Evaluation of Microsimulated Traffic Light Optimisation Using V2I Technology

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Abstract. Within the research project KOLINE a cooperative system for urban road transport is developed. Its traffic related goals are to reduce travel time and fuel consumption as well as noise and pollutant emissions. The herein described evaluation shall determine whether, to which extent and how economically the KOLINE system is able to address these goals. Three differently comprehensive quantifying evaluation procedures are applied to the outputs of a microscopic traffic simulation. Thus not only the ranking of all scenarios, but also comparisons between these procedures become possible.

Keywords: transport economy and policy, cost-benefit-analysis CBA, microscopic simulation output, data analysis.

1 Introduction and Project Aim

Within the German research project KOLINE a cooperative system for urban road transport is developed and tested. In order to reduce travel time and fuel consumption as well as noise and pollutant emissions it uses the communication between vehicles and traffic light infrastructure (V2I) to avoid stops of vehicles at traffic lights and to increase the network capacity. The system description, technical aspects and the specific component for tailback estimation are discussed in detail within two other papers presented at this conference.

This paper concentrates on two aspects of the always recommendable traffic-related evaluation at the end of ITS projects. The first aspect is the in-depth evaluation for several scenarios to determine whether and to which extent the fully productive technical KOLINE system is able to address the above mentioned goals. The thereto applied methods and procedures, the microscopic traffic simulation as single source of evaluation input data, and exemplary outcomes are described.

The second aspect is the investigation of possibilities to produce general project-independent recommendations for future ITS project evaluations. Therefore the available methodology is analyzed and some major terms are defined in the next chapter.

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2 Goals, Evaluation Methodology and Procedures

2.1 Goals

Literature lists up to six *global goals* for transport-related projects, which can be grouped and summarized as follows [1, 2]:

1. Mobility (Travel Time)
2. Resource Efficiency (Energy, Money)
3. Environment Friendliness (Noise, Pollutants)
4. Safety
5. Security
6. Customer Satisfaction.

While as the first three global goals are explicitly addressed by the KOLINE project, the latter three ones are nevertheless regarded in other ways:

4. It is investigated whether safety estimations could be gained from the simulation's single car trajectories.
5. A secure implementation of the developed technology is considered as an a-priori condition from the point of evaluation and therefore assumed as being fulfilled.
6. Customer satisfaction expresses itself amongst others in the degree of acceptance of automatic driving manoeuvres, e.g., the automatic vehicle speed control. This degree is inserted as scenario simulation input parameter rather than calculated as output.

The global goals are broken down into more detailed and project tailored *sub-goals* or *criteria*. These criteria need to be operative by *indicators*, meaning a suitable performance figure which always includes a denominator has to be defined. In a final step the necessary physical *measures* for each indicator are determined [3a]. Table 1 shows the global goals, their criteria and physical measures (without denominator) in KOLINE.

2.2 Evaluation Methodology

The generated simulation output values of the measures need to be interpreted to understand their impact. This interpretation process bases on some generic concepts - called *methods* or *techniques* - which can be carried out through different specific formalized *procedures*. The evaluation methodology for transport-related projects in general comprises several methods, which can be of either describing or quantifying nature. The latter ones further divide into non-monetizing and monetizing approaches. Representatives of the first approach are the Multi-Criteria (Utility) Analysis (MCA) and mono- or multi-criteria based qualitative assessments (QA), whilst the most popular monetizing method is a Cost-Benefit-Analysis (CBA). Legal binding CBA procedures with detailed execution directives and values are, e.g., New Approach to Appraisal (NATA) in the UK, Bundesverkehrswegeplan (BVWP) in Germany [4], and System Informatyczny Monitoringu i Kontroli Finansowej Funduszy Strukturalnych i Funduszu Spójności (SIMIK) in Poland.

The inventory of possible evaluation methods and procedures especially for ITS projects yields a broad range of results, but also shows that neither a common approach nor a dedicated or even compulsory procedure yet exist. Examples stretch from simple descriptive [5] or multi-dimensional quantifying reports [6] and specific Multi-Criteria-Analysis [7] up to recommendations for [3b] or application of Cost-Benefit-Analyses [8].

Since no clear preference or advantage for one of these approaches evolves, a bunch of three different procedures representing three methods are chosen. Thus not only the evaluation of all scenarios and their impact, but also the assessment whether these differently comprehensive methods are fit for the given task and which one is the best becomes possible.

2.3 Evaluation Procedures

The applied and - where necessary - modified procedures can all be counted as quantifying ones. Namely they are the compulsory determination of the Level of Service (LOS) according to the German HBS [9], the Performance Index (PI) calculation derived from TRANSYT [10], and the Cost-Benefit-Analysis for German road infrastructure projects "EWS" [11]. Each procedure makes use of a different number and range of the above stated criteria to determine the respective result (Table 1). Due to the procedures' fixed definitions these results are generally comparable with outcomes of other projects.

Table 1. Global Goals, their Criteria and Measures, and Procedures in KOLINE

Global Goals	**Criteria**	**Measures**	**Procedure**		
			HBS	**PI**	**EWS**
Mobility	Travel Time	s; min; h			x
	Delay Time / Stop Time		x	x	x
	Number or Percentage of Stops	n; %	x	x	
Environment Friendliness	Pollutant Emissions (No_x, CO, HC, PA)	g; t			x
	Climate Gas CO_2	g; t			x
	Noise Emissions	db(A)			x
	Fuel Consumption	l			x
Resource Efficiency	Building / Acquisition Costs	€			x
	Operating + Maintenance Costs	€			x
	Occupancy Rate	n; %		x	x

HBS. The Level of Service (LOS) according to the German HBS is stated separately for each accessing lane and traffic mode of a single junction and often uses the peak hour as its time denominator. The sole criterion for signal actuated intersections is the average waiting time. On signal actuated coordinated sections it is the percentage of unstopped vehicles. Table 2 gives an overview of the threshold values.

Table 2. Threshold values for Level of Service (HBS)

Level of Service	Average waiting time w [s]				Percentage of unstopped vehicles [%]
	public transport	bikes	pedestrians*	motor vehicles (uncoordinated)	motor vehicles (coordinated)
A	≤ 5	≤ 15	≤ 15	≤ 20	≥ 95
B	≤ 15	≤ 25	≤ 20	≤ 35	≥ 85
C	≤ 25	≤ 35	≤ 25	≤ 50	≥ 75
D	≤ 40	≤ 45	≤ 30	≤ 70	≥ 65
E	≤ 60	≤ 60	≤ 35	≤ 100	≥ 50
F	> 60	> 60	> 35	> 100	< 50

* supplementary 5 s when crossing a divisional island

PI. The bi-criteria Performance Index synthesises the waiting time w and the number of stops h of all traffic modes z and all access sections i of an intersection (Eq. 1). The weight G_h is assumed to be 60, since the emissions of a start-up after a stop equal 60 seconds idling. In difference to the HBS not vehicles but passengers P are calculated with, thus incorporating the occupancy rate. The car occupancy rate in Braunschweig is about 1.23 people per car. The rate for public transport buses is taken from detailed passenger survey data and differs between 1 passenger in the evening and more than 90 passengers in the morning peak. While in [10] only stops of motor vehicles and buses are included in the second addend of Eq. 1, KOLINE extends this to cyclists due to comfort aspects. Normally the peak hour is used as time denominator, whileas the areal denominator can comprise a single or multiple junctions.

$$PI = \frac{\left(\sum_i \sum_z w_{i,z} \times P_{i,z} + G_h \sum_i \sum_z h_{i,z} \times P_{i,z}\right)}{\sum_i \sum_z P_{i,z}} . \qquad (1)$$

EWS. This comprehensive Cost-Benefit-Analysis is based on eight benefit criteria of which six are used in KOLINE. The benefit is defined as the difference between the criterion's values of the base scenario and a comparison scenario. A project is worth to be realized when the benefits are greater than the costs.

3 IT Setup

Although the technical feasibility and security of the system are demonstrated with several research vehicles on a public road section, a realtime all vehicles comprising field operational test is impossible. Thus the assessment is solely based on the outcomes of a microscopic traffic simulation, which is described below.

3.1 Microscopic Traffic Simulation

The test area is an urban sub-network in Braunschweig, Germany, with three signalized intersections at a total distance of 700 m. The network is part of an arterial road of its inner city traffic with an average daily traffic of up to 36.220 vehicles. It is thus important for commuters, but also for other traffic, e.g., six public transport bus lines pass the network in several directions. All streets running east-west and the streets running north-south at its central intersection have two lanes per direction with some additional turning lanes at signalised intersections. The remaining streets have one lane per direction. The speed limit is 50 km/h.

The representation of the network as modelled with TSS software AIMSUN 6.1.5 [12] is shown in Fig. 1. The numbers of the nodes correspond to the numbers of real traffic signal systems as assigned by the Braunschweig authority in charge of signalisation. Detectors are located on each lane about 20 m in front of traffic signals. However, not all turning flows are detected directly because of mixed lanes.

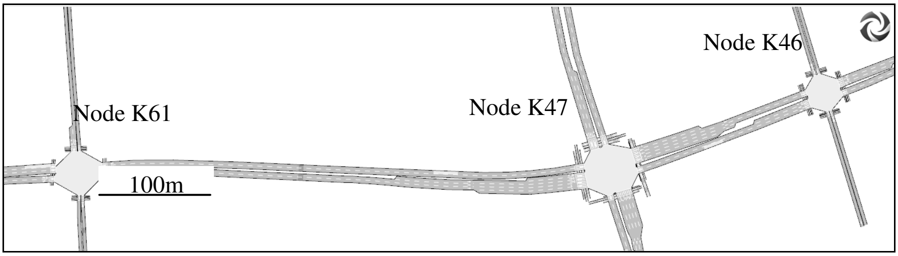

Fig. 1. Simulation model of the test area in Braunschweig, Germany

The simulation had to be specified concerning several aspects. The traffic demand has been deduced from real measurements on-site that have been taken on May 12, 2011 including detector counts over the whole day. Beside individual motorised traffic and public transport also cyclists and pedestrians are regarded within the simulation, which runs from 6 am to 10 pm. The pollutant emissions are calculated with factors taken of the German HBEFA emission model. For this purpose a total of seven vehicle types are defined to take account of the different pollutant emissions resulting from cars with gasoline or diesel engines, vans, lorries etc. The simulation model also maps the four essential system subcomponents, i.e., the signal program optimizer, the equipment rate of the V2I communication device, the automatic vehicle speed control for the approach strategy, and the tailback estimator. Table 3 gives an overview of how the parameters of these subcomponents are differentiated within the defined 12 scenarios. The vehicles penetration rate with V2I communication devices in scenarios Test 7 to Test 10 is chosen after the outcomes of scenarios Test 2 to Test 6 to give proper information about a suitable value to produce significant results.

The simulations' computed and semi-aggregated output data of 15-minutes-intervals comprises mean values and deviations for common traffic flow measures, as well as pollutant emissions. 25 replications with different random seed numbers have been run and the average of all obtained values has been calculated.

Table 3. Parameter differentiation within the Simulated Scenarios

Scenario	Applied Traffic Control	Vehicle Approach Strategy	Vehicle Penetration Rate	Tailback Estimation
Status Quo	Status Quo	No	0%	-
Reference	TRANSYT optimized	No	0%	-
Test 1	Signal Program Optimizer	No	0%	-
Test 2	Signal Program Optimizer	Yes	5%	detectors + vehicle data
Test 3	Signal Program Optimizer	Yes	10%	detectors + vehicle data
Test 4	Signal Program Optimizer	Yes	15%	detectors + vehicle data
Test 5	Signal Program Optimizer	Yes	20%	detectors + vehicle data
Test 6	Signal Program Optimizer	Yes	25%	detectors + vehicle data
Test 7	Signal Program Optimizer	Yes	5 -25%	detectors + vehicle data
Test 8	TRANSYT optimized	Yes	5 -25%	detectors + vehicle data
Test 9	Signal Program Optimizer	Yes	5 -25%	-
Test 10	Signal Program Optimizer	Yes	5 -25%	detectors

3.2 Evaluation Software

In a preparing step the voluminous AIMSUN generated MS Access Database of each scenario is filtered to leave only the average values of those 12 sections, which are accessing the three nodes under investigation. Since AIMSUN does not put out the number of stops and stop time for each lane as required by the German HBS, these values have to be estimated from the respective turn values and the ratio of turn tailback lengths. In the main step each one of the three evaluation procedures is applied to the database with JAVA software modules developed by the DLR-Institute of Transportation Systems. The results are stored in the respective scenario database.

4 Evaluation Results and Recommendations

The LOS and PI for bikes and pedestrians remain the same throughout the day at each of the three nodes since no changes to the signal plans are applied in the Status Quo scenario. Table 4 summarizes all relevant values for each node and in comparison PI evaluation outcomes for a project with multiple junctions in the German city of Münster [10], whereas Münster 0 stands for the baseline with conventional traffic light systems and Münster II for an optimized traffic adaptive regime. The LOS denotes for both East↔West and North↔South crossings. As stated in Sect. 2.3 the cyclists' PI is originally calculated without taking stops into account. It significantly rises when including this comfort aspect as the PI* values show.

Table 4. LOS and PI for pedestrians and cyclists

Node	Pedestrians			Cyclists			
	LOS E↔W	**LOS N↔S**	**PI**	**LOS E↔W**	**LOS N↔S**	**PI**	**PI***
K61 (West)	A	D	22	A	C	22	64
K47 (Middle)	D/E	E	36	C/D	D	37	92
K46 (East)	A	C	20	A	C	20	60
Test area	n.a.	n.a.	25	n.a.	n.a.	30	78
Münster 0	n.a.	n.a.	21	n.a.	n.a.	22	
Münster II	n.a.	n.a.	32	n.a.	n.a.	31	

* Performance Index for cyclists taking stops into account

The LOS values for the secondary crossing points in North↔South direction at the small junctions and for all crossing points at the big middle junction are only acceptable or even poor. Nonetheless the PI at both small junctions seems to be good in comparison to Münster. The PI for the big junction mirrors the bad LOS classification.

The PI of public buses and motor vehicles throughout the day is shown exemplary for the big junction K47 in Fig. 2. The morning peak time is depicted by the obviously augmented graph, heavily influenced by the bad performance of public buses. There seems to be no afternoon peak, but in the evening the PI shows the best values. A comparison with the morning and afternoon peak values from the Münster II optimized scenario give an idea which enhancements could be achieved within the KOLINE project.

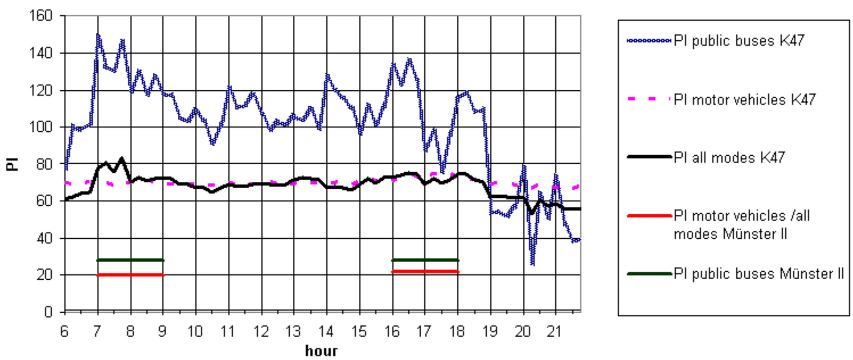

Fig. 2. PI for public buses and motor vehicles at node K47 and in Münster

The advantages of the PI compared to the LOS become clear. A PI allows to weigh the LOS of each crossing point and each transport mode by including the different amounts of affected people. It also enables the summarization of multiple junctions which lay in a row or within an area.

Nonetheless this Performance Index only enables a ranking of different scenarios and their quantifying rate against each other. It does not pay attention to necessary investments into technical equipment and engineering work and thus could prefere scenarios with excellent traffic improvements but a negative cost-benefit-ratio due to high costs. Therefore a CBA should be executed at all time for new ITS applications. Recommended monetizing values for all EU 25 countries are stated in [13].

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References

1. Transport Canada (publisher): Development of a Project Evaluation Methodology Framework for Canadian Intelligent Transportation Systems. TP 14755E, Ottawa (2007)
2. Boltze, M., Jentsch, H., Friedrich, B., Bastian, M.: OptiV – Erschließung von Entscheidungs- und Optimierungsmethoden für die Anwendung im Verkehr. TU Darmstadt (2006)
3. FESTA project syndicate (publisher): Field opErational teSt supporT Action (FESTA) Handbook, Deliverable D6.4, [3a] Chapter 5, [3b] Chapter 10 (2008)
4. Bundesministerium für Verkehr, Bau- und Wohnungswesen (publisher): Bundesverkehrswegeplan 2003, Grundlagen für die Zukunft der Mobilität in Deutschland. Beschluss der Bundesregierung vom 2, Berlin (Juli 2003)
5. ORINOKO project syndicate (publisher): Anlage Ausführlicher Ergebnisbericht mit Konzept zum Weiterbetrieb (2008)
6. Dmotion project syndicate (publisher): Düsseldorf in Motion, AK 600 – Feldversuche und Evaluierung des Gesamtsystems. Project sheet (2006)
7. CityMobil project syndicate (publisher): Ex ante evaluation report. Deliverable D5.3.1a (2009), `http://www.citymobil-project.eu/downloadables/Deliverables`
8. FAIR project syndicate (publisher): Fully Automatic Integrated Road Control Work-Package 4.1: Cost Benefit Analysis. Deliverable D04, Berlin (2006)
9. FGSV (publisher): Traffic Light Actuated Intersections. In: Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS), ch. 6. FGSV Verlag GmbH, Köln (2001) ISBN 3937356444
10. Wietholt, T.: Einsatzbereiche Grüner Wellen und verkehrsabhängiger Steuerungen. Dissertation, Schriftenreihe des Lehrstuhls für Verkehrswesen Ruhr-Universität Bochum, Heft 33, Bochum (2009) ISSN 1437-8299
11. FGSV (publisher): Empfehlungen für Wirtschaftlichkeitsuntersuchungen von Straßen (EWS). FGSV Verlag GmbH, Köln (1997)
12. Transport Simulation Systems S.L. (TSS): AIMSUN 6.1 User's Manual, Barcelona (2011)
13. HEATCO project syndicate (publisher): Developing Harmonised European Approaches for Transport Costing and Project Assessment, HEATCO Deliverable 5. Stuttgart (2006)