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GALILEO - THE ENABLER FOR ENVIRONMENTAL SUSTAINABILITY OF TRANSPORT THROUGH DYNAMIC TOLLING

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ABSTRACT

There is an urgent need for European and national transport policy to establish instruments for a better and faster adaptation of existing infrastructure capacity to policy goals. For this purpose the setup and operation of access- and usage control of the existing road infrastructure capacity need to be established.

GNSS (Global Navigation Satellite System) based dynamic tolling which reacts situation based to a set of parameters according to predefined coded thresholds is widely seen as an appropriate instrument by traffic planners, industry and policy. Therefore a new dynamic tolling scheme needs to take additional parameters like current congestion on the road, vehicle occupancy (trucks-load or passengers per vehicles), pollution, particles, CO_2 emissions, noise etc. into consideration. One essential element to such a new dynamic tolling scheme is contributed by GALILEO: detecting which vehicles are driving on which road, and possibly even on which particular lane of that road.

Galileo will provide this robust, reliable and precise positioning of the vehicle. An vehicle based On-Board-Unit will process these exact positioning data together with price relevant data provided by the tolling centre and integrate them with the relevant in-vehicle generated data (e.g. from CAN-BUS) for the calculation of the currently valid road price that will be displayed via a human machine interface (HMI).

The data transmission between On-Board-Unit and tolling operation centre will be done by terrestrial wireless infrastructure-to-vehicle communication technologies (e.g. GSM/GPRS, Infrared, Microwave).

This paper discusses the use of Galileo for vehicle positioning within dynamic tolling systems and the corresponding possible impacts of such schemes (harmonisation of traffic along the road network, reduction of CO2 emissions, noise etc.) on traffic and on transport policy.

1. INTRODUCTION

Tolling systems in use in urban areas, along motorways and on the secondary road network were originally implemented with the aim to finance/co-finance the construction work and to release the budget of the public authorities [1]. Nowadays we are faced with a still increasing traffic demand (+75% truck traffic from 2000 to 2020, +33% individual traffic from 2000 to 2020) [2] versus a marginal extension of the road capacity. Currently this becomes a major concern in all major cities including their suburbs; additionally the traffic situation along European motorways will become even worse by 2020 due the expected traffic increase. There is an urgent need for European and national traffic policy to establish instruments for a better access- and usage control of the existing road infrastructure capacity.

GNSS based dynamic tolling which reacts situation based by a set of parameters according to defined thresholds is widely seen as an appropriate instrument by traffic planners, industry and policy. Hereby Dynamic Tolling could open new perspectives on how to influence traveller behaviour and goods transportation processes against the conventional, today applied tolling schemes.

All currently operating Electronic Fee Collection (EFC) systems have one big disadvantage: they only have static or semi-static character by focusing on road class, vehicle class and type, and the time of the day. Even introduced congestion pricing systems for city areas (e.g. Milano, London) are primarily based on those factors not taking the real traffic situation/demand (congestion as well as environmental) of the concerned road network into account. In order to allow an immediate reaction on the traffic and environmental status and to introduce a fair use of the resources road and environment (e.g. noise, air quality), new Dynamic Tolling Systems based on threshold parameters need to be introduced.

The concept of Dynamic Tolling will improve the transport policy by taking additional parameters like current congestion on the road, vehicle occupancy (trucks, passenger vehicles), pollution, particles, CO_2 emissions, noise, etc. into consideration. To reach policy objectives on environmental sustainability of transport and compensate lack on sufficient infrastructure capacity it is important to define thresholds for the variable parameters, to combine them with static factors (e.g. road class, vehicle class) and to create a dynamic tolling scheme to become able to react in short periods on the current traffic and environmental status/demand.

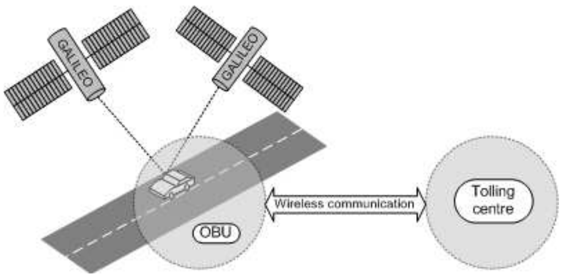

FIGURE 1 Concept of Galileo based positioning and dynamic tolling

This concept will allow the influencing of traffic demand in a positive way and support traffic management by reducing or even avoiding congestions and enhancing the safety along the road network. Dynamic Tolling will ensure a positive environmental impact by reacting on the environmental situation immediately.

Of course it must be ensured that a possible change in the mobility behaviour and patterns happens in parallel with a socio-economic stability to guarantee and increase fairness and competition.

2. TECHNICAL CONCEPT OF DYNAMIC TOLLING

Key elements of a Dynamic Tolling System are the precise, lane specific positioning of the single vehicle and the principle of output based policy objectives - the possibility to dynamically adapt the parameter thresholds to achieve the required impact in an adaptive control loop (see Figure 2). To reach policy objectives the thresholds for dynamic parameter will be defined. These thresholds will consider the road status and the environmental status by taking noise, particles, emissions, CO_2 and other green house gases, into account. After the implementation of the thresholds into the dynamic tolling adaptive control loop of the Toll Operator, the operation and evaluation of the impact on the traffic status and the environmental status needs to be performed. A review of the thresholds and the dynamic tolling scheme by taking the evaluation results into account will result in an adjustment which might be necessary to intensify the positive impact.

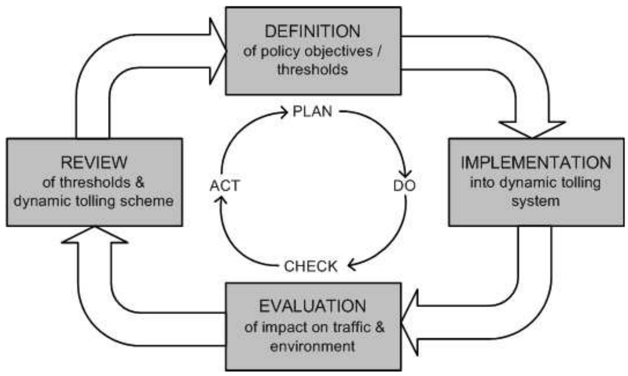

FIGURE 2 Principle of output based policy objectives by dynamic tolling

2.1.1. Tolling Operator Centre

By taking a more detailed look at the thresholds it seems to be clear that these form the basis for the dynamic tolling software within the Tolling Operator Centre (see Figure 3). Hereby currently used static thresholds are the starting point, such as

- differentiation of road classes (e.g. motorway, secondary road, main inner-city road)
- differentiation of vehicle classes. Here also emission classes (e.g. related to the engine power) for different passenger vehicles might be interesting, for trucks this is mandatory.
- occupancy/payload of the vehicle is of interest for a threshold definition to reduce trips of empty trucks.
- Also for passenger vehicles the occupancy/payload will become a topic to foster trips with high occupied vehicles (HOV).

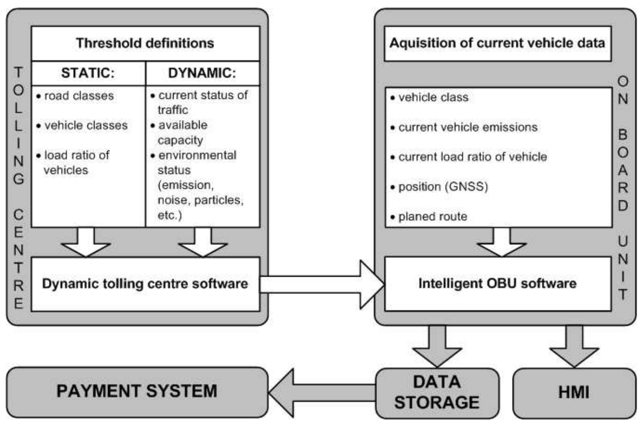

FIGURE 3 input data and data flow within dynamic tolling systems

Additionally within the concept of Dynamic Tolling dynamic thresholds need to be defined to influence the traffic on a short term basis. These dynamic thresholds need to cover:

- The current road status. If in more dense traffic situations road charges increase that might have a positive effect on decreasing the risk of congestions.
- The environmental status thresholds will ensure a quick reaction on critical environmental situations with reference to quick changing weather situations. This dynamic input into the tolling system will influence emissions, noise, particles, CO2 and other green house gases so that they do not exceed predefined threshold values.

Both inputs – dynamic and static – need to be processed within the Tolling Operator Centre (TOC), the calculation of the price needs to be performed, and the currently valid tolling scheme for the whole region needs to be transmitted into the vehicle.

2.1.2. Communication technology

The transmission of the relevant dynamic tolling-information will be done by terrestrial wireless infrastructure-to-vehicle (I2V) communication technologies as they are under development in several running R&D projects (e.g. CVIS, COOPERS) [3].

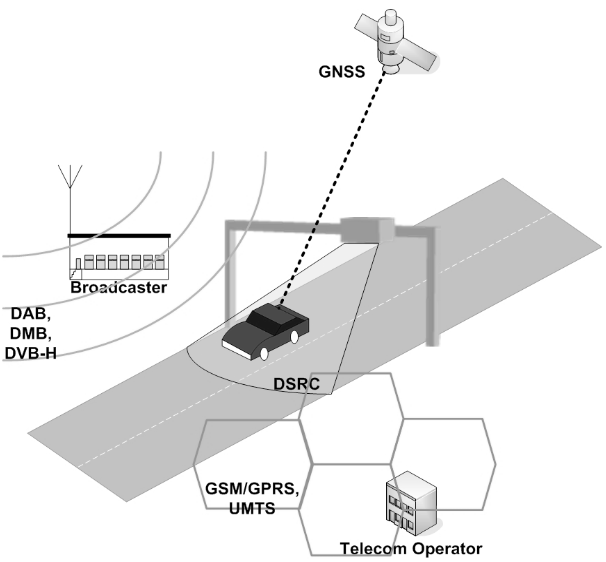

FIGURE 4 Communication technologies usable for bidirectional I2V data communication [4]

Following communication media are usable for bidirectional infrastructure-to-vehicle (I2V) communication (see figure 4): cell based technologies (e.g. GSM/GPRS, WiMAX), broadcast media (e.g. DAB, DMB, DVB-H) and Dedicated Short Range Communication (DSRC) technologies (e.g. Infrared, CALM-M5, WAVE). Via these communication media relevant dynamic tolling information can be transmitted to the drivers on a specific road segment. Hereby it is important to reach all drivers with a minimum delay time (the total delay from the detection of an event to the information of the following drivers should be below one minute) and with a geographical precise indication [5].

2.1.3. On Board Unit including GNSS-Receiver

An On-Board-Unit within the vehicle needs to process the data provided by the TOC and integrate the provided static data with the relevant in-vehicle data for the calculation of the current road price:

- For the road class information the vehicle based GNSS system needs to be used to identify the current location of the vehicle on the in-vehicle stored road map. This will ensure future value-added-services (VAS) like the price-calculation for the whole trip and the calculation of alternative routes.
- The vehicle class must also be identified by the OBU. An even more sophisticated dynamic tolling system might also be able to process the current vehicle emissions depending on the maintenance status of the vehicle, the tyre profile, etc.
- The occupancy of the vehicle will be identified by the in-vehicle sensors and transmitted to the OBU. This occupancy applies to the load ratio of trucks as well as to the passengers within a passenger car.

After the processing of the data the OBU will inform the driver via an HMI (Human-Machine-Interface) about the dynamically calculated price that has to be discharged on the current road segment. In addition the accumulated costs will be stored in an on-board data storage and periodically transmitted into the payment system within the TOC. This data storage can also be used, similar to the digital tachograph, for the detection of violations.

3. POLICY ASSUMPTION FOR DYNAMIC TOLLING

Beside the technical concept the current policy situation within Europe needs to be taken into consideration by introducing Dynamic Tolling systems. Hereby Dynamic Tolling will help to implement the Council Directive 1999/30/EC from 22nd of April 1999 [6] that forces the installation of alert thresholds for sulphur dioxide, nitrogen dioxide, oxides of nitrogen, particulate matter (PM10) and lead within the member states. This directive is also the basis for the “Preparation of an Impact

Assessment on the Internalisation of External Costs" (DG TREN) that is planned to be released in 2008 and will be valid for all transport modes. Additionally the "Review of the White Paper on the European Transport Policy for 2010" [7] calls for an effective policy on infrastructure charging. This smart charging should ensure fair and non-discriminatory prices for users, revenue for future infrastructure investment, ways to fight congestion, discounts to reward environmentally more efficient vehicles and driving.

These European wide directives and recommendations have also an impact on national tolling schemes:

- Stockholm has introduced congestion/city tolling with charges varying according to the time of day.
- Milan charges on a fixed sum per day depending on vehicle class.

A current introduced alternative approach is traffic management based on traffic volume and environmental factors. Here variable message signs are used to influence traffic and reduce congestions. Speed limits are either set automatically or manually based on traffic volume as well as on environmental factors such as noise and pollution as measured by monitoring stations. This system has been introduced in Austria.

All these policy directions and legal directives will be taken into consideration by interpreting the impact of dynamic tolling systems on

- Environment
- Congestion status
- Mobility and
- Socio-economy

4. REQUIREMENTS ON GALILEO FOR VEHICLE POSITIONING WITHIN DYNAMIC TOLLING SYSTEMS

The On-Board-Unit (OBU) within the vehicle detects when it enters, exits or passes a dedicated point on the road. This is achieved by a positioning system within the OBU (e.g. GNSS). The OBU needs an accurate and precise up-to-date map to do so. According to the position of the vehicle the OBU calculates the charge or stores/sends the bypassed roads. The data which must be sent to the road charging centre can be sent either by a continuously available connection (e.g. GSM/GPRS) or via a bypassing gantry [8].

For the process of Dynamic Tolling it might be necessary, that the vehicle's position is lane precise indicated within the OBU. For this geo-referencing the requirement on the longitudinal and transversal accuracy is +/- 1 meter. For this lane specific geo-referencing currently introduced methodologies like the map-matching process that is standard in existing Navigation Systems are not useable, because in this process the GNSS-position is switched to the logical position on the digital map of the Navigation System. To reach a lane specific position a matching process must be permitted.

The exact position elaborated by the Galileo-Receiver needs to migrated towards a real time system to the vehicles On-Board-Unit (OBU) where the vehicle position needs to be matched with the on-board map database as well as with the other OBU elements (e.g. communication gateway).

Current OBU-solutions will now match the elaborated exact position of the vehicle to the on-board map database. This process will currently produce a referencing error with up to 100 meters. So the OBU will switch the vehicle on the GIS-database to a wrong position which needs to be permitted in Dynamic Tolling Schemes. The fusion of the precise positioning data generated by the RPU into the on-board map database must be enabled. The currently existing limiting factors for a precise positioning in the map database are:

- The accuracy of the on-board map
- The content of the on-board-map

4.1.1. ACCURACY OF ON-BOARD MAP DATABASES

Every map is only a generalised picture of the reality. In current used on-board-map-databases the whole navigable geometry is represented a centreline of the road. Herby the shape of the road is followed by nodes and shape-points that are connected by links. One problem in this approach is the definition of the centreline (e.g. at huge junctions, at places, is the hard shoulder part of the road?). Here a clear and unique definition that is approved by the navigable map producers would be required.

But even if then the current used coordinate system reduces the accuracy of the navigable map databases. The whole points (nodes and shape-points) of navigable maps are referenced to the WGS84 coordinate system, where the accuracy of the coordinates has currently 10 micro-degrees. This relates in Central Europe to an accuracy of approximately 1.1 meters transversal and 0.7 meters longitudinal [9] As it can be seen, here the transversal error is higher that the requirement of 1 meter necessary for lane specific positioning.

4.1.2. CONTENT OF ON-BOARD MAP DATABASES

The second limiting factor for lane specific positioning is the content of on-board map databases. Current maps are optimised for navigational issues without lane specific advices. But with the introduction of ADAS (Advanced Driving Assistant Systems) services in the last years also the content of the maps became enlarged for the main road network and for large urban junctions. Hereby the number of lanes is stored as attribute to the single links of the map database for motorways and the main road network.

Figure 5 map representation of the “extended number of lanes” concept [10]

In the last years also maps with the “extended number of lanes” are available that indicate the exact number of lanes with the additional indication of exit lanes along motorways and turn lanes at huge junctions. Additional restrictions for lanes are indicating special users (e.g. bus lanes, HOV lanes) or time restrictions (e.g. closed for all except buses from 8am to 10am). These attributes help to improve the map content.

Additional efforts need to be taken to improve the quality of the navigable map-database:

- Unique definition of the centreline of the road
- Enhanced accuracy of the coordinate system
- Upgraded road-model with a more reliable geometry

These enhancements of existing map models to support a lane specific positioning are very complex and it is unrealistic that the whole map model will be changed, which would need a complete new collection of all geometry including all attributes.

Therefore it is necessary to develop methods to increase the map referencing process to enable lane specific Dynamic Tolling.

One possibility to increase that map referencing process is the calibration of the positioning and map-referencing-process at gantries (figure 6). In this approach lane specific information about the current real position will be sent via infra-red communication from the road operator to the vehicle. With this lane-positioning-information the on-board-equipment gets the possibility to calibrate itself. Of course, this communication link can also be used for the transmission of safety related information.

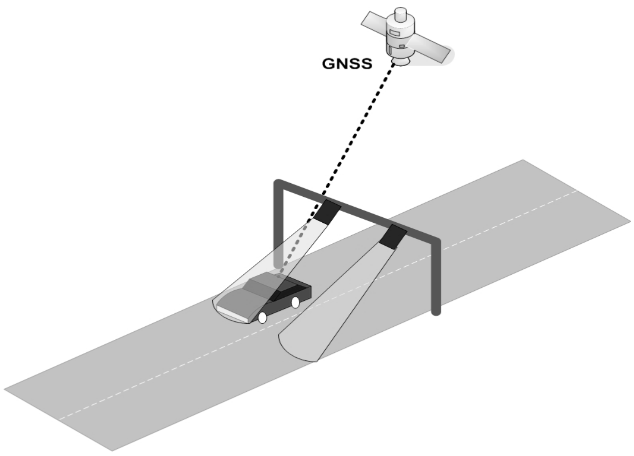

Figure 6 lane specific positioning by calibration of the OBU at gantries by using infra-red-communication.

5. POSSIBLE IMPACT OF DYNAMIC TOLLING

If described requirements on the map matching process are solved, it can be expected that the introduction of Dynamic Tolling will have a major impact in the mobility behaviour of fleet operation as well as of single drivers. Hereby fleet operators will react immediately on the new tolling schemes in order to optimise the costs for their truck fleets. This optimisation might result in

- changing of driving times
- changing of routes (ecological sensitive regions will be by-passed)
- changes in the vehicle fleet (with reductions in emissions, particles, etc.)
- reduction of deadheads, where empty trucks are driving from A to B

This will result in more fairness in competition as cleaner (and more expensive) trucks will benefit from Dynamic Tolling.

It seems to be logical, that not all results will be valid also for the private drivers, as e.g. the day-to-day traffic to work will not change the driving routes. But there might be changes in driving behaviour by promoting car pools and herewith reducing costs. Additionally also for the private drivers changes to cleaner vehicles will be fostered.

These changes in the mobility behaviour will decrease the negative impacts of road traffic on the environment. In this context the environment covers both, road network and natural environment:

- There will be less congestions along the road network, leading to enhanced traffic safety. In parallel the use of the road infrastructure will extremely be influenced by Dynamic Tolling by supporting traffic management.
- But major impact will be on the natural environment by reducing
  - pollution,
  - particles,
  - CO2 emissions,
  - noise, etc

One of the most important assumptions of Dynamic Tolling must be in the socio-economic compatibility. It must be ensured that the fairness for the use of the resources road and environment will not result in socio-economic pressures.

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