identification number does not repeats itself in a single run, it is possible to dramatically reduce the route generation time by using an auxiliary function that retrieves variables values from a given record, and an assumption about the maximal vehicle identification number. This can be assumed to be no higher than the total number of vehicles (for all modes including pedestrians) that should be entered to the model.

The routes generation algorithm uses the CA (X,7) that holds the vehicle data (StartTime-0, EndTime-1, DistX-2, VehType-3, VehTypeName-4, Route-5, LastLink-6) and is detailed next.

```
For RecordNum = StartRecord to EOF ' EOF of the VISSIM vehicle log file
          DO RecordBreake ‘this procedure retrieves the values of the needed variables from
                           the vehicle log record

          If CA(CarID,0)=0 then CA(CarID,0) = t
         Else
                CA(CarID,1) = t
          End if

          CA(CarID,2) = DistX
          CA(CarID,3) = VehType
          CA(CarID,4) = VehTypeName

          If CA(CarID,6) <> LinkID then
                    CA(CarID,5) = CA(CarID,5) & LinkID
                    CA(CarID,6) = LinkID
          End if

End RecordNum
```

At the end of the procedure, the CA array is compacted and includes the routes; the distance travelled and travel time of each vehicle in the network thus the calculation of the travel times of each mode at each of the route is easily derived.

By using this fairly short algorithm, it is possible to generate the routes and routes-related data of a 1.7GB vehicle log file in just few seconds on a common PC.

Seeds Aggregation

Any simulation study is composed of several mobility scenarios (the most common are the current and future plan scenarios). Each of these scenarios is evaluated by using the results of from several runs, each with a different seed value. The role of the seed aggregator is to collect and harmonise the measurements, either as calculated by the routes generator or by the AIRE tool (O'Brien et al, 2012) which is integrated; or as directly measured by VISSIM during the runs. As each simulation run may include more than a single time frame, the aggregation is executed to each of the defined time frames separately. By doing so, it is enabled to evaluate the trends of the KPI's along the time.

KPI's Calculations

Three of the CONDUITS KPI's are integrated in CONDUITS_DST: (1) Pollution Reduction (2) Traffic Efficiency (3) Traffic Reliability. Each of the CONDUITS KPI's is calculated according to (1)-(3) but based on different types of data.

The Pollution Reduction KPI is based on the tailpipe emissions as estimated using the AIRE auxiliary tool – CO, NOx and particulate matter. Each of the emissions type generated by a given vehicle type/mode is multiply by its relative weight and the relative weight of the vehicle type, summed and divided by the vehicle type and emission type product. The specific weights of each of the emission types as well of each of the vehicle types is defined using the weights scenario, which enables the evaluation of different KPI's calculation scenario, thus providing a better understanding of the study results.

The Traffic Efficiency KPI is calculated based on travel time either as were calculated by the routes generator or measured by VISSIM for each of the links. The travel time is divided by the route's or link length to provide the ability to compare the results from different network with different sizes. Following the methodology of the Pollution Reduction KPI, the travel times are factored by the weights assigned by the analyst to the vehicle types and to the routes in the weights scenario.

The Traffic Reliability KPI which described in (3) refers to the congestion duration as the fundamental measured value. This could be interpreted in many ways and depends on the ITS measure which is deployed. Travel time measurements could be broadly categorised to two groups: aggregated which provides data for a group of vehicles and district which can provide data for specific vehicles. ITS tools related to the former are travel times calculation using inductive loop detectors by using commonly used spot-speed methods (Soriguera& Robusté, 2013), or by the recently emerged cellular networks-based travel time measurements. In the district category, technologies such as Bluetooth, Image processing and Global navigation systems can provide detailed data for specific probes with the ability to identify the modes to different extents (Reddy et al, 2010, Araghi et al, 2012). The data these technologies can provide can either be aggregated to district times or be provided as raw data, i.e. the travel time of the probe.

CONDUITS_DST bases its Traffic reliability KPI calculation using a similar type of data – the specific travel time of each of the vehicles in the vehicle log. In order to match with the CONDUITS methodology, the following definitions were made to (3).

$$CT_{vt}^{l} = \sum_{Veh \in R} (TT_{Veh} - TT_r) > 0$$

$$T_{wl} = \sum_{Veh \in R} TT_{Veh}$$

Where:

TT_r is the acceptable travel time defined by the analyst to route r

TT_{Veh} is the travel time of the vehicle *veh*

Analysis Dimensions

CONDUITS_DST enables the calculation of different network setups, different traffic scenarios (often refers to changes in demands for trips, availability of transport modes, deployment of ITS measures, policy, and more.), different deeds and different time frames. All these are channelled to the KPI's calculation which is based on two components. The measurements values as derived from the simulation and the weighting of the travel modes/vehicle types, the routes and the emissions. The weighting scenarios enable to reflect the local policy to the space and mode as described in the following example, taken from the simulation runs of the status before the increase of the operational speed of the public transport in the southern section of line 49 in Brussels during the morning period.

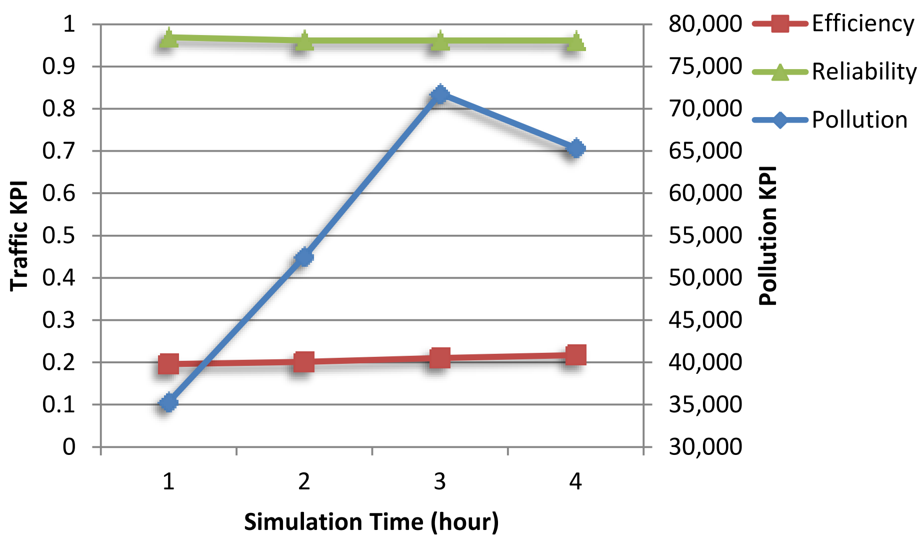

Fig 2 – CONDUITS KPI values: Equality weight scenario

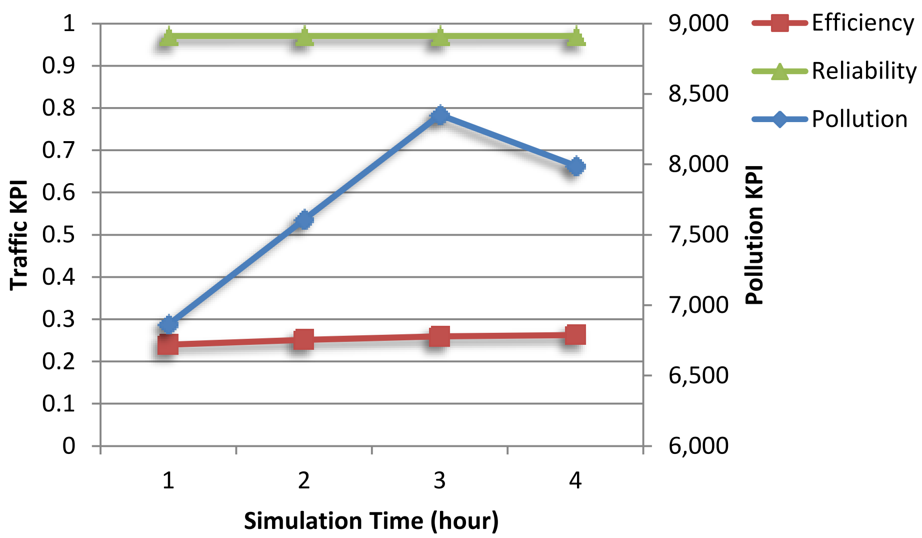

Fig 3 – CONDUITS KPI values: Pro-sustainability weight scenario

Fig 2 and Fig 3 presents the values of the three implemented CONDUITS KPI's and the same traffic scenario but with different policies. The first policy assumed equality between the modes, i.e. all transport modes has the same importance. The second policy is more pro-sustainable as it favours the public transport mode 100 times more than the private transport modes for the vehicles and for the routes. This ratio is considered conservative as the capacity of the trams in that part of the network is more than 100 passengers and during the morning it can be assumed that most of the trams capacity is consumed.

As can be seen in Fig 2 and Fig 3, both scenarios captured the increase in demands for trips which lead to an increase in the pollution index during the peak period, and with a marginal impact on trips reliability. Nevertheless, in the pro-sustainable weighting policy, it is evident that while the traffic efficiency increased, the pollution index is reduced by a scale, thus better reflects the local policy and the expected outcomes.

Conclusions

CONDUITS_DST, which is free-of-charge tool, enables the calculation of different network setups, different traffic scenarios and evaluating different policies. The CONDUITS_DST is an on-going project which just entered the second phase – the integration of the safety index and case-studies which will be conducted in three cities.

Besides Brussels which serves as the main case-study, the research project is closely monitored by two further European city authorities (Rotterdam and Zurich), giving detailed feedback on the tool's features and steering the development process.

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