A FINAL TECHNICAL REPORT ON THE BELGIAN INTELLIGENT SPEED ADAPTATION (ISA) TRIAL

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CONTENT

SAMENVATTING

Vierendertig voertuigen namen deel aan het Belgische ISA-experiment in Gent. Het geteste ISA-systeem is “Limit Advisor M2002” van het Zweedse bedrijf Imita. Een honderdtal ervan werd al getest bij andere Europese experimenten. Het systeem voldoet aan sommige EMC-reglementeringen en functionele veiligheidstests. De “Limit Advisor” kan worden geïnstalleerd in de meeste wagens, op voorwaarde dat er genoeg ruimte is onder de motorkap en dat het gaspedaal de geschikte geometrie heeft. De voornaamste ondervonden problemen hadden te maken met de ontoereikende logging tool, de slechte mechanische betrouwbaarheid, de beperkte capaciteit van de digitale kaart en de verschillen tussen de werkelijke situatie en de aangegeven lokale snelheidsbeperkingen.

ABSTRACT

Thirty-four vehicles participated to the Belgian ISA trial around the city of Ghent. The tested ISA device is the "Limit Advisor M2002" from the Swedish company Imita. Hundreds of it were already tested in other European trials. It complies with some EMC regulations and functional safety tests. The "Limit Advisor" can be installed in most cars providing that enough space is present under the bonnet and that the gas pedal articulation is appropriate. Main issues encountered are the deficient logging tool, the poor mechanical reliability, the digital map's small capacity and discrepancies between the real world situation and the retrieved local speed limits.

1. INTRODUCTION

Between October 2002 and December 2003, an ISA (Intelligent Speed Adaptation) trial took place within an area of approximately 8 x 4 sq. km in the city of Ghent, Belgium. All speed limits were represented within the area (15, 30, 50, 70, 90 and 120 km/h). The test fleet comprised twenty private cars, fourteen company cars and three city buses. The main objectives of this project are to assess the technical and legal aspects of the tested ISA device, and of ISA in general, as well as its impact on road security, driver behaviour and car emissions. This paper summarizes the results of the technical evaluation of the tested ISA device. It also compares them to the technological features of some of the most important ISA trials across the world and concludes with the future technological challenges of ISA.

The tested ISA-device is the *Limit Advisor M2002* developed by the Swedish companies Imita AB (system integrator) and Wayfinder AB (navigation unit, data recorder). Similar devices were used in Lund, Sweden (450 units between 1999 and 2002, (2)) and are also tested nowadays in Norway, Hungary and Spain. The *Limit Advisor* belongs to the semi-open static class of ISA systems. Static like the on-board digital map because it can be updated offline only. Semi-open because the driver interaction is not just a warning but also interferes with the vehicle's working through a harder gas pedal. This interaction is also called *active accelerator* or *haptic gas pedal*.

2. TECHNICAL EVALUATION

By technical evaluation, we mean, for each component of the *Limit Advisor M2002*, a short description, an assessment of the technical limits encountered (i.e. accuracy, store capacity, etc), the efficiency & reliability of its working (i.e. breakdowns, wear, etc), the compatibility with cars on the market, etc. The main components of the Limit Advisor are the GPS antenna, the navigator, the control unit (CPU), the odometer, the mechanical unit, the display and the data logger.

A. GPS ANTENNA

The GPS antenna receives the signals from the GPS constellation and transmits them to the receiver unit. The ideal position for a GPS antenna is the car rooftop (6). For practical reasons, the antennas were installed inside the passenger compartment, which reduced the reception quality. The best places are across the front dash (right under the windshield) or on the rear deck. There was no reported technical problem related to this component.

B. NAVIGATOR (GPS RECEIVER, DIGITAL MAP, SOFTWARE)

The navigator is a multifunction unit including the GPS receiver, the digital map data and the associated software (map-matching, dead reckoning, etc.).

C. Limits

Despite the fact that frequency and duration of the GPS signal losses could unfortunately not be derived from the logged data, 70 % availability in time can be accepted as a rough estimate (3). With a unidirectional speed limit as sole attribute, the map's maximum capacity was around 7000 road segments, which is few even for the relatively small area tested (8x4 sq. km.). Other conditions on segment's maximum length (500 m) and curvature were also given. The definition of a 50 km/h rectangular area with a constant speed limit (bounding box) helped lowering the amount of segments in the city area. Unfortunately, within this bounding box, many unexpected 50 km/h segments had to be added because of the slow (several seconds) retrieval time of the bounding box default speed limit (50 km/h) after a driver left a non 50 km/h segment road. The absence of online update possibility is another limitation of all static digital maps since the design and the speed limits of the road network quickly get obsolete.

Efficiency & reliability

Most users reported in the cars' logbooks several inconsistencies between the real world speed limit and the one retrieved by the ISA device. Usually, the reported inconsistency was an ISA speed limit smaller than the real one (danger perception), which probably means that many less critical discrepancies (i.e. speed limit greater than reality) were not mentioned. Main reasons of these reports are the retrieval of a wrong road segment (with another speed limit) due to the positioning inaccuracy, the road density and/or the map-matching algorithm, a wrong speed limit attribute in the database or a change in the road network speed limits since the last map update. Although no data were logged in order to evaluate the GPS accuracy, the GPS availability and the map-matching efficiency, a one shot experiment made with an on-board digital map live creation software confirmed the 25 m horizontal positioning accuracy specified by the GPS receiver manufacturer (15) in absolute mode. As a consequence of the above positioning accuracy, all motorway road segments within the test area were flagged with a 0 km/h attribute (instead of 120 km/h in Belgium), which deactivated the driver's interface on those segments for safety reasons.

There are several ways to improve the GPS accuracy and availability. When the signal is available, implementing the differential GPS technology delivers a ten times better accuracy. Driving in tunnels, urban canyons or under trees can however lead to signal losses. In this case, an inertial navigation system (INS) can compensate for the GPS outages for a limited time period whose length depends on the INS time drift. Low costs INS are called dead reckoning (DR) systems. Instead of a high quality gyroscope (direction changes) and accelerometers (distance changes), the Limit Advisor's DR system uses a basic gyroscope in conjunction with the car odometer, which means it has a much higher time drift - and thus shorter accurate working time - than an INS device. Using a higher quality gyroscope and an increased amount (or quality) of input signals (steer angle sensor from the car, accelerometers) could therefore improve the GPS availability and accuracy during signal outages. A compromise should be found between the sensors price and the expected accuracy.

The map-matching algorithm could also probably be optimised in order to shorten the processing time and to minimize the confusion between neighbouring road segments at critical places (motorway interchange, multi level crossings, etc.).

The map and the data logger used (X, Y) coordinates derived from a projection of the 3D coordinates in the Swedish RT90 reference ellipsoid. This is a heritage of the past, i.e. the 1999 Lund trial with the same positioning unit. Although this choice is neither logical in Belgium, nor in the rest of the world except Sweden, especially because global WGS84 is available as standard GPS output and can be used worldwide, it probably did not impact much on the positioning accuracy and the recorded data analysis. On the one hand, the announced extra (above GPS) accuracy loss due to the plane projection of RT90 coordinates in the Ghent area should be, according to unit manufacturer, around 1 m (<< absolute GPS accuracy). On the other hand, the data analysis only required the relative distance between successively logged points, which eliminated the main part of the (systematic) error.

D. CPU-BOX

The CPU box is an electronic board communicating with the navigator, the display and the servomotor. Along with the navigator (positioning unit), it was usually installed under the dashboard or behind the gearbox lever. The proper (invisible) installation of both components thus requires a minimum free space inside the passenger compartment. There was no reported technical problem related to this component.

E. ODOMETER

The odometer or pulse counter is a sensor measuring the vehicle speed and the covered distance. It is standard equipment in nearly all vehicles but is not always compatible with the Limit Advisor's specifications.

Limits

Using the odometer's sensitivity (pulses emitted per unit of distance), the measured pulse rate while driving allows the CPU to calculate the distance and speed. The manufacturer specified minimum values of the odometer pulse DC amplitude (4V PTP) and the amount of pulses (>1800 pulses / km).

Efficiency & reliability

The odometer sensitivity played a role at two levels of the *Limit Advisor* : at the functional level (as a speed limiter) and at the logging level (as a data recorder). Two sensitivities were therefore required : a functional one needed to trigger the active accelerator as soon as the vehicle's speed exceeded the retrieved local speed and an analytical one used to log continuously the data. Each sensitivity can be calculated using either the actual speed or the speedometer speed as a reference. Choosing for the actual speed allows the sensitivity to be corrected by on board GPS measurements (i.e. dynamic sensitivity), which means a very high accuracy but introduces a discrepancy between indicated speed and ISA triggering, which could influence driver's perception. Choosing for the speedometer speed however minimizes driver perturbation but doesn't allow the GPS correction (i.e. static sensitivity) because the (unknown) deviation to the actual speed varies with the vehicle, the speed and even in the time (tire wear).

In a purely functional ISA application (i.e. without data logging), the driver perturbation must be minimum and the calibration to the speedometer speed should be preferred. But in a study project with data logging, it is very important that the logged data match the reality, which implies that the functional and analytic sensitivities are equal. One should furthermore prefer a (dynamic) calibration to the actual speed if accurate data logging and speed comparisons between cars are required but a (static) calibration to the speedometer speed if human factors are dominating.

Trial	**Functional sensitivity**	**Analytic sensitivity**
Lund (1999-2002)	Real speed, static	Real speed, dynamic
Ghent (2003-2004)	Speedometer speed, static	Real speed, dynamic
Hungary & Spain (2003-2004)	Real speed, dynamic	Real speed, dynamic

In Ghent two different calibrations were used, which led to an unknown discrepancy between the logged speed and the speed at which ISA was actually triggering. The behavioural analysis a few seconds before and after an ISA triggering, for example, was much more difficult because the triggering instant could not be derived from the speed measurements.

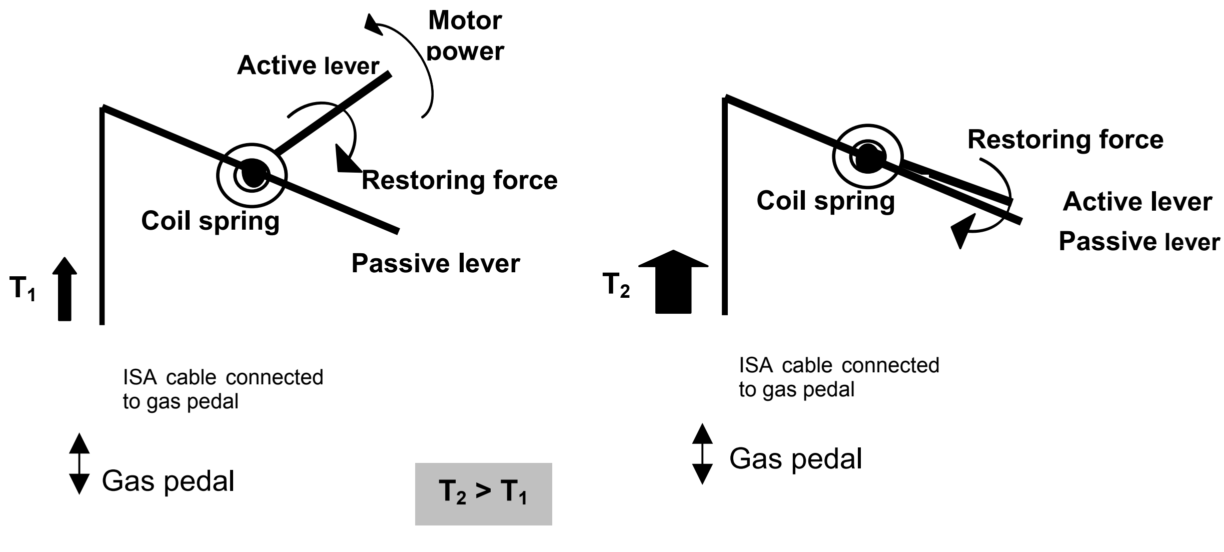
F. SERVOMOTOR (MECHANICAL UNIT)

The servomotor or mechanical unit regulates the accelerator's resistance.

Working principle

The default (i.e. without action of the motor or any other force) mechanical state of the *Limit Advisor* is represented in figure 2 : under the action of the restoring force of a coil spring, the so-called active lever pushes onto the passive lever, which creates a high tension (T2) in the cable connected to the gas pedal, making it feel harder. This happens when car ignition is off, car ignition is on and the CPU of ISA has detected a speed limit violation or when a breakdown or any other reason prevents the motor from transmitting its power to the active lever. The figure 1 represents on the contrary the state of the limiter when the driver respects the speed limit. In this case, the motor power neutralizes the coils springs restoring force, which eliminates the extra tension in the cable connected to the gas pedal, thus restoring the normal pedal "feeling".

It is interesting to note that the counter pressure is the default state of the limiter. We can raise the questions whether this is safe when the system is not working properly, since the driver has then to deliver a continuous extra physical load when driving his vehicle. A close look to the working principle can easily explain it : as soon as a speed limit violation is detected by ISA, the motor power is no longer transmitted and the active lever, under the action of the coil springs restoring force, hits within a fraction of second the passive lever, which creates the counter pressure with a very short response time. On the contrary, removing the counter pressure takes several seconds because the motor has to wind up the coil spring.



Figures 1 & 2 : The working principle of the mechanical unit

Note : the ISA cable connected to the gas pedal on the figures above is not the original cable connecting the gas pedal to the throttle, if any is present (cf. potentiometer and CPU technology). The ISA cable only connects the gas pedal to the ISA mechanical unit. In a former version of the same device tested in Lund in 1999 (named Nomix MAC, (2)), the original cable was interrupted and the mechanical unit was situated between the gas pedal and the throttle. Doing so, beside the ISA capability, a cruise control function was offered as an extra to the driver. This configuration led to insensibility of the gas pedal and uncomfortable time delay between pedal movement and motor action (2). It complied nevertheless with the functional safety tests conducted by a Swedish official testing institute (SP).

Limits

The feedback to the driver is a counter pressure in the gas pedal. This pressure is constant and can neither be adjusted statically (to the driver's strength) nor dynamically (a pressure proportional to the difference between the actual speed and the speed limit). More and more new cars have their gas cable replaced with a potentiometer and CPU. Depending on the pedal hanging and the free space under the bonnet it is sometimes impossible to install the Limit Advisor in either used or new cars or vans. According to a listing made by IMITA, around 50% of the cars on the 2002 Belgian market would be suitable for an installation of the Limit Advisor M2002, 25 % would be less suitable (problems expected) and installation is not recommended in the remaining 25%. Among the latter are old, new, lower class and higher class vehicles.

Efficiency & reliability

Among the 37 participating vehicles and within the 14 months of the trial, eight servomotors (four among them in the three city buses) had to be replaced, which represents more or less half of the total amount of technical interventions. The reason why they all had to be replaced is the continuous presence of the counter pressure in the pedal (see working principle). We dismantled six out of the eight units in order to find the origin of the breakdown. The main problem seems to be an excessive wear in the synthetic gears transmitting the motor power. It mainly occurred in vehicles with an intensive usage (city buses or private cars with a high yearly mileage). We also observed two gears sealed to each other as if they underwent a high mechanical pressure (and/or temperature) and even a broken coil spring. In two units, installed in private cars with low usage, the gears were looking fine, and we think the motor itself could have been defective because in one of them, a power cable was broken.

What are the factors contributing to the observed mechanical wear and/or breakings ?

- The vehicle usage : yearly mileage, fraction of urban drive, personal driving habits
- The vehicle type : breakdown rate is much higher in city buses ; beside their intensive usage, let's point out the larger gas pedal that can lead to a higher tension in the ISA cable
- Synthetic (instead of metal) gears
- The mechanical fatigue inherent to the working principle : shocks between the active and the passive lever every time a speed violation is detected and thus the device triggers

Newer versions of the Limit Advisor are tested in 2003-2004 in Hungary and Spain with some technical improvements (motor, shocks reduction). A short description of the reported technical problems in Hungary is presented below. At the time of writing this paper, no result was available from the Spanish trial.

G. DISPLAY

It has three functions : informing the driver about the device's status (mode, speed limit), allowing the driver to enter a manual speed limit outside the digital map and modify some ISA parameters (for maintenance purpose only). There was no reported problem connected to the display.

H. DATA LOGGER

The data logger is an onboard instrument recording driving variables over time in order to investigate afterwards the effect of the ISA device. It is situated in the navigator housing. The log frequency and logged data were different inside and outside the digital map area. Within the map, the data logger recorded 5 times per second the date and time, the position in RT90 plane coordinates, the speed, the distance, the gas pedal position (%), the heading, the speed limit and the RPM. Outside the map, the data logger recorded once per second the date and time, RT90 position, speed, distance, gas pedal position and the voluntary use of ISA by the driver.

Remark : the data logger is to be evaluated separately since it was added to the ISA device for study and evaluation purpose only.

Limits

The main issue was the absence of a logged binary value describing the speed limiter's on/off status. Such a value would have allowed us - among other things - to compare the driver's behaviour before and after ISA triggers. This could also not be derived from the logged speed since two different odometer sensitivities had been used for functional and logging purposes. Furthermore no logged data was giving us real time an indication of the GPS positioning accuracy. The use of two separate sampling frequencies inside and outside the digital map area made the comparison of driver's behaviour before and after crossing the map border more difficult. The RPM signal, when available in the car, was only logged in the map area.

Efficiency & reliability

The logged vehicle speed outside the test area – also required by the future investigations - was wrong. The bug was fixed at the end of the trial, requiring an extension of the trial period. When logged, RPM values were relative ones. An (mainly) unknown car dependent multiplying factor had to be applied to get the real values. The logged gas pedal position was ranging between zero and an unknown car and even time dependent maximum value. After the end of the data collection, we noticed too large an amount of logged points with a 15 km/h speed limit within the test area. This was a vicious problem because while the driver's interface seemed to work fine (i.e. distinguish 15 and 50 km/h zones), on the logging side, many 50 km/h segments were recorded with a 15 km/h value.

3. TECHNICAL COMPARISON OF ISA TRIALS

We compared the technical features (technologies involved, reported advantages and limitations or problems) of the following ISA projects : ISA Sweden (1999-2001, (2)), ISA-Tilburg (Netherlands, 1999-2000, (3)), External Vehicle Speed Control (UK, 1997-2000, (10,11)), Infati (Denmark, 1998-2001, (12)), ISA Hungary and Spain (Prosper project, 2003-2004), Lavia (France, 2003-2004, (9)), Divote (Belgium, 2002-2003, (8,13,14)) and some others. Here is the summary of our technical comparisons :

- Open and semi-open versions of ISA are the most usual ones.

- GPS is the favourite positioning tool, with a growing interest for differential correction. DGPS offers, in comparison to GPS, a 10 times higher positioning accuracy and a better availability of the correction signal (90 % vs. 70 % for GPS signal in (3)).
- Speed limits can match either 1D (segment) or 2D (polygons) parts of the digital map (14)
- A digital map integrating the speed limits seems more efficient than a two-layer database (digital map & speed limits). French Lavia project used such a two-layer version and reports a higher level of discrepancies between ISA and actual speed limits, especially when leaving a roundabout, on highway crossings and dense residential areas (9)
- Remote GSM or GPRS communications for map updates or logged data download are not fully reliable if a large fleet of vehicles has to be reached within a reasonable time frame (7,8,13).
- Both on- and off-board (8,13) data management solutions were tested. Hybrid solutions might be the future since they combine the advantages of both sides (availability on board, non redundant dynamic data management off board)
- The management of a dynamic speed limit database in function of traffic, road works, weather, type of vehicles, etc. variations requires multi-level information exchange, specific software tooling and is time demanding (14)
- Growing presence of CPU/ECU (and the corresponding encrypted software) in modern cars means not brand-specific ISA will be more difficult to install in the future (1,3)
- Things are starting to move on the carmaker's side since Ford (Australia) and the French carmaker's are participating actively into ISA development and testing (9)
- French (9) and Spanish trials used WGS84 coordinates, the latter with the *Limit Advisor*
- Hungarian ISA trial involving the *Limit Advisor M2002* reported far less mechanical problems (3 minor problems in total) than the Belgian trial. The possible reasons are a shorter testing time (1 vs. 12 months active accelerator), less vehicles (20 vs. 37), a newer version of the device, uniformity of host vehicles (nearly all Suzuki vs. a large range) and the installation and maintenance operations made by an official dealer

4. CONCLUSIONS

A. TECHNICAL EVALUATION OF THE GHENT ISA TRIAL

Advantages of the *Limit Advisor M2002*

- Already tested in hundreds of cars (450 in Sweden, Belgium, Hungary, etc.)
- EMC compliant (95/54/EC annexes VII, VIII & IX)
- Previous version (Nomix Mac) complied to the functional safety tests conducted by SP
- Not brand-specific (can be installed in a majority of used cars)
- Map-matching and basic dead reckoning functionalities implemented
- Navigator unit seems compatible with WGS84 coordinates

Disadvantages of the *Limit Advisor M2002*

- Mechanical reliability (system's lifetime much smaller than vehicle's lifetime)
- Digital map capacity too small
- Compatibility issues with cars expected to increase in the future
- Defective data logging software : some logged values were missing or wrong
- Incompatible with differential GPS
- Default status of the limiter is the constant presence of the counter-pressure

What should be improved in the *Limit Advisor M2002* for future trials ?

- Increase limiter's overall lifetime through higher mechanical reliability
- Use standard geographical coordinates (WGS84 for example)
- Use differential GPS for a better positioning accuracy
- Use a common sensitivity of the odometer for both the functional and the analytical sides. The choice of the reference speed (either actual speed or speedometer speed) and the dynamic or static type will depend of the relative importance of the technical and the human factors.
- The validity, accuracy and relative/absolute character of the existing logged data should be carefully checked, as well as the accordance with the limiter's behaviour. The active accelerator's on/off status and an evaluation of the GPS accuracy should be added to the list of logged variables.

- Improve dead reckoning hardware (gyroscope, sensors) and software
- Optimise the map-matching algorithm
- Testing other wireless communication technology (DAB, DSRC, UMTS, etc.) for digital map or logged data transmission. A static version is otherwise a stable solution.

B. WHAT DOES THE FUTURE OF THE ISA CONCEPT LOOK LIKE ?

With the GPS as the leading technology, the major ISA challenge can be divided into the positioning capability (accuracy & availability) and the digital map management. The first one could be improved with the differential technology, higher dead reckoning and map-matching performances and perhaps the future combination of GPS and Galileo. The management of a dynamic digital map also faces a dual challenge : frequently gathering the source information and quickly transmit it to a large amount of vehicles using standardized telecommunication protocols. Another crucial point is the design of the human machine interface (HMI). A compromise should be found between the human, legal and technical aspects in order to maximize the overall efficiency. We therefore need a functional, highly reliable, maintenance-free and tamper-proof device acceptable by a majority of drivers.

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