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A Field Trial on Smart Mobility

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Abstract

In view of services such as road pricing for passenger cars, we devised an innovative and versatile technological solution that can aid in solving some of the mobility problems. In it, each vehicle was equipped with an on-board unit, that transmitted their locations in real-time to a map-matching back-end server. The current cost per kilometre, differentiated between location, time, and vehicle type, and was then sent back such that each driver instantly knew the current cost of the trip. Based on this smart technology, we then organised an experiment that researched human behaviour and responses to an example service, i.e., road pricing stimuli within a large geographic region. As a result, road users adapted their behaviour, resulting in a lower overall cost. As a side effect, the experiment provided a solution to drive and support the city's mobility objectives.

Keywords: smart mobility; road pricing; traffic control; behavioural experiment

1. Introduction

In view of services such as road pricing for passenger cars, several companies grouped themselves into a consortium that devised an innovative and versatile technological solution that can aid in solving some of the mobility problems. In it, each vehicle was equipped with MagicView's on-board unit (OBU), based on NXP's telematics single component platform ATOP (NXP, 2008), that had a built-in GPS antenna and GPRS transceiver. While vehicles were driving, their locations were transmitted in real-time to IBM's back-end server,

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where NSL map-matched their positions and calculated their cost per kilometre. This information was sent back to the OBU's display so that each driver instantly knew the current cost of the trip. The system used intelligent tariffs for the costs per kilometre, by differentiating between the type of road (e.g., motorways versus local roads), the time of day (e.g., rush hours versus off-peak periods), and the type of vehicle (e.g., based on the engine capabilities). Based on this smart technology, we then organised an experiment that researched human behaviour and responses to an example service, i.e., road pricing stimuli within a large geographic region. As a result, road users adapted their behaviour, resulting in a lower overall cost. As a side effect, the experiment provided a solution to drive and support the city's mobility objectives.

In the following Sections, we first go into detail on the setup of the system (on both levels of policy and technology) and the calculation of an intelligent road pricing scheme, after which we explain how we set up the behavioural experiment. The paper ends with our main conclusions.

2. Setup of the testbed

2.1. General background of the project

Our testbed encompassed a technological setup, for which the City of Leuven granted its venue and cooperation. For them, the following goals were relevant in this project:

- To position the city as an innovative platform for mobility projects.
- To get a view on the mobility behaviour of people travelling within and round the city.
- To have a mutual cooperation between the government and the private sector while thinking about mobility solutions.

With respect to this latter goal, a smart road charging scheme should be part of a packet of measures that can ease trips by reducing their total delays. As such, they increase the liveability and traffic safety in the city.

Our testbed focused on 2 important aspects:

- A demonstration of technology: it was a concrete, clearly defined proof-of-concept. We showed that the technology was more than mature and tested, and offered a lot of possibilities and opportunities.
- A demonstration of policy: a smart road charging scheme (by means of a competition within this project) could serve as a personalised instrument that steered people's mobility behaviour (for example recreational traffic that avoids the rush hours). The pricing mechanism put the focus on the use and not the ownership of a vehicle. And because of the close cooperation with the City of Leuven, the testbed also addressed the city's mobility policy.

2.2. Technological overview of the testbed

The whole system consisted of a set of components, manufactured by different companies and integrated within the testbed, as depicted in Fig 1.

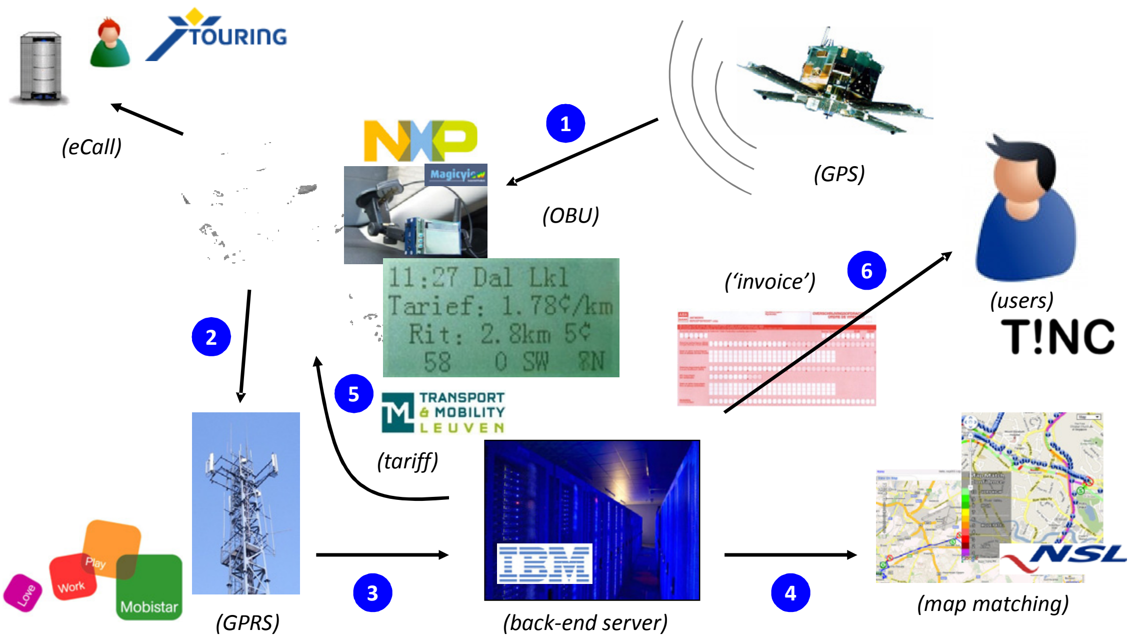

Fig. 1. conceptual overview of the technological operation of the testbed.

Referring to this conceptual overview, the system largely operated as follows:

(1) The vehicle contained an 'on-board unit' (OBU) that registered its GPS position every second (note that the OBU was equipped with full eCall functionality). It was attached to the frontal windshield of the vehicle and connected to the 12V-lighter adapter. It also contained a battery such that, in case there was no power, the GSM network had outage, or the back-end server was unreachable, all its data could still be kept and sent to the back-end servers.
(2) The OBU also contained a SIM-card and sent its information in real-time via the GSM/GPRS network.
(3) All GPS positions were received in a central computer (i.e., the 'back-end' server).
(4) All raw GPS positions were matched in the back-end server with a digital roadmap, such that it was known on which road each vehicle was at each moment in time.
(5) Based on the type of road, the time of day, and the type of vehicle, a predefined tariff per kilometre was sent via the GSM/GPRS network back to the OBU. As such, the driver was able to see the current tariff of his trip in real-time.
(6) At the end of a trip, all information was aggregated into a single virtual invoice that the user could consult via Internet.

2.3. Dealing with privacy and security

As users were tracked every second they drove in the testbed, we had to take care of various privacy issues. In order to offer more clarification on this topic, we made a distinction between privacy on the one hand and security on the other hand. Note that our testbed was a proof-of-concept, and illustrated some of the following issues and techniques. A more fully developed analysis of privacy and security was done in the IBBT project 'NextGenITS'.

2.3.1. What do we mean by privacy?

Privacy is mainly the authorisation a person gives to let his/her personal data to be used by others, e.g., for purposes of analyses. It remains nevertheless a fundamental right for the user to access his/her own data at any time. Note the slight nuance, that data could in principle also be requested for legal purposes in light of judicial investigations. Within the testbed, all data was sent from the OBU to a central server; other scenarios were however also possible, in which all data was retained within the OBU itself. In that case, all the map-matching et cetera should also be done by it, which put more computational effort on the OBU. Another feature of privacy is that databases containing various strands of information can be physically and logically seperated from each other. All stored data should also be destroyed after a certain amount of time, as is dictated by law. Within the testbed, all users gave their formal approval for the analysis and use of their data. To that end, they signed a contract that, among other issues, stipulated the confidentiality of the data.

2.3.2. What do we mean by security?

Security implies how software, hardware and policies are protected. Examples are the cryptographic ciphering of information in order to tackle piracy of data, or the obfuscation of computer program codes which makes it harder to reverse engineer some om the algorithms. Besides that, we also incorporated fraud detection in our testbed. An example of this was users that did not always connect their OBU (either by mistake or on purpose), or deviated significantly from their normal trip behaviour (again, either because of vacation periods or on purpose).

3. Calculation of an intelligent road pricing scheme

One of the main, unique aspects of the system, was the derivation of an intelligent road pricing tariff scheme. The intelligence was incorporated by differentiating the cost per kilometre based on:

- the type of road (i.e., motorways, secondary roads, and local roads),
- the time of day (i.e., morning and evening rush hours, and off-peak periods),
- and the type of vehicle (i.e., different engine capabilities).

The scheme was based on the external costs to society made by passenger cars, thereby making it a fair implementation of road pricing (i.e., the user pays for the amount driven and pollution caused). It was furthermore based on national statistics, leading to a cost-neutral implementation in which society as a whole would not pay more on a yearly basis than before. This is a very important aspect in view of gaining political and social support for adopting this type of solution.

3.1. External costs as background

All transport has associated costs. The total cost of transport to society is split into private costs and external costs. The former are costs that the user takes into account when making a trip. Examples are the stock price of the vehicle, insurance fees, maintenance, fuel, taxes, … But traffic also causes external costs, differentiated by effects on congestion, the environment and climate, noise levels, accidents, and infrastructure. These costs are however not directly paid by the road user but by the entire society; they are consequently ‘external’ to him or her. A user does not take these external costs into accounts when making a trip (Delhaye et al., 2010; European Parliament, 2011). Based on these external costs, we proposed a tariff scheme that incorporated elements of the cost structure.

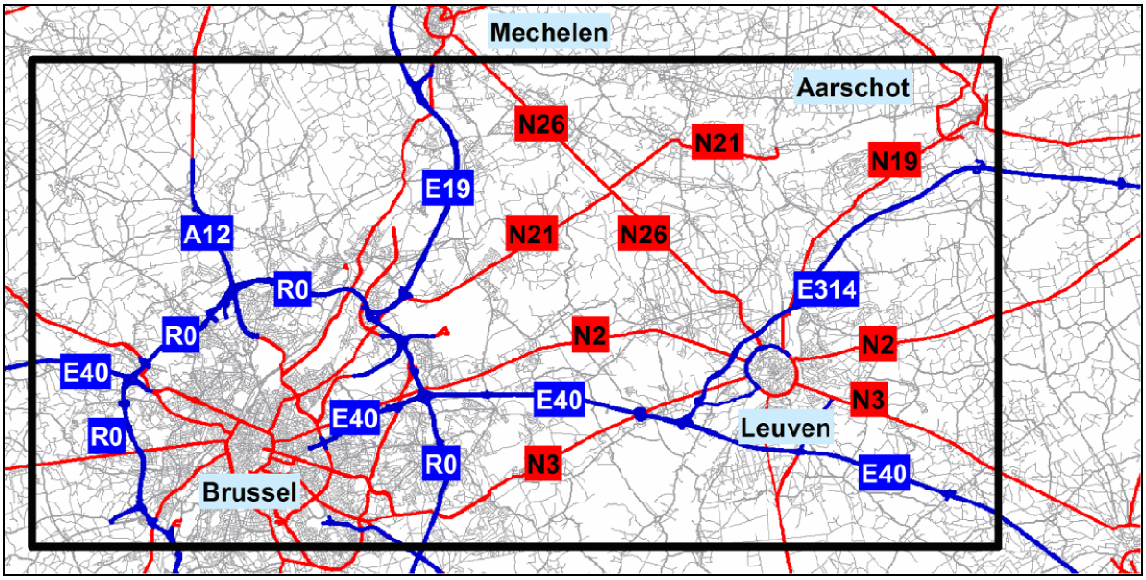

Fig. 2. the detailed study area in which the road charging scheme was active (black rectangle), containing motorways (blue), secondary roads (red), and local roads (gray).

3.2. Calculation of an intelligent road pricing scheme

3.2.1. The reasoning behind an intelligence scheme

As mentioned before, the tariff scheme is intelligent because of its differentiations into space, time, and type of vehicle. The following Sections shed some light on each of these aspects.

3.2.1.1. Differentation between the type of road

Considering the complete geographical area of Flanders in Belgium, Europe, we defined a certain boundary in which all roads had an associated tariff, as shown by the black rectangle in Fig 2. All roads outside this rectangle were not taken into account.

Within the region, we differentiated between:

- motorways (coloured in blue) defined as road type W1,
- secondary roads (coloured in red) defined as road type W2,
- and local roads (coloured in gray) defined as road type W3.

3.2.1.2. Differentation between the time of day

We split the day into several time periods, mainly the two morning and evening peak rush hours, and all off-peak periods in between. Within the testbed we included a simplification that the time periods are valid irrespective of the location. They were thus defined as:

- Peak periods (working days):
  - On mornings between 6h and 9h.

  - On evenings between 16h and 19h.
- Off-peak periods (working days and weekends):
  - During the day from 9h until 16h.
  - During the evening, night, and mornings between 19h and 6h.

3.2.1.3. Differentation between the type of vehicle

In order to keep the road charging tariff scheme cost neutral, we transformed the tax a user yearly pays. This tax is, in Flanders, directly based on the engine performance of the vehicle (e.g, horse power). As a result, we defined 4 categories of vehicle types:

- Low class: a yearly paid total cost of 268.03 euro.
- Medium class: a yearly paid total cost of 373.30 euro.
- High class: a yearly paid total cost of 501.73 euro.
- Electrical vehicles: a yearly paid total cost of 71.28 euro.

3.2.2. The final road pricing tariff schemes

After incorporating the previously mentioned differentations, we were able to derive a road pricing tariff scheme for each type of vehicle, thereby also taking the external costs into account. Other information that we used were the number of yearly driven vehicle kilometres by passenger cars, and the distribution of them over the various road types and times of day. This resulted in the following tariff scheme in Table 1.

Table 1. Overview of the differentiated tariff scheme (all amounts are expressed in cent/km)

Time of day	Road type	Low class	Medium class	High class	Electric
Peak periods	*W1 (motorways)*	1.63	2.26	3.04	0.44
	W2 (secondary roads)	2.19	3.06	4.11	0.64
	W3 (local roads)	3.47	4.83	6.50	0.93
Off-peak periods	*W1 (motorways)*	1.46	2.03	2.73	0.38
	W2 (secondary roads)	1.51	2.10	2.82	0.42
	W3 (local roads)	1.78	2.48	3.34	0.39

Note how the external costs took care of the various differences between road types and time periods. Driving on motorways is the cheapest, followed by secondary, and local roads. Similarly, driving during rush hours is more expensive than driving in the off-peak periods.

4. Setup of the behavioural experiment

4.1. Description of the experiment

Using the testbed, we set up a small-scale behavioural experiment, consisting of 35 anonymous and randomly selected users, driving around in a relatively large geographic region of some 600 km² (encompassing the city of Leuven and the Belgium’s capital city Brussels). These users mainly fell into the following categories: living outside but working inside Leuven, vice versa, living and working in Leuven and some visitors. They were selected such that their travel patterns still gave large geographical spread within the study area. Besides this, they were also selected on characteristics such as flexible working environments (e.g., working at home, flexible time schedules, …). All of the were actively recruted at various companies within the Brussels and Leuven area. We tracked all movements in 3 phases over the course of almost half a year, as shown in Fig 3:

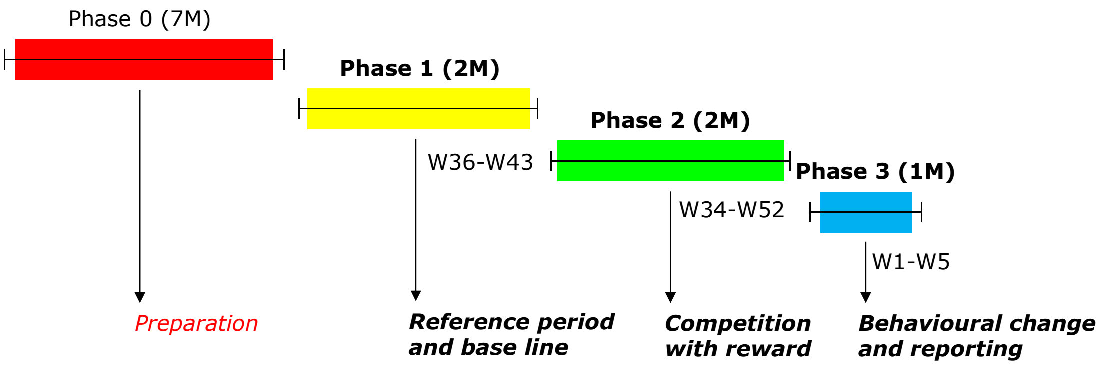

Fig. 3. Schematic overview of the various project phases during the behavioural experiment.

In the first phase (2 months) we measured their base line behaviour by extracting weekly travel patterns. In the second 'game-oriented' phase (2 months), the OBU displays were activated, giving real-time feedback to the users. Drivers were encouraged to change their behaviour, stimulated by the challenge to win a competition ("*Who would exhibit the best behavioural change?*") (Vansteenkiste 2003; van Delden et al., 2009). After analysing their travel patterns by means of statistical distributions of travelled distances, total costs, relative costs per kilometre, and travel times, as well as per-user origin-destination matrices, we provided all users with feedback on how to further improve their behaviour for the second halve of the game phase. The advice mainly centred around the different types of road and time periods driven by them. All normalised trip costs from phase 2 were compared to each user's history from phase 1, after which we gave pointers such as "*Try to drive more on motorways during off-peak hours*" (3 road types times 2 time periods gave 6 combinations to evaluate their behaviour upon). Because drivers saw their trip costs instantaneously on the OBU's display as they were driving, they got more insight into their own behaviour and as such were more inclined to change it in line with the given advice.

At the end of phase 2 we declared a winner, based on the best improvement in both their absolute total generalised cost and their relative generalised cost per kilometre (note that we statistically filtered and adjusted outlying measurements). In the third and last phase (1 month), we analysed to what extent their changed behaviour remained once the competition ended and the prize-stimulus vanished.

4.2. Results

During the experiment, all users together made some 10,000 trips, covering a distance of some 100,000 km. A geographical overview of all their trips is shown in Fig 4. As can be seen from the figure, a lot of the positions were registered near Leuven (right side) and within Brussels centre and main ring road (left side). The median of the average speeds of all trips was 35 km/h.

The distribution of driven vehicle kilometres over the various road types is given in Fig 5. Note almost 60% of all distances were driven on motorways, with equal fractions driven on secondary and local roads. In total, they drove 43% of them during the peak rush hours, and 57% during the off-peak periods.

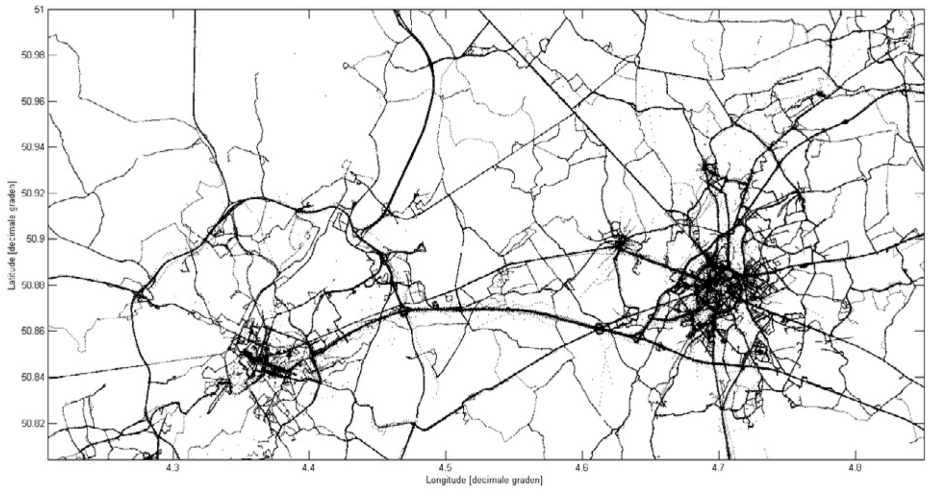

Fig. 4. Overview of all registered GPS positions in the area in which road pricing was active.

Considering the behaviour of the group, we noticed as was expected how more than half of them improved their behaviour during the competition phase as a whole (Rietveld, 2001). This resulted in a lower overall cost: traffic went from local roads to motorways (which carry a lower external cost) and shifted from rush hours to the off-peak periods (they drove 5% less on secondary and local roads during the peak hours). As a side effect, the experiment provided a solution to drive and support the city's mobility objectives, as some of the rat running diminished, and it gave insight into road usage. Interestingly, most of the improving users thought they had retained their 'good' behaviour, but 3 out 4 defaulted back to their previous behaviour when the prize incentive was removed at the end of the competition.

During phase 2 we noted a higher absolute cost than during phase 1 (see Figure 6, left). This was because there were more trips recorded during phase 2. The variation between the absolute costs was lower during phase 2 than during phase 1, and the relative costs also came out lower, implying that the group as a whole improved its behaviour (see Figure 6, right).

5. Conclusions

Concluding, we believe that road pricing based on external costs and vehicle usage forces people to think about their travel behaviour. This will provide one part of the intricate mobility problems of society because most people tend to improve their behaviour, as testified by our innovative experiment. However, road pricing is just one tool in the box, and it should be used with care, optimally accompanied by other measures (Maerivoet, 2006). And even though many may consider it as an instrument primarily for policy makers and public authorities, road pricing also offers a fairer taxation of vehicle usage that can lead to financial benefits for the road users themselves.

In light of future opportunities, we stress the system's high level of flexibility: it can be used with all types of vehicles (e.g., passenger cars, vans, trucks, …); the OBU can be uniquely identified with the vehicle, making the technology fraud-proof; the ATOP platform can accommodate different services such as road pricing, eCall, and other value-added services; and the back-end provides complete user-invoicing functionality.

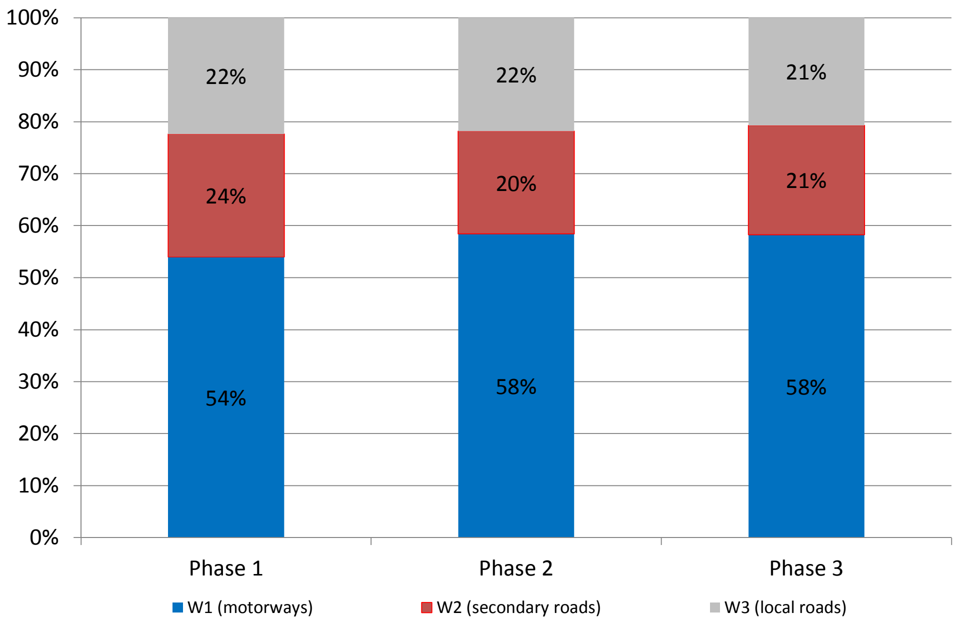

Fig. 5. Road usage during the various project phases, split according to road types W1 – W3.

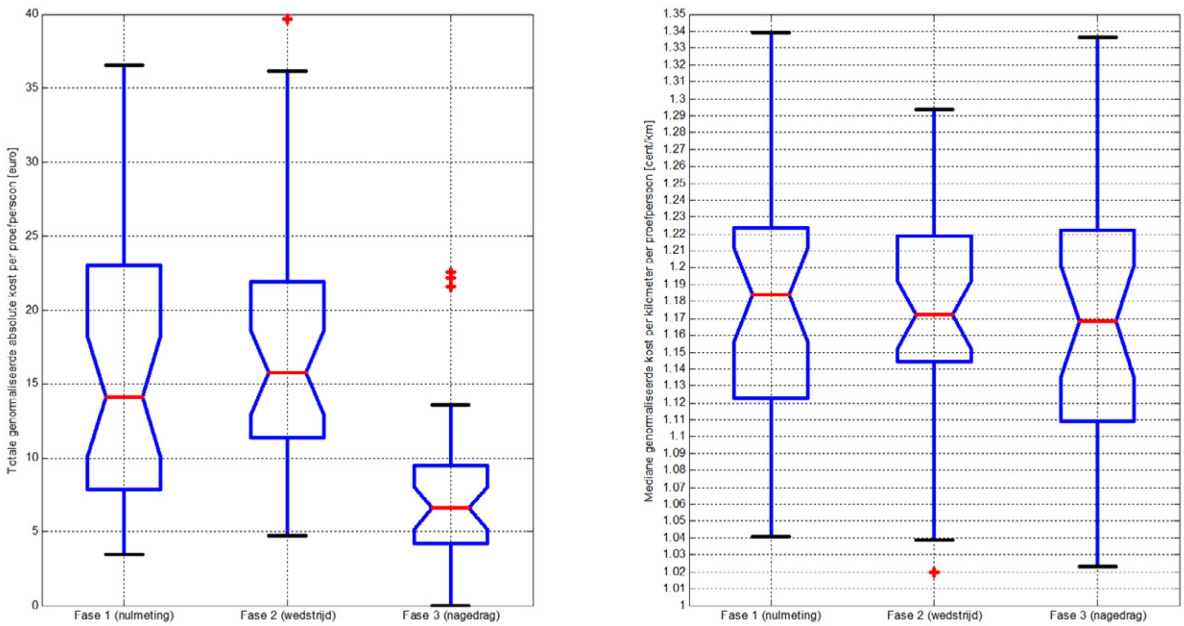

Fig. 6. Statistical boxplots of the distributions of the total normalised absolute costs per test user per phase (*left*) and the median normalised relative costs per kilometre per test user per phase (*right*).

Acknowledgements

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References

Delhaye, E., De Ceuster, G., Maerivoet, S. (2010). Internalisering van externe kosten van transport in Vlaanderen, *Final report for Vlaamse Milieumaatschappij*, MIRA Milieurapport Vlaanderen, Belgium.

European Parliament (2011), Directive 2011/76/EU of the European Parliament and of the Council, amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures, *Official Journal of the European Union*, L269, September.

Maerivoet, S. (2006). *Modelling Traffic on Motorways: State-of-the-Art, Numerical Data Analysis, and Dynamic Traffic Assignment*, PhD dissertation, Katholieke Universiteit Leuven, Belgium.

NXP (2008). *Automotive Telematics On-board unit Platform (ATOP): the basis for a new international private car road pricing system*, The Netherlands.

Rietveld, P. (2001). Pricing Mobility: Experiences in the Netherlands, *European Journal of Transport and Infrastructure Research*, nr. 1, pages 45 – 60.

Vansteenkiste, M. (2003). *Straffen, belonen, Big Brother of aanleren?*

van Delden, J., Cluitmans, C. (2009). Beprijzen, belonen of een budget?, *Colloquium Vervoersplanologisch Speurwerk*.