ADDITIONAL BENEFIT OF ITCS DATA USED IN ROAD TRAFFIC CONTROL SYSTEMS – WAYS TO ENHANCE MULTIMODAL TRANSPORT QUALITY AND ENERGY EFFICIENCY

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INTRODUCTION

Urban agglomerations are facing increasing traffic demand with telematics to save high transport quality for both - public transport and motorized individual transport. On the one hand public transport operators use Intermodal Transport Control Systems (ITCS) to locate and dispatch the vehicle fleet. On the other hand road traffic control systems monitor road traffic conditions and derive measures to improve road traffic flow. In principle these systems are being operated separately without interchanging information. However, linking multi-modal monitoring data generates new options to improve transport quality of public and private transport. Some municipalities already set up applications based on the connection of ITCS with Traffic Control Centers (TCC). Thereby, municipalities are focusing a change in commuter habits, especially the modal shift from car to public transport. The following strategies are realized:

- Multi-modal journey preparation services (example: 511 services in U.S., see Lo et al. 2004)
- Transit information services at park and ride facilities giving real-time departure times of public transport modes (example: Halle, Germany, see Kolbert 2010)
- Changeable message signs at radial roads displaying expected journey times of public and private transport modes to the city centre (example: Cologne, Germany, see Association of German Transport Undertakings 2001)

In Dresden, Germany, the responsible institutions combined ITCS data of the surface public transport system with the urban road management system to figure out the benefits for public transport and road traffic. Since 2008 four inbound main roads have been equipped with changeable message signs being located close to park and ride facilities. Road traffic gets informed about traffic conditions and events influencing traffic flow (traffic jam, construction

sites, parking space) as well as real-time departure times of public transport. As follow up, the Dresden Public Transport Company (Dresdner Verkehrsbetriebe AG), the Urban Road Department (STA Dresden) and the Dresden University of Technology (TU Dresden) initiated a project to enhance intermodal transport quality by modifying traffic light control strategies. Depending on current intermodal traffic situation a new approach of actuating traffic light controllers had been developed: public transport vehicles should receive differential priorities at traffic signals to enhance punctuality, regularity or dynamic connection services.
In addition, the Dresden Public Transport Company is going to employ a driver advice system for tramway vehicles to avoid unnecessary stops at traffic signals. Thus, a reduction of energy consumption and running times will be enabled.

SYSTEM ARCHITECTURE

In order to use monitoring data of both systems efficiently, TU Dresden has developed a multi-modal interface module (MIM, see Figure 1).
In consideration of multi-modal traffic situation MIM predicts arrival times of each public transport vehicle at traffic signals. Because of non-trivial influences on journey time (dwell times, waiting times at previous traffic signals and conflicts with other vehicles) prediction horizons have to be ascertained in such a way that the journey time from a current vehicle position to a traffic signal can be calculated with high accuracy.

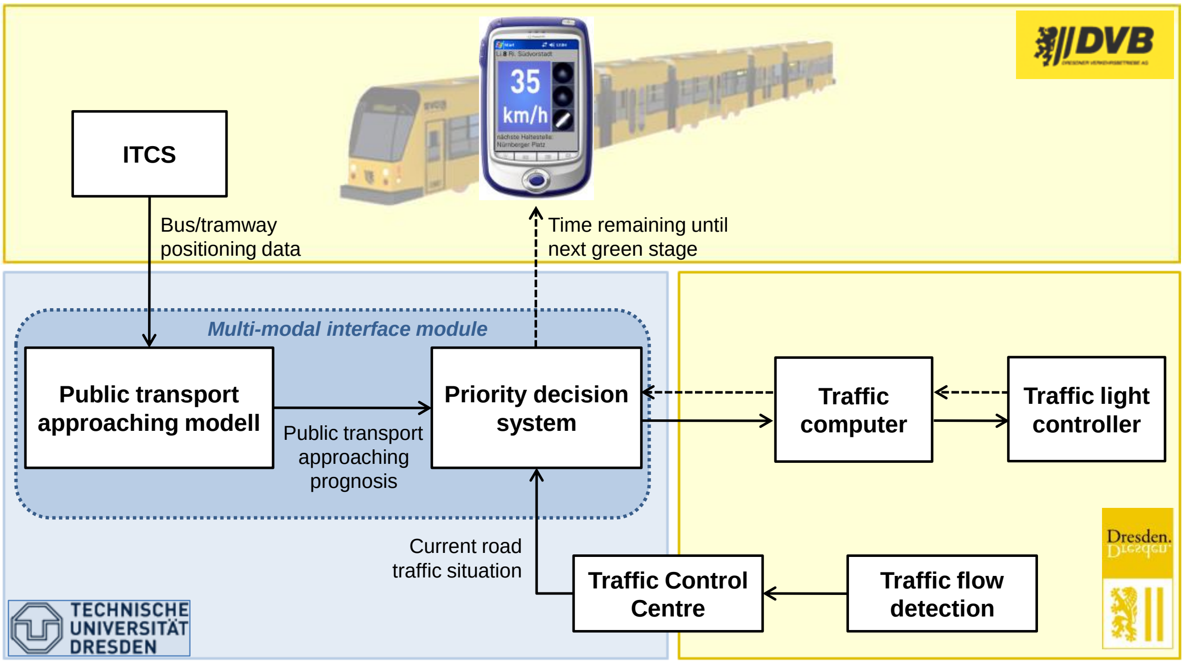

Figure 1 *- System architecture*

In order to predict arrival times in real-time two types of AVL-telegrams (Automatic vehicle location) are interpreted by MIM:

1. Traffic light login/logout telegrams – they are used locally to activate/deactivate public transport priorities at ordinary traffic signals. Generally, these telegrams are not involved into real-time monitoring of ITCS.
2. AVL-telegrams sent to ITCS directly. In Dresden data transmission is based on cyclic call procedures. The central system asks periodically all vehicles to send a protocol, which contains among other data current position and delay.

Incoming telegrams are matched with empirical driving trajectories to ascertain arrival times at specific traffic signals. As a result MIM generates a prospective image of all approaching vehicles at the intersection whose traffic light program can be influenced. On that basis MIM sets priorities in a 7-stage-priority-system for each public transport vehicle approaching. Priority setting is influenced by following criteria:

- *Punctuality:* Traffic signals heavily influence schedule deviation. Improvements on punctuality by giving priority to public transport have already been proven in various cities (Gardner et al. 2009). However, most differential priority systems only consider delayed vehicles (Hill 2000, Furth et al 2000, Witbreuk 2004).
- *Headway regularity:* In high frequency services (e.g. headway 5 minutes or less) passengers pay less attention to schedule. Consequently, passengers arrive randomly and expect short waiting times. Traffic signals are able to slow down/speed up public transport vehicles to avoid bunch formation respectively assure stable headways (van Oort et al. 2007, Hounsell et al. 2009, Kim et al. 2005).
- *Connection services:* These services are divided into static and dynamic services. Static services are defined before starting the ride, for instance in the timetable. When the incoming vehicle is delayed, the driver of an outgoing vehicle is bound to guarantee that service, even if the outgoing vehicle gets delayed, too. In general the drivers get information from ITCS about guaranteeing the static connection. In practice additional connection possibilities arise by chance, so called dynamic connection services. Coordinating the vehicles in a useful manner, traffic signals are able to reduce inefficient waiting times when realizing static and dynamic connection services.
- *Private transport conditions:* For the sake of balanced priorities and high acceptance by road users, private motorized transport has to be taken into consideration. The Dresden TCC measures the Level of Service (LOS) of relevant road sections by analyzing multiple kinds of traffic detectors (floating car data, infrared sensors, single and double induction loops, see Körner 2006). In case of unstable traffic flow or activated motorway diversion route programs, public transport priority is reduced.

Finally these priorities are commuted into modifications of the ordinary signal timing plan. Therefore, the Urban Road Department, which is responsible for traffic light control, has to determine feasible options of modifying the signal timing plan. While vehicle priorities always are determined in seven stages, the amount of modification options at intersections can vary

case-by-case. For each intersection the public transport priorities are matched with realizable modifications.
The modification chosen is sent wireless by MIM to the signal control units. In doing so MIM uses login/logout telegrams having the same structure as ordinary telegrams sent by public transport vehicles. Thus, actuation of signal timing plan modifications is shifted from local public transport vehicles to the central Multi-modal Interface Module. In case of being out of order actuation falls back to the telegrams, which are sent by public transport vehicles.
Within the project, the traffic computer also supplies MIM with the constraints of current and future signal states (e.g. adjustment times because of changing signal timing frameworks with different cycle times). Depending on these signal states MIM has to prove whether modifications can be realized at all (e.g. adjustment times could block modification requests or traffic signals are totally switched off). Finally, MIM transmits information about the signal state and expected green time windows to vehicles approaching traffic signals. This data can be processed onboard by a driver advice system, which supports the driver to avoid unnecessary stops at blocking signals.

ENERGY-EFFICIENT LIGHT-RAIL TRANSIT CONTROL

Driver advisory systems (DAS) supporting energy efficient driving have already been developed for European railways and metro systems (Voss et al. 1998, Lieskovsky et al. 2008). These systems calculate optimal trajectories in real-time, whereby algorithms used differ in single-train and multi-train optimization, single-section and multi-section optimization as well as heuristic and numerical optimization approaches (further information see Howlett et al. 1995, Liu et al. 2003, Albrecht 2008). In average DAS in railways can provide energy savings of 5-10% (RailEnergy 2010).
Whereas energy savings in railways are investigated thoroughly, the influence of DAS on energy-efficiency in light-rail transit (LRT) systems, respectively tramway systems having their own right of way, is rarely discussed in literature. Many LRT networks feature a series of intersections in city centres where absolute priority cannot be given to light-rail vehicles (LRV). As the number of those intersections increases, the influence on energy consumption increases as well (Maltese 2010). Driver information and advisory systems considering green stages enable drivers to save energy by avoiding stops at traffic signals.
So far some public transport companies are using “Close doors” signals at stops (Association of German Transport Undertakings 2001). The “Close doors” signal is flashing shortly before the start of a green stage. If the driver closes the doors while flashing and starts acceleration, the vehicle will pass the next intersection without waiting at the traffic signals. Generally, “Close doors” signals are located at stops with intersections in short distance. The benefit of these signals is decreasing by the distance between stop and traffic signals, because of increasing possibility of disturbances. However, onboard DAS are able to react quickly in case of such disturbances on the ride. Having knowledge of optimum and real driving trajectory DAS can adjust speed advices while moving.

Because of operational and infrastructural differences TU Dresden is investigating driver advisory systems for LRT separated from railway and metro systems. Therefore, the driver advisory system COSEL (Computer Optimized Speed Control for Efficient Light-Rails) has been designed. COSEL is respecting the attributes of LRT systems as well as tramway systems featuring sections with exclusive rights-of-way.

In contrast to DAS in railways, COSEL has to deliver advices for short sections. The journey time between important operational points (stops, signals) rarely exceeds one minute. Optimization algorithms using numerical solutions with high frequencies of changing tractive effort are not useful for LRT. For the sake of saving energy, speed control actions shall be reduced to minimise possible distractions. For this reason, COSEL calculates the optimal trajectory by applying the Maximum Principle. That approach obtains the following four regimes:

- Full power (limited by the maximal permitted acceleration of the vehicle)
- Cruising at constant speed (either by applying partial power or partial braking, depending on the prevailing track and running resistance)
- Coasting (Inertia motion without consuming traction energy)
- Braking with full power (limited by the maximal permitted deceleration of the train)

The whole trajectory is found by considering the section length, track resistance, current state of the vehicle (position, speed) and the target state (e.g. arrival time at next stop or green window at the next signal) as well as vehicle properties. As a result running time reserves will be determined first. Afterwards, these reserves will be distributed energy efficiently in terms of coasting or reduced cruising speed advices.

Figure 2 shows different ways of displaying COSEL speed advices (cruising at 40 km/h). The following set of advices already has been tested on the Dutch heavy rail network in cooperation with ProRail (Albrecht et al. 2010):

1. Displaying optimum and actual trajectories (magenta/green curve). The driver is able to compare his ride with the optimum. However, the large variety of information can lead to distractions.
2. Textual speed advices. These advices can easily be interpreted by the driver and can also be displayed by almost any integrated onboard unit.
3. Advices within the speedometer. A magenta arrow indicates target speed. In case of coasting advice a blue lamp is switched on. This solution can be integrated in the speedometer without having additional devices onboard.
4. Punctuality indicator. Similar to (3) the driver will be informed about a target speed and a coasting indicator. In addition, the temporal deviation to optimum driving style is given in the scale of seconds.

Currently, the most suitable display for realization in LRV is being examined with the Dresden Public Transport Company. Scientists, drivers and the LRT operations director are involved in several simulation runs at the TU Dresden driving simulator (Figure 3). At the simulator human factor engineering aspects are evaluated as well as influences on safety. During first trials on LRV in Dresden the chosen advisory system will be implemented on smart phones.

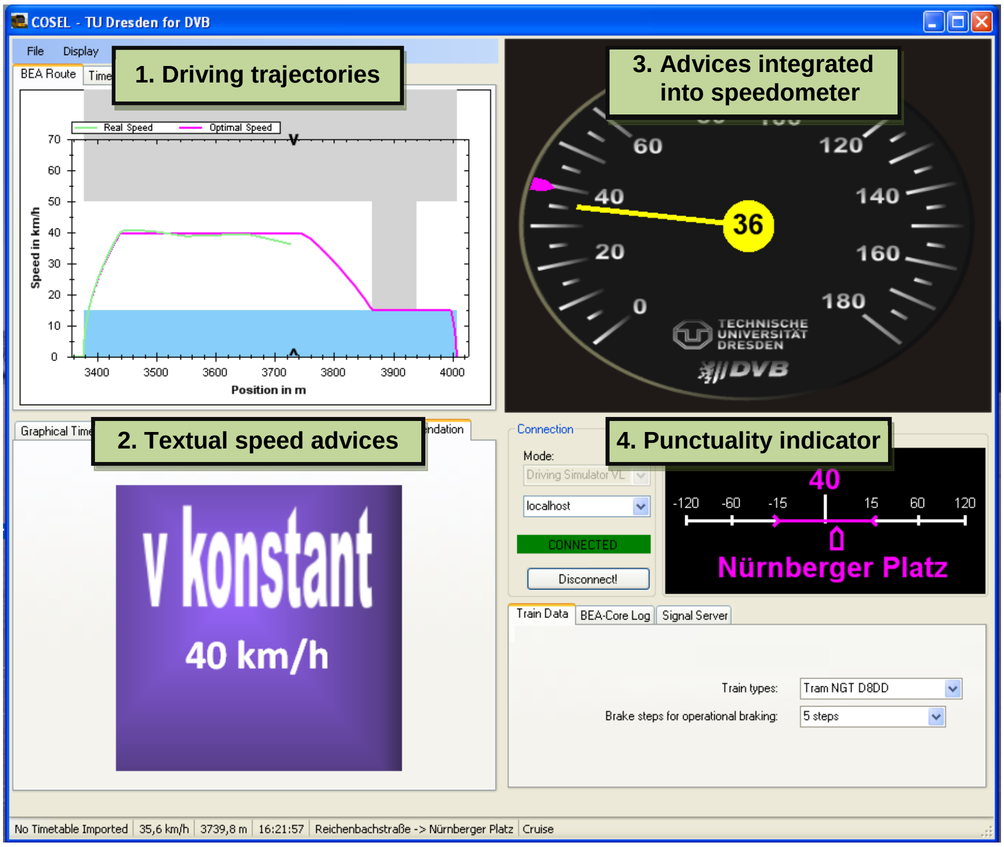

***Figure 2** – Sample of displaying COSEL speed advices*

***Figure 3** – COSEL test runs at the TU Dresden driving simulator*

CASE STUDY NÜRNBERGER PLATZ

For demonstration purposes, the intersection Nürnberger Platz was chosen. At Nürnberger Platz two tramway lines (3, 8) are operating as well as bus line 61. Especially line 61 features a short planned headway at the peak periods (~5 minutes). Due to long dwell times at previous stops the real headway strongly varies. In contrast the tramway lines are operated with 10 minutes headway each and don't suffer from bunching problems. Except for a few intersections the tramway lines are operated like LRT with private rights-of-way.

This intersection also plays an important role for private transport. Nürnberger Platz is part of diversion routes when traffic jams or tunnel closures occur on the motorway nearby.

For the sake of balanced prioritization of transport modes, the traffic light priorities are adjusted according to tramway schedule deviation. Consequently, tramways being late expect a higher priority. In case of early arriving tramways, priority is lower and therefore road traffic profits from extended green phases.

The schedule deviation is detected in real-time by analyzing time stamps of login/logout-telegrams at traffic signals prior to Nürnberger Platz. Figure 4 shows the distribution of schedule deviation of tramway line 3 approaching Nürnberger Platz.

78% of all vehicles are defined "on time" (deviation 0 to +2 minutes). At peak hours the priority system offers two green stages within a cycle time of 120 seconds. In case of being late, traffic disturbances of competing road traffic will be checked first. Whenever high road capacity is needed (motorway diversion route or LOS E/F) modifications restricting car traffic flow are prohibited. Otherwise the signal programs are modified by lengthened green stages and if required even a third green stage can be introduced.

If public transport vehicles approach the intersection before schedule, the tramway priority will be reduced. In that case tramways only receive one green stage per cycle time and the other green windows are accorded to private transport.

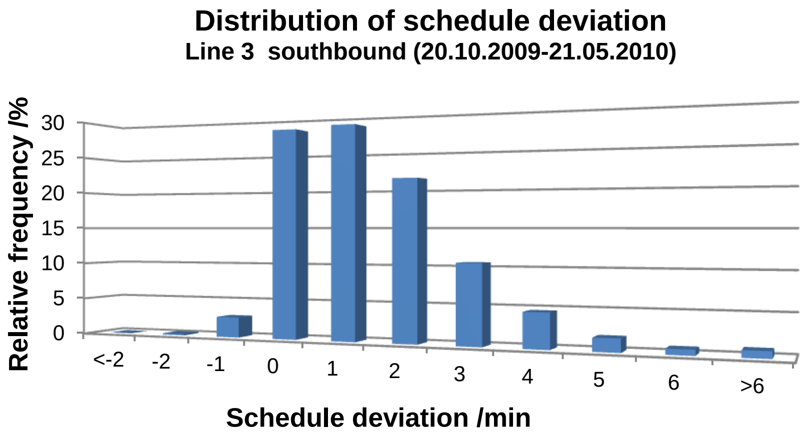

Figure 4 *– Schedule deviation of tramways 220 meters before approaching traffic signals at Nürnberger Platz*

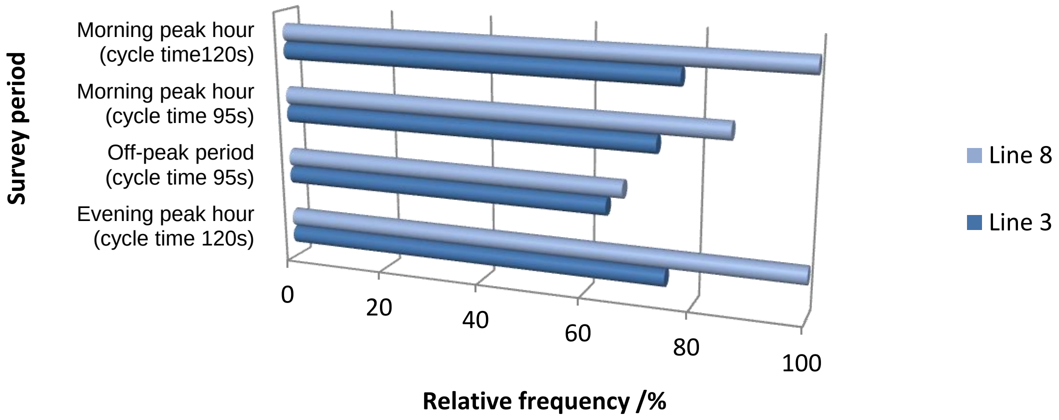

***Figure 5** – Empirical stopping probabilities of LRV at the traffic signals Nürnberger Platz (survey period: Oct 29th 2009, direction southbound)*

In addition, the multi-modal interface module also supports dynamic connection services between tramway line 8 and bus line 61. For this connection service the bus line mainly is used as outgoing vehicle. Traffic signals are switched in a coordinated manner, respecting MIM approaching prognosis at Nürnberger Platz for vehicles being involved. If vehicle bunches are detected at line 61 at the sections before, the MIM targets on saving connection services with the last vehicle of the bunch. Whenever applicable the bunch is broken up by differential priorities at traffic signals. By relieving the first bus of passengers changing times (resulting from connection service) the headway regularity will be improved. The following busses, generally less overcrowded, take the passengers from the incoming tram. This will lead to longer dwell times at the bus stop and consequently contributes dissolving the bunch.

The section between stop Reichenbachstraße and stop Nürnberger Platz was selected to prove anticipatory driving. Without applying DAS between 65% to 100% of tramways moving southwards had to stop at this section at the traffic signals Nürnberger Platz (depending on daytime and signal program, see Figure 5).

In order to reduce stopping probabilities COSEL will be tested. Light-rail vehicles closing doors at stop Reichenbachstraße, also send a login-telegram. Having received that login telegram, MIM initializes the priority setting process and finally sends back parameters of the next green stage. Due to vehicle actuated signal programs at Nürnberger Platz, expected start and end time of the green stage differ in the scale of a few seconds. Therefore COSEL calculates the optimum trajectory considering the mid value of the green stage as passing time at the traffic signals. In addition, vehicle parameters of Dresden tramways (Bombardier Flexity trams) are derived from measurements of Dresden measuring tram (Harter et al. 2009).

The section between both stops has a total length 630 m with gradients up to 4.1%. Except for two intersections with low conflict probabilities the LRT track is separated from road traffic until reaching the traffic signals at meter 530. Different driving trajectories for this section can be seen in Figure 6.

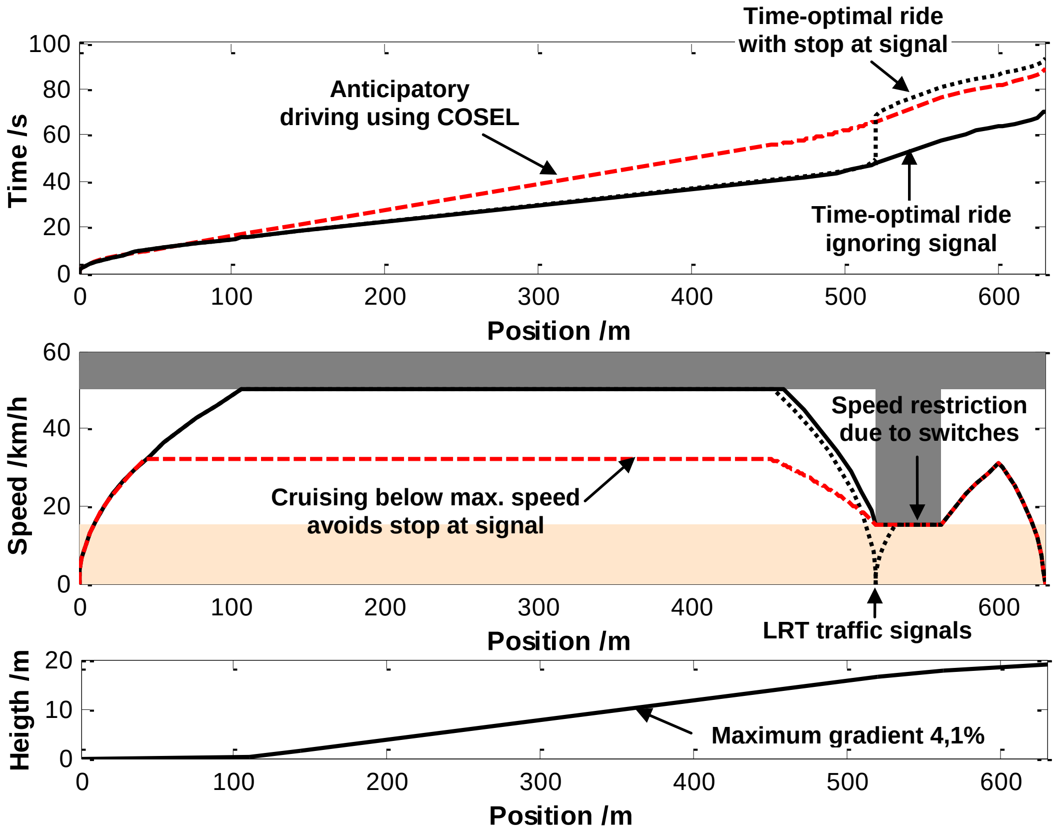

Figure 6 *– LRT trajectories between both stops Reichenbachstraße and Nürnberger Platz (scenario: Passing time at signal 67 seconds after doors have been closed at stop Reichenbachstraße – Improvements by COSEL compared to time-optimum rides: Energy savings 19% and running time savings 4 s)*

Between both stops time-optimal driving styles are commonly used today, approaching the traffic signals 47 seconds after having left stop Reichenbachstraße. In case of getting green lights not before second 67, the driver will have to wait at the traffic signals. In contrast, anticipatory driving avoids that stop by combining cruising below maximum speed and coasting. This driving style improves energy efficiency and passenger comfort.

In addition, COSEL also influences the total running time between both stops. On the one hand COSEL assumes passing times which involve a temporal off-set from the start time of the green stage. Thereby, assisted drivers pass the traffic signals a few seconds later than drivers without using COSEL. On the other hand COSEL supports driving with maximum permitted speed while passing the traffic signals. Time losses being caused by acceleration from standing still are avoided. Therefore, the running times of assisted and non-assisted drivers are almost balanced and differ in the scale of seconds.

The impact of COSEL on energy savings and running time will be evaluated in test series onboard by the end of 2010.

CONCLUSIONS

Within the project an intelligent multi-modal interface module has been developed connecting AVL-telegrams of public transport with road management functionalities. The commonly used vehicle actuated signal timing plans are modified in order to improve multi-modal transport quality. Thereby, private traffic conditions are taken into account as well as widespread claims of public transport (punctuality, headway regularity, connection services, energy consumption and driving comfort).

Finally, the drivers of public transport vehicles get informed about the signal state indirectly, using a new driving advice system for light-rails. Drivers following the advices will be enabled to pass traffic signals without stops.

The system architecture currently described is tested at the intersection Nürnberger Platz in Dresden. For the sake of high system acceptance the manner of giving driving advices is being discussed with Dresdner Verkehrsbetriebe. Having decided the kind of displaying advices, the driver advice system will be deployed on LRV by the end of 2010. By then, the whole system developed will be in operation.

Furthermore, Dresdner Verkehrsbetriebe plan to replace acoustic announcements of dynamic connection services by giving detailed data on the onboard passenger information displays. In future, research on energy efficiency will be extended to one of the heaviest charged transport corridors in Dresden (North-South-Route).

LITERATURE

Albrecht, T. (2008). Energy-efficient train operation. Railway Timetable & Traffic. Eurailpress, pp. 83-105

Albrecht, T.; Gassel, C.; Binder, A.; van Luipen, J. (2010). Dealing with operational constraints in energy efficient driving. International Conference on Railway Traction Systems. Birmingham

Association of German Transport Undertakings (VDV) and VDV Promotional Group (ed.) (2001). Telematics in public transport in Germany. Sponsored by Federal Ministry of Transport, Building and Housing. Alba Fachverlag, pp. 181-187

Furth P. G.; Muller H. J. (2000). Conditional Bus Priority at Signalized Intersections: Better Service with Less Traffic Disruption. Transportation Research Record 1731, pp. 23-30.

Gardner K.; D'Souza C.; Hounsell N.; Shrestha B.; Bretherton D. (2009). Review of Bus Priority at Traffic Signals around the World. UITP Working Group: Interaction of buses and signals at road crossings. Final Report 2.0

Harter, M.; Beitelschmidt M.; Striegler G.; Sauermann I. (2009). Special measuring tram for Dresden – concept, architecture and components (in German). ETR – Eisenbahntechnische Rundschau, February, pp.716-721

Hill, R. (2000). Real Time Passenger Information and Bus Priority System in Cardiff. Proceedings of the 7th World Congress on Intelligent Transport Systems. Turin

Hounsell, N.B.; Shrestha, B.P. (2009). A new strategy for differential bus priority at traffic signals for high frequency services. 16th ITS World Congress. Stockholm

Howlett P.G.; Pudney, P.J. (1995). Energy-Efficient Train Control. Advances in Industrial Control. Springer. London

Kim S.; Park, M.;Chon K. (2005). A bus priority signal strategy for regulating headway of buses. Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 435 - 448

Kolbert, P.(2009). Innovation and Research – Experiences of MOSAIQUE (in German). Presentation. Final Conference. Leipzig

Körner, M. (2006). Traffic data processing and modelling for the Dresden operational traffic management system. 10th IFAC Symposium Control in Transportation Systems. Delft

Lieskovsky A.; Myslivec I. (2008). CRV & AVV - modular control system for all kinds of vehicles with special respect to energy savings. Presentation at Trainer Demotour II Workshop. Bratislava

Liu, R. I.;Golovitcher, I.M. (2003). Energy-efficient operation of rail vehicles. Transportation Research Part A 37, pp. 917-932

Lo H. K.; Yip C.W.; Mak B. (2004). Passenger route guidance system for multi-modal transit networks. International Conference on the Application of Information and Communication Technology in Transport Systems in Developing Countries. Kalutara

Maltese (2010). Management and Assessment of Light Trains for Energy Saving and Efficiency. Project website. Address: http://www.ivv-aachen.de/maltese/english/start.htm (Access: 23.05.2010)

Railenergy (2010). Project website. Address: http://www.railenergy.org (Access: 23.05.2010)

van Oort, N.; van Nes, R. (2007). Randstadrail: Increase in public transport quality by controlling operations. 2nd International Seminar on Railway Operations Modelling and Analysis. Hannover

Voss G.; Sanftleben D. (1998). Computer Assisted, energy-saving driving method in closed-loop control mode (in German). ETR-Eisenbahntechnische Rundschau - January, pp. 25-31

Witbreuk M.; Zoontjes P. (2004). Sabimos Twente: A Satellite Based Public Transportation System, Proceedings of 10th World Conference on Transport Research. Istanbul