# DO BENEFITS JUSTIFY COOPERATIVE SYSTEMS? A COST-BENEFIT-ANALYSIS

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**Abstract**

Cooperative systems comprising the V2I and V2V communication, ADAS (Advanced Driver Assistance System), and traffic management applications are well-researched, technically sound and nearly ready to be installed in the real world. Their general benefits regarding traffic flow and emission improvements could be proved in simulations and FOTs. What remains underinvestigated is the question whether the costs of installation and operation are outweighed by these benefits from the economical point of view. Therefore Cost-Benefit-Analyses have been conducted in the European research project eCoMove which aimed at reducing fuel consumption and therefore $CO_2$ emission by 20%, and independently in the German research project KOLINE. This paper concentrates on the transformation of the traffic simulation results into monetised benefits, the cost derivation and the resulting Cost-Benefit-Ratios (CBR) of the different scenarios. The most important scenario parameters hereby were the penetration rate of vehicles and traffic light control optimisation. It is shown that good CBR values can be obtained.

**Keywords:** GLOSA, Advanced Driver Assistance System ADAS

## Introduction

Generally evaluations of publicly funded projects are often legally demanded, e.g., in Germany by the Federal Budgetary Regulations, or for major investments where the EU Cohesion Fund is involved. Legal binding Cost-Benefit-Analysis (CBA) procedures with detailed execution directives and cost unit rates are well established in some countries, e.g., New Approach to Appraisal (NATA) in the UK, and Bundesverkehrswegeplan (BVWP) in Germany [BMVBW 2003]. An extensive overview about the practice in transport project appraisal in the EU25 countries can be found in [HEATCO 2005].

As it is likely that the infrastructure technology of cooperative ITS, e.g., Road Site Units (RSU), is publicly financed a CBA should be carried out to mirror the resource-based societal perspective of economic effects.

This paper outlines in brief the common methodology but different investigated scenarios of both projects, followed by presenting the way of benefits and costs derivation. The resulting CBRs are then compared and taken for the conditional justification of the tested cooperative systems.

**Methodology**

A comprehensive methodology for CBA of cooperative systems can be found in [SAFESPOT 2009]. Both projects described in this paper follow the V-Cycle of test planning (cf. [FESTA 2008]) with the definition of Performance Indicators (PI) and representative *scenarios* (also called *test setups*). Each scenario is thereby a certain combination of situational parameters, including the spatial layout of the network, a temporal load curve of the traffic flow, and the investigated driver assistance functionalities. As field operational tests with significant penetration rates were not feasible, the experiments were carried out using microscopic traffic simulations. The therefore applied software was AIMSUN 6.1.3 (KOLINE) respectively VISSIM 5 in conjunction with EnViVer for emission calculation (eCoMove). The obligatory baseline scenarios were calibrated in a way to represent the current real traffic situation *without* any cooperative application. Calibration of the scenarios *with* cooperative technology was partially accomplished with data derived from driving simulators. The traffic simulation models were also validated with a second data set of the baselines (for more on the correct usage of traffic simulations cf. [Brackstone et al., 2014]). The computed PI values were processed in a spatio-temporal semi-aggregate to allow for a distinguished monetisation into the beneficial criteria. As all scenarios are situated in German cities the German CBA procedure called "Bundesverkehrswegeplan (BVWP)" [BMVBW, 2003] was consulted with unit rates taken from the update [BMVBS, 2009]. Manufacturing costs were estimated by the eCoMove consortium and ranges were used to reflect their uncertainty. As the KOLINE cost assumptions were significantly different and seemed to be outdated they were updated and streamlined with the eCoMove values.
Based on the assumption of static annual benefits and costs throughout the valuation period of 20 years the effects were calculated for a representative year. The final number hence to be computed for each scenario is the benefit-cost-ratio (BCR).

**Scenarios**

Both baseline scenarios were deducted from the real world. They comprise a road stretch either with four traffic actuated closed-loop controlled intersections in the north-west of Munich (eCoMove), or with three fixed-time signalized intersections in the north-east of Braunschweig (KOLINE). The spatial layouts and Average Daily Traffic flows (ADT) are depicted in Figure 1 and Figure 2.

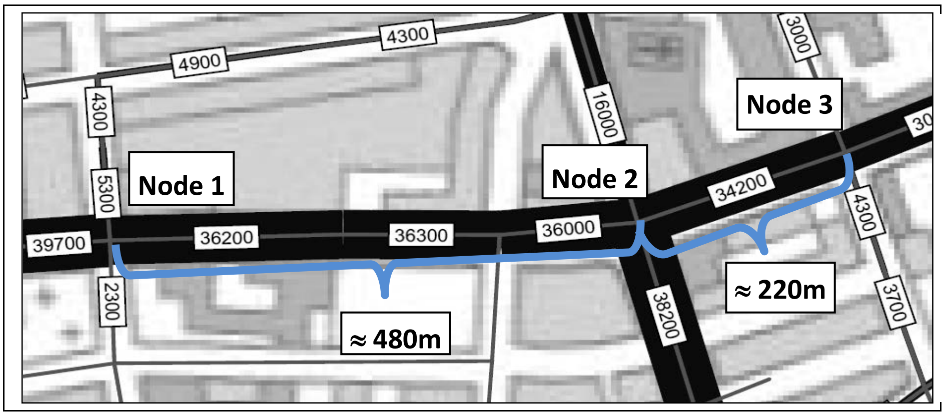


**Figure 1 - Layout and ADT of KOLINE Scenarios in Braunschweig**

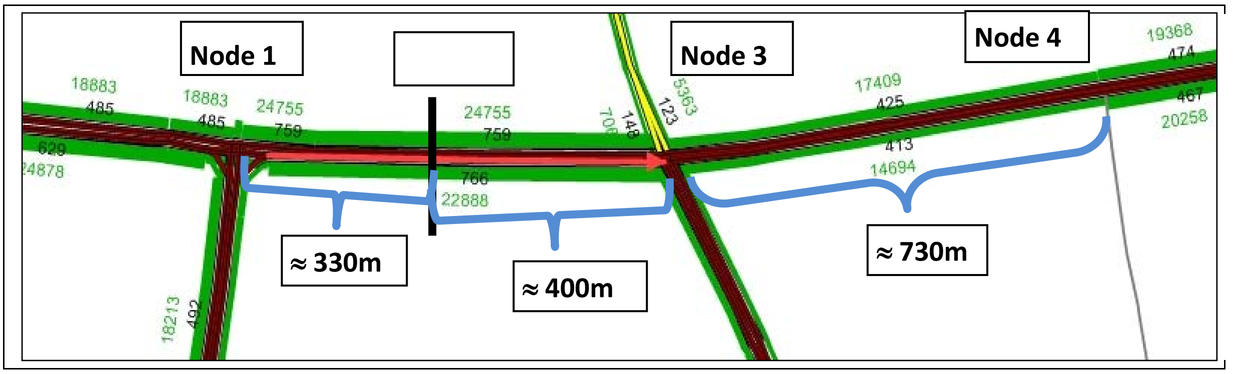


**Figure 2 - Layout and ADT of eCoMove Scenarios in Munich**

The cooperative functions were tested on different rates of equipped vehicles as marked in Table 1. The Braunschweig scenarios assumed rates between 0% and 35%, the Munich scenarios between 0% and full deployment at 100%.

**Table 1 – Scenario Parameter Combinations**

| Equipment Rate [%] / Cooperative Function(s) | 0 | 5 | 10 | 15 | 25 | 30 | 35 | 100 |
|---|---|---|---|---|---|---|---|---|
| Baseline KOLINE | x | | | | | | | |
| GLOSA + TLC Optimisation “Green Wave” | x* | x | | x | x | | x | |
| ↳ - Tailback without cooperative data | | | | | | | x | |
| Baseline eCoMove | x | | | | | | | |
| TLC Optimisation „ Balanced Priority“ | | | x | | | x | | x |
| GLOSA (only) | | | x | | | x | | x |
| ↳ + TLC Optimisation „Balanced Priority” | | | x | | | x | | x |
| ↳ + TLC Optimisation “Green Wave” | | | x | | | x | | x |

* in this case GLOSA is not operational

The cooperative functions are explained in detail in [Bley et al., 2012], [Naumann, Bley, 2012], and [eCoMove, 2013]. In brief they are as following:

- *GLOSA* (Green Light Optimised Speed Advisory) is an advice given to the driver at which speed to approach the intersection in order to minimise fuel consumption. Travel time reductions are not an objective of this function, but might arise in small portions.
- *TLC* (Traffic Light Control) Optimisation aims either at producing a *Green Wave* to reduce the overall number of vehicle stops, emissions, and travel time, or to give *Balanced Priority* to heavy vehicles like trucks and buses to reduce their number of stops and hence high emissions.
- *Tailback* estimation supports a correct GLOSA and relies either on cooperative data transmitted via V2I, or on classic loop detector data, or on a fusion of both inputs.

**Benefits**

PI values for Munich were semi-aggregated per hour between 6 a.m. and noon, per vehicle category *car* or *truck*, but aggregated over the whole network with all four intersections. It is noteworthy that the driven kilometrage of the according fleets can be slightly different between the baseline and the test setups at 10, 30, and 100% equipment rate due to the insertion model of traffic demand. Thus a downscale to veh*km-specific values must be calculated first for each scenario and afterwards a re-upscale by multiplying with the reference kilometrage of the baseline. The differences between the test setups and the baseline at 0% were calculated still for their original physical units of measurement. Table 2 shows these differences exemplary for eCoMove scenario GLOSA, 10%.

**Table 2 - Absolute Differences per PI for eCoMove Scenario GLOSA , 10%**

| **Criterion / PI** | **Unit** | **hour 1** | **hour 2** | **hour 3** | **hour 4** | **hour 5** | **hour 6** |
|---|---|---|---|---|---|---|---|
| | | *off-peak* | *peak* | *peak* | *peak* | *off-peak* | *off-peak* |
| Δ $CO_2$ cars | kg | 5.407 | -21.529 | 21.326 | -122.698 | -66.251 | 1.546 |
| Δ $CO_2$ trucks | kg | 8.639 | -3.316 | 4.507 | -6.111 | -9.053 | 1.939 |
| Δ Fuel cars petrol | l | 1.686 | -6.714 | 6.650 | -38.263 | -20.660 | 0.482 |
| Δ Fuel cars diesel | l | 0.562 | -2.238 | 2.217 | -12.754 | -6.887 | 0.161 |
| Δ Fuel trucks | l | 3.285 | -1.261 | 1.714 | -2.324 | -3.442 | 0.737 |
| Δ $NO_x$ cars | g | -17.139 | -116.053 | -9.252 | -377.775 | -235.418 | -59.076 |
| Δ $NO_x$ trucks | g | 100.921 | -20.086 | 36.318 | -72.730 | -136.790 | -32.722 |
| Δ Travel time cars | s | -23,235 | -100,764 | -50,079 | -316,767 | -211,175 | -66,394,365 |
| Δ Travel time truck | s | -726 | -4,429 | -4,229 | -7,968 | -8,659 | -4,931,250 |

PI values for Braunschweig were semi-aggregated per 15-minutes between 6 a.m. and 10 p.m., for each of the seven vehicle categories defined in [BMVBW, 2003], and for each of the intersections.

In both projects these PI differences were then multiplied by the unit rate of their respective criterion according to Table 3. These rates were also used in the project EasyWay [EasyWay, 2012].

**Table 3 - Unit Rates**

| **Criterion** | | **Region** | |
|---|---|---|---|
| **Travel Time** | | **Germany** | **Europe** |
| Cars & vans | EUR/veh*h | 15.00 | 20.00 |
| Trucks | EUR/veh*h | 30.00 | 30.00 |
| **Vehicle Operating Costs - fuel** | | | |
| Petrol (net) | EUR/l | 0.760 | 0.760 |
| Diesel (net) | EUR/l | 0.780 | 0.780 |
| **Environmental Costs** | | | |
| $NO_x$ | EUR/t | 9,600 | 4,400 |
| $CO_2$ | EUR/t | 70.00 | 60.00 |

The monetised benefits of each criterion and each simulated hour of the eCoMove example scenario *GLOSA*, 10% can be seen in Table 4. Positive values express additional economic spending which the (partially) equipped fleet causes in comparison to the baseline; negative values denote an economic improvement due to fewer necessary spending. Adding up values column by column yields the overall benefit per hour; aggregation within a row yields the beneficial contribution of the respective criterion per investigated six hours.

An analysis of the relative contributions of each criterion reveals that travel time savings make up almost the entire beneficial amount, during some hours even compensating negative effects of other criteria. Beside, only fuel savings further contribute a fraction of 2% to the overall sum.

**Table 4 - Monetised Benefits per Criterion for Munich Scenario GLOSA, 10%**

| **Criterion** | | hour 1 | hour 2 | hour 3 | hour 4 | hour 5 | hour 6 | Sum |
|---|---|---|---|---|---|---|---|---|
| $CO_2$ emissions | € | 0.98 | -1.74 | 1.81 | -9.02 | -5.27 | 0.24 | -12.99 |
| Fuel consumption | € | 4.28 | -7.83 | 8.12 | -40.84 | -23.76 | 1.07 | -58.96 |
| $NO_x$ | € | 0.80 | -1.31 | 0.26 | -4.32 | -3.57 | -0.88 | -9.02 |
| Travel time | € | -102.87 | -456.77 | -243.91 | -1,386.27 | -952.06 | -317.74 | -3,459.62 |
| **Sum** | **€** | **-96.80** | **-467.64** | **-233.72** | **-1,440.45** | **-984.66** | **-317.31** | **-3,540.59** |
| $CO_2$ emissions | % | -1% | 0% | -1% | 1% | 1% | 0% | 0% |
| Fuel consumption | % | -4% | 2% | -3% | 3% | 2% | 0% | 2% |
| $NO_x$ | % | -1% | 0% | 0% | 0% | 0% | 0% | 0% |
| Travel time | % | 106% | 98% | 104% | 96% | 97% | 100% | 98% |

The traffic volumes of these six simulated hours were not representative, neither for all hours of a working day, nor for weekends and holidays. Nevertheless a visual search for similar traffic patterns was conducted. It led to the conclusion that the traffic flow amount and load curves of the morning period are mirrored by the afternoon period between 3 p.m. and 9 p.m. The working hypothesis was then that the simulated morning effects might occur again in the afternoon and thus can be accounted for twice. Hence the daily amounts count for 12 hours. They are finally multiplied by the 201 normal workdays per year [eCoMove, 2014].

Daily amounts in Braunschweig (KOLINE) comprise all 16 simulated hours. Furthermore the annual sum was scaled up from 201 workdays to all 365 days of a year by a factor of 1.4 [KOLINE, 2013].

**Costs**

Cost elements taken into account comprise investment as well as operating and maintenance for both vehicles (on-board-units OBU), and infrastructure (road-side unit RSU). The vehicle maintenance costs are for map updates. Energy consumption can be neglected. All investment costs have to be discounted with an applicable interest rate and afterwards annualised, i.e., broken down into equal amounts for each year of their life cycle. With an interest rate of 3% [BMVBW, 2003] the annual costs per technical unit as in Table 5 arise. OBU costs have to be accounted for each equipped vehicle of that particular traffic volume which is traversing the network within the simulated time frame. Disregarding of this it was assumed that all vehicles from the morning hours would travel back again in the evening to care for real mobility patterns during working days. Thus only half of the simulated Braunschweig traffic volume was accounted.

**Table 5 - Determination of Annual Costs [€] per Technical Unit**

| Tech. Unit | Life cycle [yy] | Annuity factor | invest costs per piece | operating costs p.a. | Σ p.a. [€] |
|---|---|---|---|---|---|
| RSU | 20 | 0.067 | 10,000 | 400 | 1,072.16 |
| RSU Software | 10 | 0.117 | 3,000 | - | 351.69 |
| OBU | 10 | 0.117 | 100 | 20 | 31.72 |

**Benefit-Cost-Ratio**

The Benefit-Cost-Ratios (BCR) are calculated as $BCR = \frac{Benefits}{Costs}$ based on the assumption of static annual benefits and costs throughout the valuation period of 20 years. The BCRs of all Munich (eCoMove) and Braunschweig (KOLINE) scenarios are depicted together in Figure 3, although not fully comparable. The crisp numbers given are for the best and worst eCoMove application(s) as well as for KOLINE.

It becomes clear that all scenarios have the best ratio at the lowest deployment rate. Furthermore the Balanced Priority outnumbers the other three functionalities. The combination of Green Wave with GLOSA under full deployment (100%) even yields a ratio <1 where costs are higher than benefits which makes it not advisable at all.

Sensitivity calculations revealed that assuming OBU costs at the lower boundary of only 50€ would cut fleet costs by 18.5% and thus put even this scenario into a positive rank [eCoMove, 2014].

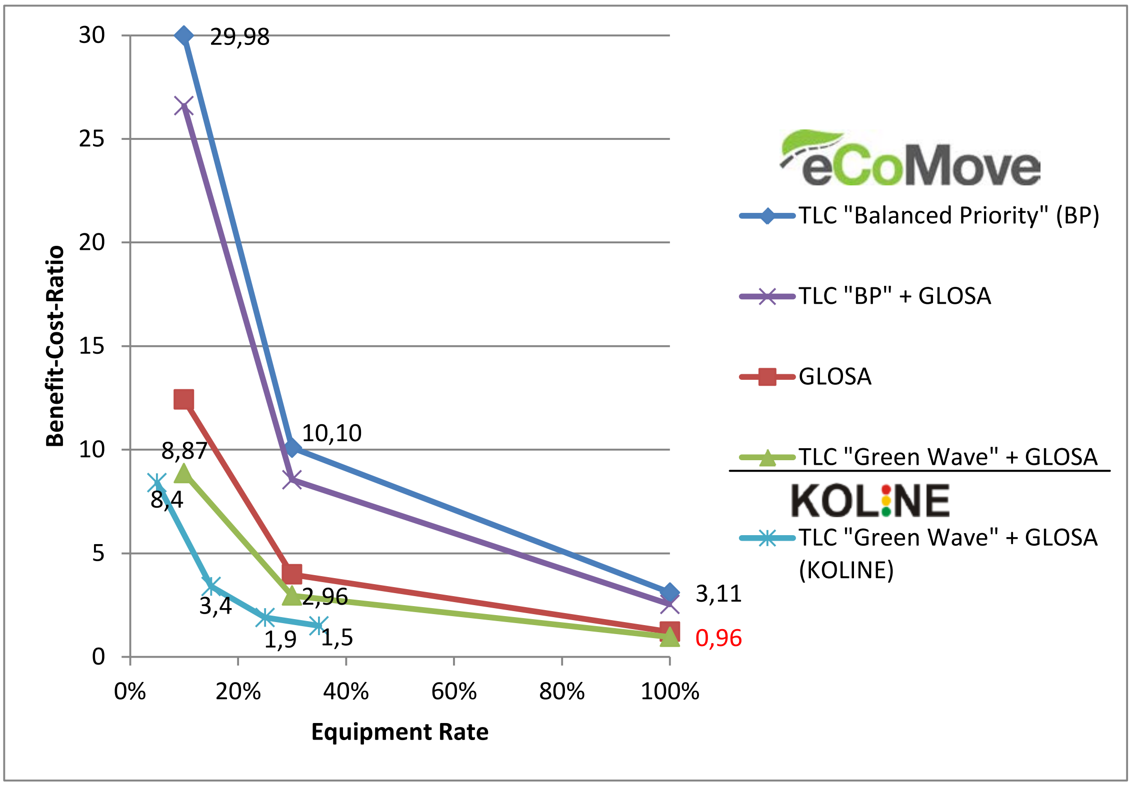


**Figure 3 - Benefit-Cost-Ratios for all Munich and Braunschweig Scenarios**

## Recommendation and Limitation

The implementation of the investigated cooperative functions can be supported from the economical viewpoint. This recommendation must currently be limited to identic or similar scenarios concerning the spatial layout and traffic demand. A scale up of the results to a larger local or regional level was not possible for several reasons and must be further researched in future. The decrease of the utility at rising penetration rates and the connected worsening of the CBR underline the necessity of conceptual and algorithm adjustments to the different states of deployment. It does not necessarily mean that stopping deployment should be envisaged after a certain penetration rate has been reached – unless it has been shown that the algorithms cannot be adapted to take advantage of higher penetration rates [eCoMove, 2014].

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