BENCHMARKING FOR ROBUST POSITIONING IN eSAFTY APPLICATIONS ON ROAD NETWORCS

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Abstract

At this paper there were described properties of powertrain with diesel engine and CVT transmission. At this system, engine load is not directly proportional to acceleration pedal position. Position of this pedal is only interpreted as the driver will, about demanded vehicle speed, and the way of achievement of it (dynamic, economic drive) in other word strategy choose. Nowadays ecologic conditionings, it means EURO 3,4,5 standards, requires from drive strategies to be ecologic. Decision of shift value and engine load (proportional to fuel dose, 100% for maximal dose) is elaborated at primary controller, in spite of driver, enabling economic and ecologic powertrain work. CVT transmission introducing additional degree of freedom to powertrain facilitate above steering strategies realization. Presented system has possibility, within the framework of possessed degrees of freedom, the realization of the modes of economic drive or dynamic drive. Assuming given acceleration in vehicle impetus gaining cycle, system is in possession of only one degree of freedom (the point of the constant angular engine speed) limiting the performance of system in optimum areas (proportional participation of PHASE II in all vehicle impetus gaining cycle). Advantages resultant from the above mentioned control method are particularly visible in the vehicle impetus gaining cycle, to the speed of 15 m/s, characteristic for the municipal conditions. For proposed control variant with „test 150" one is observing the lowering of the fuel expenditure and also lowering of toxic elements exhaust emmisions. In the case of the emissions, decrease was at the level of 28% in comparison with the worst variant (regarding to this criteria) „test 315"; for cruise expenditure of fuel we obtain decrease about 17% for analogous tests.

Keywords: *global positioning system, inertial positioning, vehicle position testing equipment, Intelligent Transport Systems*

SYGNAŁ REFERENCYJNY W ZASTOSOWANIU DO eSAFTY W SIECIACH DROGOWYCH

Streszczenie

W pracy zaprezentowano własności sterowania układu napędowego pojazdu z silnikiem o ZS i przekładnią bezstopniową CVT. W tym układzie, obciążenie silnika nie jest wprost proporcjonalne do położenia pedału przyspieszenia. Położenie pedału przyspieszenia jest interpretowane jako informacja o woli kierowcy, o zadanej prędkości pojazdu i sposobie jej osiągnięcia (jazda dynamiczna, ekonomiczna), czyli wyborze strategii jazdy. Obecne uwarunkowania ekologiczne tj. normy EURO 3,4,5, wymagają by odpowiadające im strategie jazdy były realizowane ekologiczne. Decyzja o wyborze przełożenia i stopniu obciążenia silnika (proporcjonalnym do wielkości dawki oleju napędowego, 100% dla dawki maksymalnej) jest podejmowana w sterowniku nadrzędnym, poza kierowcą, pozwalając ostatecznie na ekonomiczną i ekologiczną pracę całego układu napędowego. Przekładnia CVT wprowadzając do *układu napędowego dodatkowy stopień swobody ułatwia realizację w/w strategii sterowania. Prezentowany układ ma możliwość, w ramach posiadanych stopni swobody, realizacji trybów jazdy ekonomicznej czy dynamicznej (tabela 2 próba 150 i 315). Przyjmując zadane przyspieszenie w cyklu rozpędzania pojazdu, układ posiada tylko jeden stopień swobody (punkt stałej prędkości kątowej silnika) ograniczający pracę układu w obszarach optymalnych. (udział procentowy FAZY II w całym cyklu rozpędzania). Korzyści wynikające z powyższego sposobu sterowania są szczególnie widoczne w fazie rozpędzania pojazdu, do prędkości 15 m/s, charakterystycznej dla warunków miejskich. Dla proponowanego wariantu sterowania z „próbą 150" obserwuje się obniżenie zużycia paliwa a także toksycznych składników spalin. W przypadku emisji spadek ten wyniósł 28% w porównaniu do najgorszej pod względem tego kryterium wariantu tj. „próby 315"; dla przebiegowego zużycia paliwa uzyskujemy zmniejszenie o 17% dla analogicznych prób.*

Słowa kluczowe: *system nawigacji satelitarnej, pozycjonowanie inercyjne, aparatura badawcza do określania pozycji pojazdu, Inteligentne Systemy Transportowe*

1. Introduction

The focus of the COOPERS project is on cooperative telematic systems that enable an infrastructure to vehicle (I2V) interaction, in order to enhance safety on road networks. The communication of safety relevant information on traffic, weather and road condition ahead, to the driver via an adequate human machine interface (HMI) will be the main innovation, to contribute to the defined target to establish and demonstrate new services for eSafety on road networks. In this regard, the functionality of position determination forms an essential part of the required information, to support the process of decision making of each driver, to gain a higher level of safety. Therefore a robust positioning unit (RPU) will be developed by pwp-systems, to cope with the advanced requirements of the COOPERS-services for eSafety applications. A special development environment is currently being set up to include Galileo signals into the RPU algorithm already today. This approach supports either the introduction of Galileo into the world of traffic applications and allows the user to get hands on the benefits generated for the individual operational constraints in the respective applications.

The assessment of the technical performance of the RPU will be executed by the TU of Lodz as a neutral instance for this task. In order to quantify the remaining error behavior of the RPU by measurements, hard facts will be generated for the process of the technical assessment. This requires the application of costly high performance sensor equipment during the execution of the test trials and in parallel to the operation of the RPU itself in the concept car. On the basis of these measurements a so called reference trajectory is generated by the TU of Lodz. The output of the RPU can then be compared against this reference trajectory and will be analyzed within the assessment process The description of this task of the reliable generation of a highly accurate reference trajectory and its integration into the technical assessment will be the main focus of the current paper.

2. Application for eSAFETY

The main focus of COOPERS is on motorways and corresponding services are set up to inform the driver quickly on dangerous situations ahead. Consequently several situations may arise, where recommendations are generated, to leave the motorway and follow a re-routed pathway including secondary and urban roads. The COOPERS-demonstrator in the region of Darmstadt has its focus on such a service of „Adaptive speed limit warning and curve warning on secondary roads".

The analysis of relevant reports shows that a high number of fatalities are caused by accidents on secondary roads. Two main factors have been identified, that are responsible for the event of the accident. Especially on weekends the influence of alcohol has been recognized as a major influence and this deficit in the behavior of drivers needs to be cured with educational measures. But another dominant factor has been detected, when the driver does not know the track and under estimates the condition of the road, the strength of a curve and his own speed.

With the improved information on motorways through COOPERS equipment and the resulting advice to leave the motorway, because of certain incidents, the driver could come exactly into such a situation. If this coincides with bad weather conditions the risk of unknown terrain is even worse through the reduced visibility conditions. The implementation of this service into an application combines the robust positioning property of the RPU, with advanced road data basis. With the development of a special algorithm, the driver should be provided with adequate warning, when the current speed is too high for the trajectory of the road ahead.

Taking this basic functionality this service can contribute to road safety as a stand alone driving assistance system and this basic level of service (LoS) shall be realized with the prototype setup in the concept car containing the scientific platform for the assessment of Galileo benefits for this application. This is an in vehicle based application with the combination of the RPU and advanced road databases.

With the available communication technology inside COOPERS and the provision of advance traffic information, this service can certainly be enhanced to a higher LoS. If the weather information is e. g. capable to provide reliable information on areas with iced road surface, this feature could be integrated. Another improvement or LoS could be generated, if the sensor information of the vehicles on secondary roads is used to derive appropriate messages on degraded road conditions, which can then be re-distributed to other traffic participants.

3. The Coopers Concept Car

The individual Coopers services have different requirements towards the performance of the positioning task. Every service has its specifically own requirements with respect to the positioning performance, but not every service can be equipped with an own positioning unit. Consequently the development of the RPU has to be executed in a sense to fulfill all the requirements in one unit.

Besides the often discussed aspect of the required position accuracy, the attention has to be drawn to the important aspect of reliability as well. In this regard the property 'robust' stands for high accuracy, but also for high availability and integrity in one unit. The approach is to develop a fault tolerant system, which can overcome the deficiencies of single sensors. Therefore we deploy satellite navigation with on board sensors from the vehicle. Such sensors are available in modern cars and shall be integrated via CAN-bus.

a. Provision of real sensor data measurements from the RPU

Within the COOPERS-approach a hybrid navigation system combining GPS, differential odometry and dead reckoning will be developed by pwp-systems. Therefore a concept car has been selected with the technical capability to provide all the required information from on board sensors inside the car. Further it has been checked, that this data is available via the open CAN of the test vehicle and can be taken via a passive CAN interface, which is only listening to the data stream, but not sending any information. This concept car is depicted in Fig. 1.

In the intended approach, the RPU consists of a measurement acquisition system, which is based on a commen mico-controller and has a modern, but low cost GPS module on board, with WAAS/EGNOS capability. Since the test vehicle is equipped with several sensors, the sensor assembly is already complete by the provision of the CAN interface. In order to compare the yaw rate information, which can be derived from the ESP-system, a separate vibrating structure gyro is also incorporated on the controller board.

b. Data recording for the integration of Galileo signals

The capability of proper data recording is a prerequisite for the execution of the methodology for the integration of Galileo signals into the conducted test trials. The measurements will be acquired in real life test trials with the described concept car. This vehicle has been especially equipped with the scientific platform for the development of the RPU. The measurement acquisition system includes the provision of measurements from a GNSS module, a vibrating structure gyro and a CAN bus interface for further sensor access to the on board sensors of the car.

Fig. 1. COOPERS-Concept-Car for the development of the RPU
Rys. 1. Samochód koncepcyjny projektu COOPERS do badań jednostki RPU

c. Data recording for the integration of Galileo signals

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The aspect of synchronization is very important for the further data processing, thus time information becomes part of every sensor data record in the form of a time stamp. This time stamp should not exceed a relative error of 10 milliseconds with respect to a common clock (e.g. the GPS clock which is very accurate). In this time threshold all the possible delays from the data acquisition at the physical sensor have to be incorporated.

If the processing time of raw measurement needs a longer time period for whatever reason, these additional delays should also be quantified with an accuracy of 1 millisecond and come as part information together with each measurement.

4. Reference System

For the correct and precise determination of the performance of the RPU during kinematic test trials with the concept car a reference system is necessary that operates at the same time reference as the RPU. For this task a SPAN system (Synchronized Position, Attitude, Navigation) will be applied by the TU of Lodz. The core of the SPAN (see Fig. 2)system is an inertial navigation unit (INU), which is combined with an external odometer providing 1000 increments resolution from the wheel revolution of the concept car. The good quality of the odometer signal can limit the immanent drift of the INU already significantly. In addition the GPS information of a NovAtel receiver is used as aiding information to provide highest accuracy of the differential GPS with the reliability of an odometer aided INU.

Installing the development environment for the RPU into the concept car in conjunction with the sensor equipment of the reference system, an appropriate power concept has to be planned, to ensure proper operation of all the components. The INU must be powered with voltage from + 10V to + 34 V and requires an own traction battery, which must be mounted according to general goods transport laws inside the concept car.

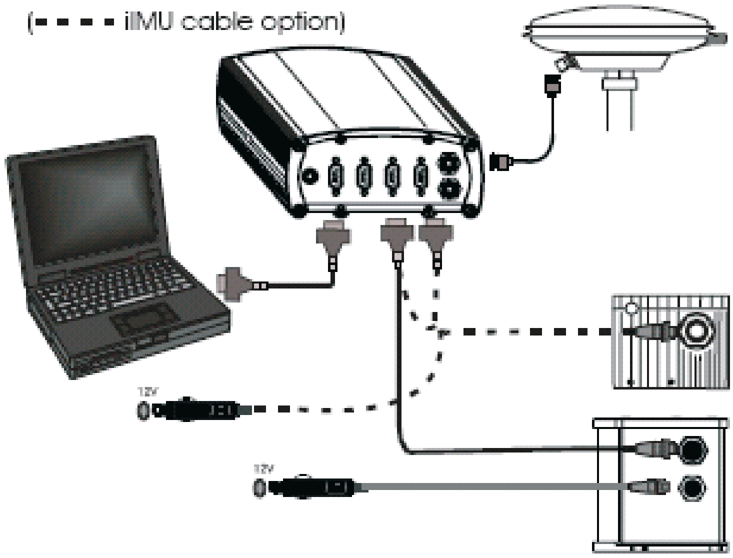

Fig. 2. SPAN connection scheme [4]
Rys. 2. Schemat podłączenia układu SPAN [4]

For the signal flow, the system has been configured, that the position is calculated inside the GPS receiver. Thus the measurements from the gyroscopes and the accelerometer have to be fed into the GPS receiver. When the GPS signal is insufficient, the position determination can be executed with the compensated INU measures. According to relative position description by the INU, the position must be calculated considering the last good position from GPS - absolute position. When the GPS signal is recovered, position is based on GPS signal again. Because of the gyro drift (0.75 deg/hour), the dominant INU error depends directly and proportion to time. While the GPS signal reception is good, the resulting gyro drift is compensated through the use of this aiding information. The connection scheme in Fig. 2 shows, that only the GPS receiver is connected to the computer for recording of the measurements. Partition of priority between GPS and INU is made at the GPS receiver (PROPAK V3).

With respect to the proper signal transmission, the cable length should be minimized to avoid unnecessary influence from disturbance sources inside the car. Furthermore the high cost of sensor equipment motivate additional precautions from technical threads, like e.g. strikes, humidity and temperature changes. To ensure save operation, the equipment was packed to two cases. Thanks to that transport and mounting of equipment is easiest, units are provided for mentioned emergences, as it was shown in Fig. 5. The mounting elements of the reference equipment has been prepared in a way, to support installation at many cars. As shown in Fig. 3 the equipment can easily be serviced. Since the two cases are equipped with two PC ventilators, the valuable components are also protected against over heating even under summer conditions.

In addition to the GPS/IMU combination, a wheel pulse transducer (WPT) is connected to the SPAN as odometer. The WPT comes from Corrsys Datron and states major and accurate equipment for the measurement of the wheel revolution in automotive industry. The information about the angular wheel velocity (wheel distance at time) based on the WPT measurement limits the evolving drift of the SPAN significantly. Thus the WPT is used, in the same way as aiding information as the GPS signal, to reduce the drift influence towards the position calculation of the SPAN. The absolute position can be corrected using relative change of positions based on WPT.

Fig. 3. Testing equipment mounted at the testing vehicle
Rys. 3. Zestaw pomiarowy w samochodzie badawczym

In Fig. 4 the positive influence of the usage of the WPT, can be recognized. The position error can increase even to 1 meter during two phase calculation algorithm after 60 seconds of measurements. The usage of the WPT limits the position error. For the case of a two phase calculation, the position error can be limited from 1 meter down to 0.5 meters.

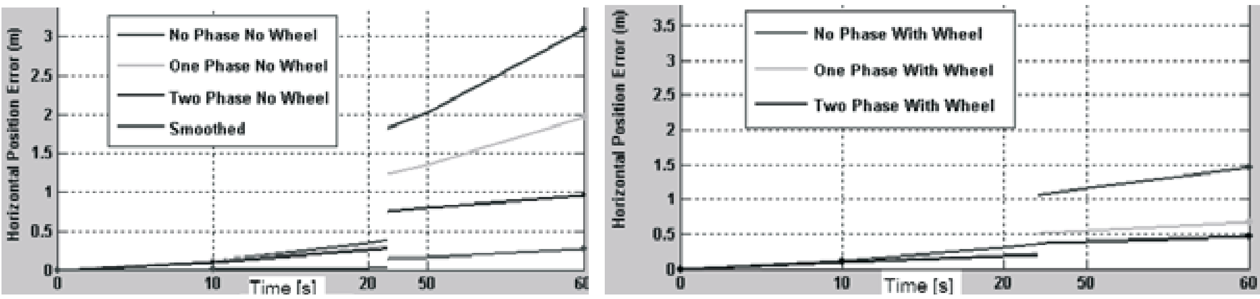

Fig. 4. Position error growth over GNSS outages without and with WPT [3]
Rys. 4. Przebieg zmiany błędu pozycji podczas zaniku sygnału GNSS z I bez czujnika WPT [3]

As it was shown, the application of a WPT to the SPAN system can reduce position error even to 50%. Generally, manufacturer estimated WPT position error reduction on the level from 5% to 20% [6].

5. User Interface

The interface of hte SPAN system is kept quite simple and has a similarity with the view of cockpit instrumentation. This comes with the fact, that such costly equipment is rather used for aviation, than for land transport. This shows the high reliability that comes with inertial sensor systems und proofs again the this high effort is appropriate, in order to generate a reliable reference trajectory for robust positioning applications like the COOPERS-services.

The layout of the interface of the SPAN comes as 32 bit Windows application. The application provides a graphical user interface to allow the operator during the test trials, to set-up and monitor the operation of the SPAN system by providing a series of windows. The details of Fig. 8 can be divided into four categories:

- The position, velocity and attitude (roll, pitch and azimuth).
- IMU status (INS_INACTIVE,INS_ALIGNING, INS_SOLUTION_GOOD, INS_BAD_GPS_AGREEMENT, INS_ALIGNMENT_COMPLETE) [9].
- local date/time information
- The dial is a graphical display of the roll, pitch and azimuth values indicated by an arrow on each axis.

During the operation of the SPAN system the following messages are provided at 2). INS_SOLUTION_GOOD (move the vehicle), which requires special trajectories (e.g. a full circle to the left) for the right excitation of the individual sensors, in order to calibrate the error modals for the finite alignment procedure.

6. Comparison Of Gps And Span System Based On Journey At Tu Of Lodz Campus

In Fig. 9 the measurements made by GPS and the INU technology are shown. The settings were the same for each system. GPS data was collected using "#BESTGPSPOSA" log, and the INU data by „#INSPOSA". The results of the mentioned tests are shown in Fig. 10. The points represent estimated positions of the car using only GPS technology. At the shown trajectory, 23% of the position fixes were insufficient with respect to the accuracy. The main problems were outages in the reception of satellite signals. They are caused by so called „city canyon", made by: trees, bridge, flyovers and buildings in the neighborhood. City canyon, block or degreases the power of the GPS signal that finally gets to the moving antenna of the test vehicle. Consequently the number of visible satellites is reduced and can drop below four, which means a three dimensional position calculation is not possible.

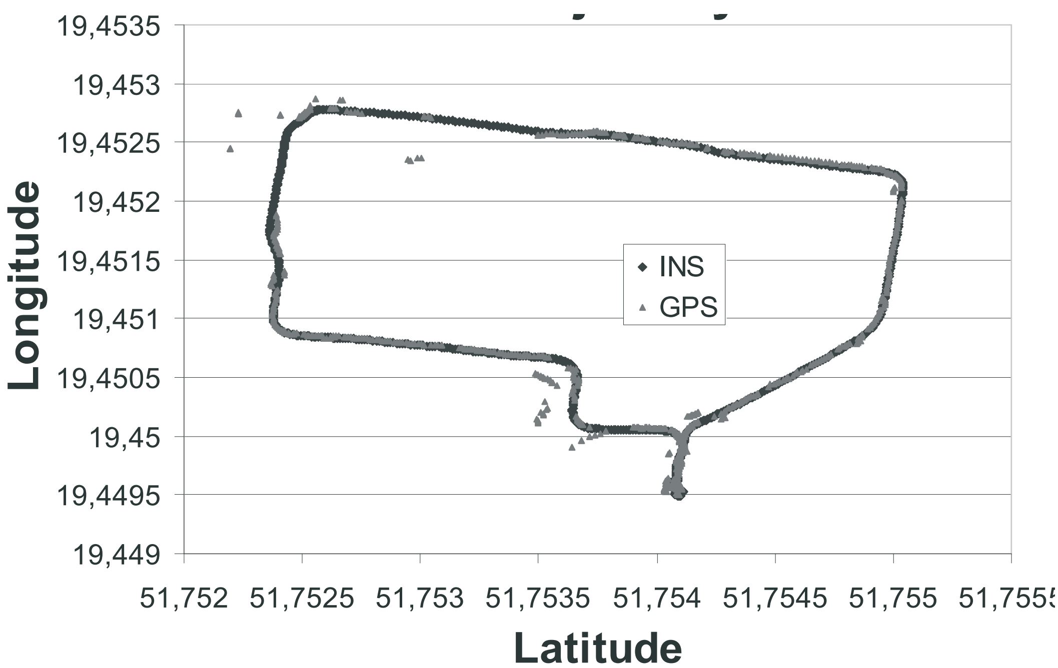

Fig. 5. Vehicle trajectory calculated by GPS and SPAN system
Rys. 5. Trajektoria ruchu pojazdu wyznaczona w oparciu o systemy GPS I SPAN

The dark points of the trajectory show the vehicle positions determined by the SPAN technology. As one can see, there are no problems like the ones mentioned above. The position is calculated at every time step and the position is determined with a higher accuracy. The SPAN technology is not sensitive towards GPS signal losses. Thanks to that capability, it becomes possible to localize the vehicle also in critical environments, like city canyons, tunnels, etc., what was impossible for GPS technology as stand alone system. In addition to the significant improvement of the reliability, the SPAN system enables higher accuracy for the position fixes as well. Those tests confirm the legitimacy of the extension of the measurement spectrum from GPS to inertial sensors.

7. Road Investigations

There will be described road investigations from Cracov. According to the possibility of making tests at Cracov, the following test trials have been conducted:

- System test at Cracov with urban-canyon
- compare position calculation using GPS and SPAN

In the following picture 6 will be presented which show zoomed elements of the described trajectory. It Should be remembered that here are serious mistakes at position calculation by only GPS procedure. With such results it becomes impossible to implement new services to enhance safety on urban roads.

Fig. 6 shows zoom of the journey at centre of Cracov at a section containing a tunnel. It is the second main area, where the operation of GPS as sole means shows problems. GPS signal is totally lost inside the tunnel and there is no possibility to localize car. When the car drives out of the tunnel, it takes some time to turn back at the traffic circle, until the GPS - signal can recover, but it gets lost again after the new tunnel entrance. When the car leaves the tunnel, only the GPS system need a while to „see" more than three satellites and deliver positions again. It looks quite different for SPAN technology, which is independent of environmental influences, like outages.

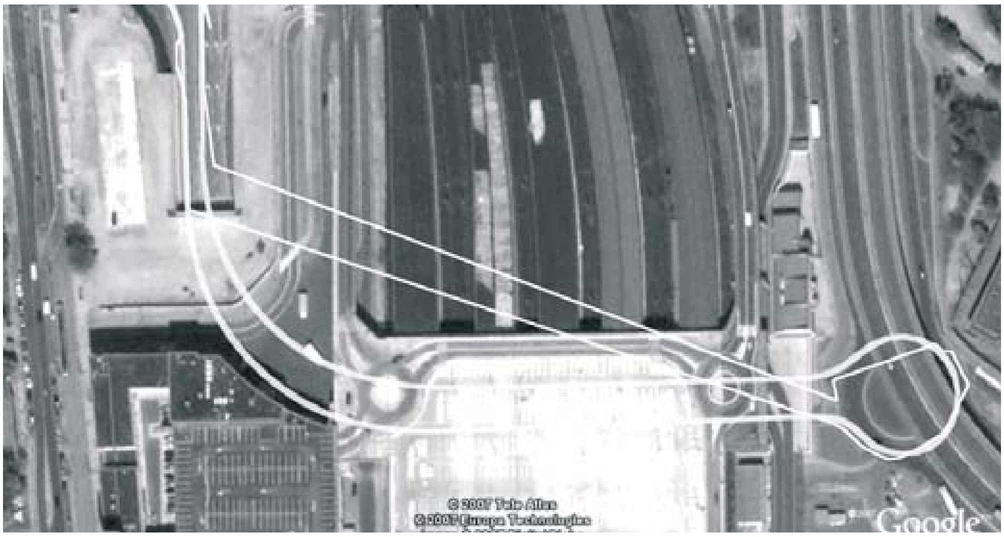

Fig. 6. Zoom of cente Cracov journey at tunel, wider line -GPS, narrow line- SPAN [2]
Rys. 6. Zbliżenie przejazdu w centrum Krakowa w tunelu, grubsza linia - GPS, węższa linia - SPAN [2]

The last zoom from this test trial is presented in Fig. 13, which shows the influence of outages in the neighborhood of trees. As we can see, also trees can cause problems for the task of position determination. It is faintly know, that trees have so much influence for accuracy at GPS positioning.

8. Conclusion

Generally, there are many new possibilities at objects trajectory measurement caused by SPAN system. Proposed research equipment seems to be very useful at vehicle tests. The main advantage is the independence from external signals. Second advantage is the easiness of application to any vehicle or airplane.

The application of such costly equipment is valuable to enable an assessment process, based on hard facts. With the rising requirements on positioning tasks form traffic applications, better benchmarks are essential. Currently the definition of such benchmarks is still missing, but with the provided equipment in the concept car, COOPERS will provide first steps towards a benchmarking of eSafety services.

References

[1] *Tachograph information* http://en.wikipedia.org/wiki/Tachograph
[2] Lipiński, E., *Novatel Span training materials*, http://gps.pl/SPAN.html
[3] Kennedy, S., Hamilton, J., Martel, H., *GPS/INS Integration with the iMAR FSAS IMU*, http://gps.pl/arch/SPAN_INTERGEO_2006.pdf
[4] *OEMV Family, Installation and Operation Manual*, www.novatel.com.
[5] *GPS + Reference Manual*, www.novatel.com
[6] *iIMU-FSAS-SI/-EI Inertial Measurement Unit with Multiplexer Fiber Optic Gyros and Servo Accelerometers-Interface Description*, www.imar-navigation.de
[7] Kennedy, S., Hinueber, E., *Integration of Inertial Measurement with GNNS – Novatel SPAN Architecture, Symposium Gyro Technology*, Stuttgart 09/2005, www.novatel.com
[8] *Waypoint products groups Novatel precise positioning products- Inertial Explorer - user guide*, www.novatel.com
[9] *SPAN Technology for OEMV - user manual*, www.novatel.com
[10] *Incremental Wheel Pulse Tranducer*, www.corrsys-datron.com.
[11] *COOPERS Project information*, www.coopers-ip.eu