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# Cost benefit analysis of three different urban bus drive systems using real driving data

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ABSTRACT

One of the CIVITAS-ELAN project measures in Ljubljana, Slovenia, was the introduction of alternative city bus propulsion systems (CNG, hydraulic hybrid buses) into the public transport and comparison of their performance in terms of costs and benefits with conventional (diesel) buses. A cost-benefit analysis was conducted to provide a model for identifying the most attractive alternative, with aim of aiding the decision making process for future rational up-scaling of the alternative propulsion technologies in PT fleet in Ljubljana. This paper focuses on presenting the key findings of this CBA, using real driving data, while demonstrating the sensitivity/variance of different parameters of a CBA, as well as the differentiation between uncertainties of parameters in an ex-ante analysis versus an ex-post analysis.



## Introduction

For over two decades transport problems are recognised as one of most important contributors to the question of sustainability and have been as such a topic of numerous large scale research and demonstration programmes/initiatives supported and co-funded by the European Commission (CIVITAS,[3] ELTIS,[4] UITP,[5] EPOMM,[6] European mobility week,[7] PUSH&PULL,[8] Evidence,[9] etc.). The aim of these initatives is to improve the social, environmental, and economic impacts of transport (Pucher and

*Abbreviations*: BCR, benefit to cost ratio (Benefits ÷ Costs); CBA, cost benefit analysis; CIVITAS, city vitality and sustainability – cleaner and better transport in cities, EC project, 2008–2012; CNG, compressed natural gas; COL, city of Ljubljana; D2, diesel fuel, D2 quality; EC, European Commission; GHG, Green House Gases; $L_{bus}$, noise level emitted by bus, dB(A); $L_{den}$, short term noise level during day, dB(A); LPP, Ljubljanski Potniški Promet (Ljubljana public transport operator); $PM_{10}$, Particulate Matter with mean diameter 10 μm; PT, public transportation; RDE, real driving emissions; THC, total hydro carbons (unburned fuel).

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3 CIVITAS – City vitality and sustainability, www.civitas.eu (last accessed 05.10.2015).
4 ELTIS – Urban mobility observatory, www.eltis.org (last accessed 05.10.2015).
5 UITP – Advancing public transport, http://www.uitp.org (last accessed 05.10.2015).
6 EPOMM – European platform for mobility management, www.epomm.eu (last accessed 05.10.2015).
7 European mobility week – www.mobilityweek.eu (last accessed 05.10.2015).
8 PUSH & PULL – Parking management and incentives for energy-efficient urban transport, http://push-pull-parking.eu (last accessed 05.10.2015).
9 Evidence – Economic benefits of sustainable transport, www.evidence-project.eu (last accessed 05.10.2015).

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Buehler, 2009) by testing integrated strategies for clean urban transport, or more precisely, to generate a decisive breakthrough by supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies that should make a real difference for the welfare of the European citizens.

The work behind this paper has been performed in the framework of the CIVITAS ELAN project[10] in the city of Ljubljana in which a number of hard and soft sustainable mobility measures have been planned, implemented and evaluated. The particular measure considered in this paper consisted of planning, implementation and evaluation (the CBA was part of that) of alternative bus technologies for public transport in Ljubljana. The Municipality of Ljubljana (COL) and its public transport operator (LPP) were considering alternatives to the conventional diesel bus technology, as it has serious deficiencies in terms of high fuel consumption and related high pollution through exhaust gases.

As the capital and the country's largest city (276,000 inhabitants), Ljubljana is a strong center of economic and cultural activities for the wider region. Over the last 15 years there has been a constant growth in urban and regional car (and cargo) traffic. Transport in the city is causing air ($NO_X$, CO, $CO_2$, THC and $PM_{10}$) and noise pollution. The expected reduction of these depend on successful implementation of a number of measures and their specific impacts – one of these is making the public transport (PT) efficient, comfortable, and reliable, by introducing a fleet of hybrid and CNG buses, as envisaged by the CIVITAS-ELAN project (measure 1.11-LJU). If all of these expectations were to come true it would be reasonable to expect that transport in the city centre would reorganise in a way to decrease air and noise pollution, etc. Occurrence of these effects has been monitored/evaluated by means of direct measurable indicators (e.g., travel times in the corridor) and semi-qualitative and qualitative interpretation of the benefits (e.g., general improvement of air quality in the city as a consequence of reduced fuel consumption/pollutant emission) and presented through the Cost-Benefit Analysis (CBA) results.

The motivation behind CBA in this case was to understand costs and benefits of introducing alternative city bus propulsion systems (CNG, hybrid buses) into PT and to compare their costs with costs of the conventional (diesel) buses. CBA was selected in this case in order to provide a model for examining the rationale behind the bus selection – it was used for identifying the most attractive alternative, with aim of aiding the decision making process for future rational up-scaling of the alternative propulsion technologies in PT fleet in Ljubljana (Sudiana, 2010; Campbell and Brown, 2005). Also the results of this CBA are to be used to identify and improve the key net benefits in order to make the PT more efficient (Harford, 2006).

Additionally, this paper also focuses on demonstrating the sensitivity/variance of different parameters of a cost-benefit analysis for selected drive technologies in city busses, as well as the differentiation between uncertainties of parameters in an ex-post analysis versus ex-ante analyses. Namely, numerous factors, such as bus fleet, PT usage, maintenance costs, external costs, fuel prices are uncertain in an ex-ante analysis, but are known in an ex-post analysis (Börjesson et al., 2014).

Correspondingly, the Sections Second, Third and Fourth (Transportation system characteristics, CBA approach/methodology and Results) present the overall approach for the ex-ante CBA analysis for five detailed bus alternatives while Sectio n 'Discussion' presents revised results considering partial ex-post assessment using important updated parameters as encountered after about three years of exploitation.

## Transportation system characteristics

The transportation systems – midi sized urban buses – considered for the evaluation in the cost-benefit analysis were:

- a conventional bus with conventional diesel engine and automatic gearbox,
- a bus with the hydraulic hybrid powertrain and diesel engine and
- a bus with SI engine fuelled by CNG and automatic gearbox.

All buses were approximately 12 m in length operating on the selected bus route #2 in the city centre. The main properties of the three bus types are given in Table 1. The reader will note that the passenger capacity varies among the three bus types and that was explicitly considered by five alternatives in the scope of CBA – details are given in Section 'Results'.

## CBA approach/methodology

The main questions for the bus operators to be answered with the aid of CBA analysis, both in terms of purchase and optimised operation of new buses were:

i. How much fuel can be realistically saved?
ii. Are fuel savings enough to compensate for higher purchase price of hybrid drive/CNG types of buses (compared to the conventional diesel bus)?
iii. What are overall costs of hybrid/CNG bus ownership & exploitation (maintenance and similar costs)?

[10] For more details please see web page at http://www.civitas.eu/content/elan (last accessed on 07.02.2015).