Towards optimal passenger transport: the role of ICT solutions in promoting co-modality

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Samenvatting

Naar optimaal personenvervoer: de rol van ICT-toepassingen in de promotie van co-modaliteit

Vanuit het oogpunt van klimaatverandering en energiezekerheid is er een noodzaak om binnen het personenvervoer CO_2 te reduceren. In het Witboek Transport van de Europese Commissie is een sectorale reductiedoelstelling van 60% opgenomen voor het jaar 2050 ten opzichte van 1990.

Deze doelstelling kan op verschillende manieren bereikt worden. Co-modaliteit, waarbij per verplaatsing voor de meest efficiënte vervoerswijze of combinatie van vervoerswijzen wordt gekozen, kan de efficiëntie in transport verbeteren en zo bijdragen aan de reductiedoelstelling. Een manier om efficiëntie te bereiken is de inzet van ICT-toepassingen binnen het personenvervoer. Hierbij kan onderscheid worden gemaakt tussen reisinformatiesystemen, betaalsystemen en verkeersmanagementsystemen. In het onderzoeksproject OPTIMISM worden de diverse mogelijkheden onderzocht. In dit paper worden enkele eerste resultaten van dit project samengevat.

Reisinformatiesystemen zijn o.a. routeplanners, navigatiesystemen en real time informatieborden bij openbaar vervoer haltes of langs de snelweg. Reisinformatie stelt de reiziger in staat om beter afgewogen keuzes te maken en kan zo het mobiliteitsgedrag beïnvloeden. De effecten hangen hierbij onder andere af van de beschikbaarheid en kwaliteit van de reisalternatieven en gemak waarmee reizigers van deze alternatieven gebruik kunnen maken.

Elektronische betaalsystemen, zeker als deze multimodaal zijn, kunnen het overstappen tussen vervoerswijzen vergemakkelijken en drempels voor het overstappen naar het openbaar vervoer wegnemen. Sommige betaalsystemen maken zelfs geheel nieuwe vormen van mobiliteit mogelijk, zoals OV-fietsen en deelauto's.

Tot slot kunnen ook verkeersmanagementsystemen bijdragen aan een efficiënter transportsysteem, doordat bestaande infrastructuur beter benut kan worden en de doorstroming verbetert. Zowel reistijd als brandstofgebruik kan hierdoor verminderen.

Alle groepen ICT-toepassingen kunnen bijdragen aan een meer efficiënt en betrouwbaar personenvervoer en zo leiden tot co-modaliteit. Daadwerkelijke CO_2-besparing is vanwege mogelijke rebound effecten echter niet vanzelfsprekend. Beleidsmaatregelen rond bijvoorbeeld infrastructuur of prijsbeleid kunnen helpen om het maximale CO_2-reductiepotentieel te halen en om tegelijkertijd de rebound effecten zoveel mogelijk te beperken. In het vervolg van OPTIMISM zal dit nader worden onderzocht.

1. Introduction

1.1 The need for decarbonisation of the transport sector

Due to climate change and energy security issues there is a strong need to decarbonise European energy consumption, including the energy consumed in the transport sector. In the White Paper on Transport and in the Energy Roadmap 2050 the European Commission has set a long term goal of achieving 60% GHG (greenhouse gas) reduction in the transport sector by 2050 compared to 1990 levels. (EC, 2011a; EC, 2011b) This is a reduction of more than 70% compared to the current level. In this White Paper the European Commission indicates that decarbonisation can be realised by the use of new sustainable transport fuels and propulsion systems, but also indicates the need for better use of the most efficient transport modes and overall efficiency gains in transport and infrastructure. Co-modality is mentioned as one of the concepts, which has the potential to contribute to a higher efficiency in passenger transport.

1.2 Objective and background of this paper

The objective of this paper is to identify and describe ICT solutions, which can promote co-modality and therefore have the potential to contribute to the decarbonisation of the transport sector. This paper is based on work carried out in the Seventh Framework Programme (FP7) project OPTIMISM.[1] The abbreviation stands for *Optimising Passenger Transport Information to Materialize Insight for Sustainable Mobility*. The main aim of the project is to create and develop different sets of strategies and methodologies for optimising passenger transport systems based on co-modality and ICT solutions.

1.3 Scope and data gathering

The scope of this paper includes passenger transport in both urban as well as rural areas and covers all distances. All transport modes are taken into account. The main focus is on ICT solutions on a commercial scale in the short or medium term (2020/2030). During the process of identification national studies, international (scientific) literature, interview with experts and other European projects, like other FP6/7 programmes, have been analysed. In the next phase of OPTIMISM, a broad assessment and the selection of best practices will take place followed by an exercise aimed at the quantification of potential effects of these best practices.

1.4 Outline

The next section provides the definition of co-modality and ICT. In the other sections of this paper different examples of ICT solutions and their potential effects on the decarbonisation of the transport sector will be described in a qualitative way. Where available quantitative outcomes of evaluations are presented too. Due to the wide range of ICT solutions the following categories will be used: travel information, payment services, including new business models, and traffic management.

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[1] http://www.optimismtransport.eu/

2. Co-modality in relation to decarbonisation of transport

2.1 The role of co-modality: how can co-modality contribute to decarbonisation?

Different literature sources, like EasyWay (2012), refer to the definition already included in the 2006 mid term review of the White Paper on Transport. Here co-modality was defined by the European Commission as:

> *'the efficient use of different modes on their own and in combination'*

As can be concluded from this definition, co-modality requires a critical assessment of mode choice. CEPAL (2011) describes the concept of co-modality in more detail:

> *'The principle of co-modality within transport policy should be understood as an approach which seeks to achieve efficiency in the modal distribution of transport and related services, for each journey and group of journeys, through the optimal use of each mode of transport and its possible combination with others, making the complete journey efficient and sustainable in accordance with the particular requirements of transport and the distance to be covered.'*

Co-modality differs from the also frequently used terms multimodal and intermodal. The European Commission uses the term co-modality as an umbrella term in order to capture both the terms multimodal and intermodality. Multimodal is mostly used with respect to the travel information services, which offer similar travel information for more than one transport mode. On the contrary, intermodal services are focused on the combination of different transport modes within one route. (EasyWay, 2012) Based on this distinction it can be concluded that an intermodal journey should be preferred in case multimodal information shows that an intermodal journey is more efficient compared to a single-mode journey.

In case of co-modality, a modal split can be achieved in which the less-intensive carbon modes are used in an optimal way. Due to efficiency gains the amount of passenger-kilometres can be reduced and energy efficiency can be improved making that less emissions are emitted per kilometre. This is also depicted in Figure 1.

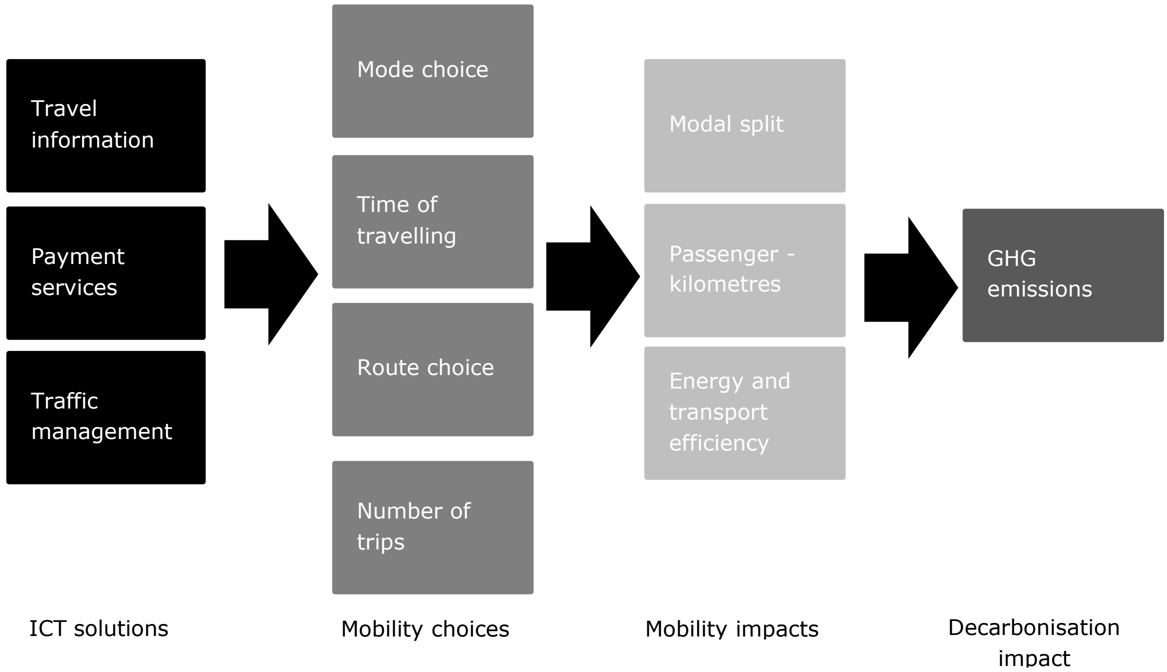
2.2 The role of ICT-solutions: how can ICT-solutions contribute to co-modality?

In the recent decade market penetration rates of navigation devices, smart phones and applications for these smart phones have risen sharply and it seems that ICT solutions will also be more and more integrated in our daily activities in the future. Cohen et al. (2002) define Information and Communication Technologies (ICT) as:

> *'A family of electronic technologies and services used to process, store and disseminate information, facilitating the performance of information-related human activities, provided by, and serving the institutional and business sectors as well as the public-at-large.'*

Such technologies and services are nowadays also very common in the transport sector. It is therefore a legitimate question to what extent these ICT solutions have the potential to contribute to the goal to meet the 60% GHG reduction. (EC, 2011b)
Figure 1 shows which mobility choices can be influenced by ICT solutions and how these mobility choices are linked to mobility impacts.

Figure 1. Linkages between ICT solutions and GHG emissions



These mobility impacts can finally result in a reduction of GHG emissions. It must be noted that this is a simplified figure: in reality there are more linkages and feedback loops.

3. Travel information

3.1 Introduction

The term travel information is a very broad catch-all term, while there are numerous differences with regard to means and types of travel information. The following classification can be useful to understand the diversity:

- Means of information provisions: desktops, mobile phones, dynamic route information panels, navigation devices, road signs
- Type of information: dynamic and actual information versus static data, personalised versus general information, visual versus audible etc.
- Content of information: departure and arrival times, costs, accessibility, availability, services, etc.

The current trend is that travel information becomes more personalised, mobile, real-time and dynamic. Nowadays information from different (open) sources can also be combined more easily, which makes it possible to provide information on more aspects than in the past.

According to Spruijtenburg (2009) travel information can play a significant role in the travel decisions of individuals, because it can reduce uncertainty in decision making, help travellers make better travel choices by increasing their knowledge levels and consequently lead to a more efficient use of the available transport infrastructure networks.

In general, the potential mobility effects as a result of travel information are change of departure time, change of mode choice, route optimisation and cancellation of trips. (Chorus, 2007; Goudappel Coffeng and TU Delft, 2009; KiM, 2009) These mobility effects will result in changed environmental impacts of transport. This is schematically presented in Figure 1. Emissions can be reduced by a decrease of passenger kilometres or by lower emission factors per passenger-kilometre. Although GHG emission reductions can be reached, rebound effects should also be considered. Empirical evidence shows that people have a rather fixed time-budget for travelling. As a consequence, reducing the time needed for a specific trip may stimulate people to make more trips (not consequently by car) or choose destinations further away. (Levinson and Kumar, 1995)

3.2 Route planners

Route planners do probably form the most well known sources of travel information. In the past, these online route planners were mainly associated with the pre-trip phase of journeys. Due to the market introduction of smart phones and navigation devices with internet connection a shift occurred from solely pre-trip information acquisition to the use of route planners en-route. Examples of route planners are Transport Direct in the United Kingdom, 9292 in the Netherlands and Reiseauskunft in Germany.

The contribution of route planners to the decarbonisation of transport depends on multiple factors. Firstly, the mobility effects depend on the phase of consulting a route planner. Pre-trip there are mostly more alternatives available. Secondly, mobility effects strongly depend on the type of information provided. Current route planners not only provide information on departure and arrival times, but also on aspects like costs, accessibility and available facilities. Based on the provided information, a traveller does not necessarily choose for the less carbon intensive journey option. Furthermore, there may be some type of lock-in, as a car driver, who has already made the decision to go by car will use an (online) route planner for cars rather than considering public transport alternatives. Thirdly, not all travellers need travel information. A commuter going to work on a daily basis only has a need for travel information in case of disruptions, while travellers making irregular trips will tend to use route planners for their trips more often. The factors above show that insight in these and other factors is needed when assessing the potential to contribute to decarbonisation.

A good example of a multimodal route planner, which' use has also been evaluated is Transport Direct in the United Kingdom. This multimodal route planner, developed by Atos Origin, was launched in July 2004 being the world's first national door-to-door public transport planner. In 2007, AEA Technology has carried out an evaluation. Through a qualitative and quantitative analysis of public surveys this evaluation showed that:

- most people used the single-mode options (46%) instead of the door-to-door option (43%).
- the portal was mostly used for unfamiliar trips (around two third) and occasionally made trips (almost 25%). To a large extent this involved business trips (36%) and trips to friends (14%).
- 21% of the respondents intended to change their modal choice as a result of the travel information provided.
- 7.7% of the respondents indicated they would switch to public transport, while 2.3% indicated to switch from public transport to the car. Combining these two outcomes results in a net modal shift of 5.4% from car to public transport.
- Concerning route and time, 17% stated that they would change the route of a earlier made trip based on provided information, 3% said to make a journey they would otherwise not have made. 24% also mentioned a change in time.

Overall, the survey results show that almost half of the respondents would change their behaviour in some way based on the information provided by the Transport Direct portal. (AEA, 2007)

3.3 Infrastructure-bounded travel information

Travellers cannot only be informed via route planners, but also via information provided at railway stations, bus stops or along motorways. In areas where the frequency of public transport is low, travellers have a higher need for information on exact departure times compared to urban areas with high-frequent public transport lines. Knowing that a metro will stop every 5 minutes is mostly sufficiently satisfying to these travellers. (source: interviews OPTIMISM)

Although public transport information en-route can be valuable, it can be questioned to what extent dynamic panels at stops are the best means to provide this information. A disadvantage is the effort it takes a traveller to filter infrastructure-bounded travel information. The amount of information can be overwhelming at for example large railway stations. Secondly, it must be noticed that infrastructure-bounded travel information in public transport only reaches the travellers, who already have chosen to use the public transport and will not have an effect on the mobility behaviour of car drivers. Finally, the high investment costs of dynamic panels could raise the question to what extent these investments should be made in times where the majority of travellers are able to look up expected departure times through their smart phones. (source: interviews OPTIMISM)

Car drivers are nowadays informed via Dynamic Route Information Panels (DRIPs) along motorways. Those panels can in addition to static road signs improve the use of existing infrastructure by variable speed limits, lane keeping directions and information on traffic jams, alternative routes and road construction works. Where road transport and public transport were strictly separated in the past, DRIPs are increasingly used to provide information on public transport to car drivers, like P+R facilities and expected travel times by public transport. However, in practice DRIPs with this kind of information result in a negligible modal shift from the car to public transport. The target group for multimodal information is only 5%, because travellers do not see themselves as a potential modal shift traveller and the message shown is only relevant for a few travellers. According to Dicke-Ogenia (2010) this can be explained by the six steps of the information processing theory of McGuire.[2] This theory states that all six steps need to be finalised before behavioural change will occur. Reasons why not all steps are finished are for example information uncertainty (how should the indicated time be interpreted) and negative attitudes towards public transport. A better approach is to not focus on direct transit, but to show the advantages of public transport in such a way that a traveller might choose to use the public transport in case he/she is prepared, for example, after a traveller had, inspired by the provided information, the time to look for the possibilities for public transport at home. (Dicke-Ogenia, 2010)

3.4 In-vehicle travel information

The market penetration of navigation devices per household in the Netherlands has been estimated at around 61% in 2011. (Connekt, 2011) On the contrary to infrastructure-bounded DRIPs, navigation devices (including navigation devices on mobile phones) can show personalised information. Navigation devices can promote co-modality in two ways: those devices can result in more efficient road transport and when these devices not only show information related to road transport, but also in relation to public transport they may also result in a modal shift. The Dutch province Noord-Holland is testing a smart phone application called vDRIP, where the 'v' stands for virtual DRIP. The application only shows the messages which are relevant for the car driver. Because a car driver does not necessarily have to read all the messages he will be less distracted, which benefits road safety. No test results are known. (personal communication at Intertraffic, 2012) Due to the possibility to provide personalised travel information in-vehicle it is more likely that a car driver has attention for the provided information and therefore a car driver is more likely to adapt his/her behaviour.

Another example of in-vehicle travel information is Sensor City Assen, run by the Dutch province Drenthe and municipality of Assen. In this project a large system of sensors has been installed in Assen to test different sensor-driven applications. Sensor City Mobility focuses partly on the provision of travel information. In autumn 2012 different actors will be involved in a pilot project. In cooperation with TomTom, 1000 car drivers will use an android OBU (on-board unit) and tablet from January 2013 until November 2013. With the help of sensors installed everywhere in the city and travel time predictions of TNO the OBU informs the car driver when the travel time by public transport will be faster, cheaper or more comfortable compared to travelling by car. The car driver can decide to shift from the car to public transport and can decide to reserve a parking space at the same time. The parking fee will be paid automatically and the amount of money needed to travel by public transport will be automatically loaded on the smart card of the car driver. (Sensor City, 2012)

[2] detecting the information, pay attention to the information, understand the information, conform to the information, remembering and finally act on the information

3.5 Personalised travel advice

Travel information will not only become more dynamic, but the role of travellers will also become more passive. This trend entails the on-going provision of travel information through applications, which automatically propose the most ideal options based on the daily schedules of travellers (like in MS Outlook). These advices can change over time depending on the current state of the transport network. The role of the traveller will change from an active role into a more passive role, where the traveller no longer has to take the initiative to collect travel information. This also results in less bias with respect to travel mode choice, because the traveller receives the travel option, which is based on his indicated travel preferences the best option to travel. When a traveller needs to search for travel information him/herself, he/she could be biased by habitual behaviour. An example of such ICT application is GoAbout, which provides an MS Outlook plug-in, making that travel time is automatically reserved when planning appointments in Outlook, including detailed travel advice. (GoAbout, 2012)

4. Payment services

4.1 Introduction

Besides travel information, there are other mobility services, which are generally related to payment of trips. Several examples of payment services within public transport can be identified. With respect to payment services the development of ICT solutions is very similar to the developments in travel information: where it was first only possible to buy paper tickets at desks or vending machines, ICT solutions made it possible to buy tickets online or pay by mobile phone. These new payment options have enabled new forms of mobility, like car sharing or public transport bikes.

With respect to intermodal trips the term integrated ticketing is often mentioned. Bak and Borkowski (2010) have provided a state of the art overview of integrated ticketing and have included the definition used by NZTA (2008):

> *'Integrated ticketing can be easily defined as the purchase of a single ticket to allow travel on one or more modes of transport provided by one or more operators'*

The need for only one ticket can save a substantial amount of time for travellers and in this way public transport can become more attractive and user-friendly to travellers. This can also be said for integrated ticketing through electronic payments, which requires fewer operations. The examples of ICT solutions provided in this section can be applied in such a way that those technologies enable integrated ticketing, although these can also be used for single-mode trips.

4.2 E-ticketing

Buying a ticket online can reduce waiting time at public transport stations making it unnecessary to stand in line for a ticket. Due to this time saving, public transport can become more attractive. This makes that e-ticketing can influence the modal split towards the less carbon intensive transport modes.

However, many e-ticketing services require printing tickets and by buying a ticket in advance a traveller becomes less flexible. Due to these disadvantages, e-ticketing might be less suitable for short trips. On the contrary, for transport modes that require reservations, like touring cars and international trains, e-ticketing can save a substantial amount of time. Because people are planning those trips mostly long time ahead, it is less likely that time and destination will change.

4.3 Contactless smart cards

A means of payment which is becoming more integrated in public transport is the use of contactless smart cards. Smart cards were introduced for the first time in London in 1964. (Turner and Smith, 2001 in Bak and Borkowski, 2010) At that time smart cards had magnetic stripes, but nowadays most smart cards have an integrated Radio Frequency Identification (RFID) chip, which does not require physical contact, but makes it able to read the card by the use of radio signals. Due to this chip, two-way information exchange is possible and cards are reprogrammable. By presenting the card to a card reader when entering or leaving a public transport vehicle (check-in/check-out) travellers can easily pay, but smart cards can also be used to enable access to public transport station, which increases safety. (Bak and Borkowski, 2010; EMTA, 2011)

Some studies on the effects of smart cards have shown positive results in relation to modal shift and amount of passenger kilometres. In London the introduction of the Oyster card has resulted in an increase in daily use of public transport of 9.3% and on average 123,000 less car journeys on a daily basis. Based on these numbers a net modal shift of 5% is ascribed to the introduction of the Oyster card. (Forum for the Future, 2009)

According to a social cost benefit analysis of the application of a smart card in the Netherlands, the smart card can reduce travel time with 20 seconds per trip, because of a reduction in ticket purchase time. This will result in a total reduction of 4 million hours nation-wide annually. Due to these time savings and a decrease of incidents in public transport (molesting) the net increase of passenger kilometres in public transport is expected to be 1.0% which is similar to 200 million passenger kilometres. The resulting CO_2 emissions reduction is estimated at 0.7%. (Nieuwenhuis et al., 2003)

4.4 Mobile phone payments

RFID chips can also be applied in mobile phones instead of smart cards. This so-called application of Near Field Communication-technology (NFC) in mobile phones has some advantages over the use of smart cards. A major advantage is that mobile phones enable travellers to change settings on their way, while in case of smart cards travellers need a smart card reader or vending machine to load special settings like reduction options. The share of NFC phones is estimated to increase to 20% of all phones in operation over the next 5 years. (AECOM, 2011)

An example of a pilot project testing NFC-technology is the project Touch & Travel. This project has been jointly conducted by Deutsche Bahn, the German rail authority, Vodafone, Deutsche Telekom and O2 Germany. The pilot project focuses on long-distance trains between Berlin, Cologne, Dusseldorf and Frankfurt, but also on some regional trains, metro and trams in Berlin and all modes of transport in Potsdam. Since the start of the project in 2008, 3,000 participants used the service frequently. NFC-enabled mobile phones are used to check-in and –out to test the technical feasibility and pre-commercial application of this new technology. (NFC Forum, 2011)

Besides time savings for the travellers, one of the major advantages of electronic ticketing in public transport is the huge amount of information provided to public transport operators on mobility behaviour of their customers. With the help of this input operators are able to improve their services, for example by adapting capacity during rush hours. Another advantage of electronic ticketing is the possibility to implement more complex pricing differentiations to influence travellers and to distribute revenues among the operators in case of intermodal trips. (Mezghani, 2008) This means that information from payment services can be used for influencing users or even traffic management. It however must be noted that the use of this information also raises questions on privacy issues.

4.5 Rental services

A fourth advantage of electronic ticketing, which has not been mentioned so far is the extension of the use of it to other services like payment of parking fees or rental services. In different cities, smart cards can be used to access public-bicycles schemes or to make use of car sharing services.

In several large cities in Europe, e.g. Paris, Seville and Dublin, bicycle-sharing schemes have been implemented in order to promote this more sustainable transport mode. One of the main aims of these schemes is to provide an alternative for transport between public transportation points and final destinations and in this way enhance the existing transportation network. The pricing structure is often designed in such a way that short-term usage is promoted: in most cases the first 30 minutes are free.

In Dublin the Dublinbikes scheme officially opened in September 2009 with 450 bicycles at 40 stations installed. In a questionnaire-based research it was found, among other things, that (Murphy, 2011):

- 68% of respondents claimed not to have cycled for their current trip prior to the launch of the Dublinbike scheme
- 45% of respondents use the scheme as a substitute for walking, 34% of respondents use the scheme as a substitute for public transportation modes and only 19% use it as a substitute for the car.
- 39% of respondents use Dublinbikes in combination with another mode: 56% of the respondents use it with rail, 35% use it for bus. (Murphy and Usher, 2011)

5. Traffic management

5.1. Introduction

ICT solutions are not only used at the side of the customer, like mobility services and travel information, but are also used at the traffic management side of the transport sector. In general it can be concluded that information plays a key role in the management of road transport as well as in public transport. By better management of transport flows, the system itself can be more efficient. Increased fuel efficiency and a reduction of kilometres will reduce GHG emissions.

5.2 Public transport

The ICT solutions identified in relation to traffic management are mainly in cities where traffic management centres have been established. As mentioned before, the use of for example smart cards can generate a flow of information which can help transport operators and municipalities to better manage the traffic flows. Besides the reduction potential described in the introduction, traffic management in public transport can also stimulate a modal shift towards public transport as a result of time savings for travellers.

VMZ Berlin
One of the examples is the Verkehrsmanagementzentrale Berlin (VMZ Berlin), which was completed in 2003. The aim of the management centre was to integrate the public, private and commercial transport of the city in one single management system. Throughout Berlin 50 webcams, 2,000 traffic lights and more than 200 infrared sensors have been installed at strategic locations, all supplying data to the management centre. Based on this data input 22 outdoor electronic display panels and a network of other data centres are controlled. The information is also used to inform travellers (multimodal route information) and also serves as input in the decision making process to improve the Berlin traffic situation. (Osmose, 2009)

5T system Turin
Already in the 90s, a city traffic management centre (called 5T) has been become operational in Turin. The system itself consists of nine subsystems, which the City Supervisor integrates in one system. In evaluating the system, the following results were found (Gentile, 2000):

- increase of 3% of modal split in favour of the public transport
- decrease of the average origin-destination trip time by 21%, which is 7 minutes per trip
- decrease of 10-11% of pollutant emissions

Although reducing travel time in public transport and road transport can be beneficial for pollutant emissions, these time savings also may cause rebound effects on the long term. For example, the increased attractiveness might generate more traffic.

5.3 Towards autonomous vehicles and cooperative systems

Over the years, cars are equipped with all kinds of driving assistance systems like cruise control, intelligent cruise control (taking also the distance between cars into account), collision warning and avoidance, lane-keeping support and all kind of navigation systems. (Giannopoulos, 2004) This trend will continue and will probably end in completely autonomous vehicles. At the moment it is already technologically possible to let vehicles drive autonomously (without any intervention of a car driver). However, due to non-technical issues the introduction of autonomous driving in practice will take years. Examples of issues are consumer confidence and legal aspects. Because ICT will be more capable of optimising driving conditions compared to individual car drivers, a reduction of GHG emissions can be expected as a result of a more fuel efficient driving style. (TNO, 2009)

For decades, communication between car drivers was done by light signals, hooting or hand gestures, but there was no interaction between vehicles. However, interaction between vehicles and infrastructure can optimise individual driver assistance. With the help of ICT a car driver can for example be informed about vehicles approaching outside a driver's range of vision. We can identify the following types of communication within cooperative systems:

- **Infrastructure-to-infrastructure (I2I):** components of infrastructure can communicate with other infrastructure components. A good example is the use of loops in the road surface to provide input to traffic lights.
- **Vehicle-to-infrastructure (V2I):** these technologies allow vehicles to send information to the infrastructure on the state of the vehicle and to some extent also on the immediate environment of the vehicle. V2I can for example be used to determine congestion. In case of I2V the messages come from the infrastructure and are received by the vehicles.
- **Vehicle-to-vehicle (V2V):** there is a direct information flow between vehicles. An ambulance approaching an intersection and sending a warning to other vehicles near that intersection is a good example. (Kantowitz and LeBlanc, 2006)

The cooperative systems have the potential to result in better use of existing infrastructure capacity (distances between vehicles can be shortened) and a decrease of accidents and general improvement of road safety. It might also result in higher fuel efficiency and therefore reductions of GHG emissions (TNO, 2009) Most of these technologies are still in development and are only tested in pilot projects. Factors which determine a successful transition to these types of cooperative systems in the future are for example the juridical aspects in relation to for example responsibility in case of accidents, harmonisation and standardisation of technologies and reliability of the communication technologies

6. Conclusions

A wide variety of ICT solutions related to the transport sector exists and will become available in the coming decade. When these ICT solutions are applied in public transport and road transport several mobility effects can be expected. This as a consequence of mainly time savings, quality improvements, increased comfort and reliability. In this way public transport can become more attractive to travellers, which might result in a modal shift to these less carbon-intensive transport modes. However, ICT solutions are also applied in road transport and also have the potential to reach efficiency gains, improve road safety and influence mobility behaviour of car drivers.

Based on the described examples and the evaluation outcomes in this paper it can be concluded that it is very likely that ICT solutions will have a positive effect on mobility behaviour from the perspective of decarbonisation. The quantitative data presented in this paper are mainly related to a modal shift towards public transport (including details on which modes have been replaced), time savings and pollutant emissions and GHG emission savings.

However, based on these data nothing can be said yet on the total reduction potential for the European passenger transport system. CO_2 reduction should not be assumed automatically. The impacts strongly depend on the type and application of the ICT and especially to what extent the ICT will be used. Because potential rebound effects should also be taken into account additional policy measures, like pricing measures, should be considered aimed at maximising actual emission reduction and preventing the rebound effects on the long term.

The next step in OPTIMISM will exist of the definition of best practices and the further quantification of the expected mobility effects and related mobility impacts of these best practices. Based on these outcomes a translation will be made to the expected potential of ICT solutions to save GHG emissions and thus contribute to the decarbonisation of passenger transport.

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