Test Results and Validation of the FeedMAP Framework with ADAS Applications

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***Abstract*— Up-to-date map data is a must for current and future navigation and Advanced Driver Assistance System (ADAS) applications. Today, digital maps are normally stored on DVDs or hard disks, with periodic updates only available on replacement disks. However, new mechanisms for updating maps have been investigated and some of them already reached the market. As the real world is changing every day, detecting changes to the road network quickly and at a low cost is a challenge. Although mapmakers continuously survey the European road network for changes, map information is not always up-to-date or accurate. This paper presents the test and validation results and two example applications from the FeedMAP project and how they can be used for increasing driving safety by integrating map deviation detection and incremental update technology into ADAS applications using the ADAS Horizon concept.**

I. Introduction

THE development of Advanced Driver Assistance Systems (ADAS) and, more generally, of in-vehicle ITS applications which support the driver in driving safely, comfortably and economically, are of major importance to the automotive industry. Typical examples of ADAS applications are Adaptive Cruise Control (ACC), Lane Keeping System (LKS), Adaptive Light Control (ALC) or Adaptive Speed Recommendation (ASR). ADAS currently perform their function on the basis of information generated by on-board sensors observing the vehicle's environment. There is a significant potential for the use of a digital map and the vehicle's position to predict the road geometry and to track related attributes ahead of the vehicle. ADAS applications can benefit from this potential, and new functionality may likely be enabled. In particular, ADAS applications can use map data for recognizing road infrastructure at the vehicle's current position, and for a preview along the track ahead.

The ActMAP framework provides concepts and methods for wireless distribution of incremental map updates for in-vehicle navigation and Advanced Driver Assistance System (ADAS) applications with the general goal to achieve highest up-to-dateness of an in-vehicle map database [1].

Although the ActMAP framework helps to shorten the time span between updates significantly, there is still space for improvement in terms of detecting map errors, changes in the real world, or giving attention to highly dynamic events like local warnings automatically. One basic assumption of the ActMAP framework is that such deviations, which lead to map updates, are detected and provided by the update suppliers. Since constantly checking wide areas of a road network is a time consuming and cost intensive process for update supplies, which obviously can only be done periodically and not in a permanently manner, the basic idea is to use the end customer's vehicle equipped with either a navigation system or ADAS application for the automatic detection of map deviations. The subject of the FeedMAP project is to provide a framework for implementing this solution, to achieve an even higher degree of map up-to-dateness for in-vehicle map databases (see Figure 1).

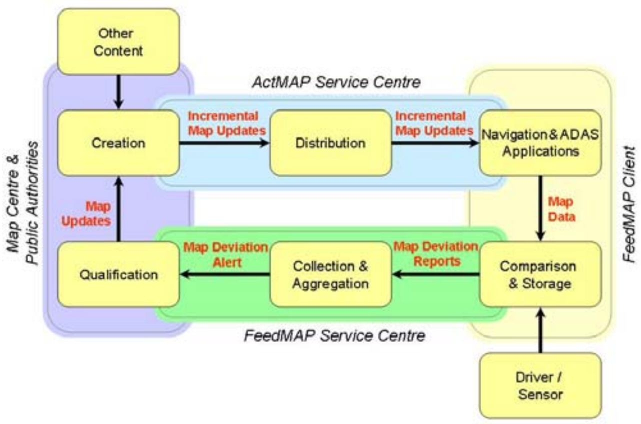

Figure 1 Chain of the ActMAP FeedMAP Framework

Consequently, the driver or even the map-supported ADAS application will always experience a deficit in his or her expectations if the subjectively perceived information does not correspond to the full picture of the driving environment. First approaches of map-supported ADAS entering the market use the vehicle's navigation system as the map data source for previewing the ADAS horizon [2]-[5]. In this case, the navigation system also acts as ADAS

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horizon provider using its stored record of the map data, and the available vehicle positioning and map matching algorithms. If needed, a simple extension of the navigation map database can guarantee that specific ADAS-related map attributes are provided to the ADAS applications.

II. Deviation Detection

The FeedMAP/ACTMAP loop is triggered when the difference between ground truth and content of the digital map is detected. Difference may be in absence of real-world entity in the digital map, presence of digital map entity that does not exists in reality or in difference between value of entity attribute stored in the digital map and actual real-world value of the attribute.

In the FeedMAP framework, those differences are called Map Deviations and they are described in XML-formatted data structures referred to as a Map Deviation Report (MDR). These Map Deviations are detected by 'FeedMAP Clients' (FMC). A FeedMAP Client generally fits into two categories:

1. Car Probes are FeedMAP clients equipped with sensors and algorithms that are used in Deviation Detection.
2. Public Authorities (PA) are FeedMAP clients that generate 'Map Deviation Reports' as well. However, since PA initiates or at least keeps official records about many attributes contained in the Digital Map, they are the reference source for that information.

Map Deviation Detection algorithms implemented in car probes can be generally grouped into three categories: autonomous, manual, and joint detection.

Autonomous detection does not involve any conscious driver action; the source of the data that indicates the deviation is only provided by different vehicle sensors. An example of the Autonomous detection is detection of link 'travel time' errors. This attribute tells to the navigation system the average time necessary to transverse one map link and it is one of most important attributes used in calculation for fastest route. Car probe can simply measure time necessary for the car to drive along one link and if this value significantly differs from the value stored in the digital map, Map Deviation Report can be generated. The detection algorithm can be improved taking the time of the day and many other parameters into account.

Manual deviation detection algorithms rely only on driver interventions. For instance, detection of Scenic Routes or changes in Point-of-Interest attributes (telephone number, opening hours) can only be updated via manual intervention. In general, all manual deviation detection algorithms can be automated by use of hardware sensors and by applying complex software algorithms, but in most cases such approach is not feasible.

Joint detection algorithms are a combination of autonomous and manual detection. While the system detects the deviation, the driver is asked to confirm its existence. This confirmation may be explicit (the user, for instance, pushes a 'deviation' button); or implicit. During implicit confirmation, the system monitors user's behavior, such as acceleration and braking, and based on this information it deduces if deviation really exists.

III. Application Example: Adaptive Speed Recommendation

BMW/NAVTEQ Adaptive Speed Recommendation (ASR) is an ADAS application that advises the driver about maximum recommended speed on the road ahead. This recommendation is calculated by taking in to account the current speed, vehicle dynamic characteristics (braking, acceleration), drivers' preference (relaxed, normal, sport driving) as well as the number of information about road ahead: curves, crossings, slope, and, of course, Legal Speed Limits.

The ASR system has been extended with map deviation detection, reporting and dynamic map update capabilities. It is now active part of the ActMAP-FeedMAP loop. The Figure 2 on next page shows a block diagram of the developed ADASRP[1] platform connected to the BMW sensor CAN box with respect to the vehicle data.

Speed Deviation Detection is a typical example of complex joint detection system with implicit driver confirmation. ASR-based detection system monitors the driver's behavior – namely speed, and its response to the speed information given by the adaptive speed recommendation.

For instance, a digital map may contain legal speed limit of 60 km/h for some road segment but the driver consistently keeps the speed of 100 km/h despite speed warnings given by the ASR. In this case, speed deviation detection will assume that the data about 60 km/h speed limit might be erroneous and it generates an corresponding map deviation report.

Taking the opposite example, let's assume that the driver keeps the speed of around 60 km/h along one particular road segment where the legal speed limit is 100 km/h. It is not obvious that the legal speed limit on the map has a wrong value as there might be another reason for driving at lower speed.

The BMW/NAVTEQ Speed Deviation Detection system uses different sensors and algorithms to answer this issue: the Adaptive Cruise Control (ACC) radar to indicate presence of slow vehicle in front; rain and temperature sensor to detect difficult weather conditions that may force the driver to drive slowly, road geometry in front that may reveal sharp curves, etc… (see Figure 2).

[1] The ADASRP is the NAVTEQ Advanced Driver Assistance System Research Platform 2008. It is a Windows-based framework application for hosting various map-based ADAS solutions.

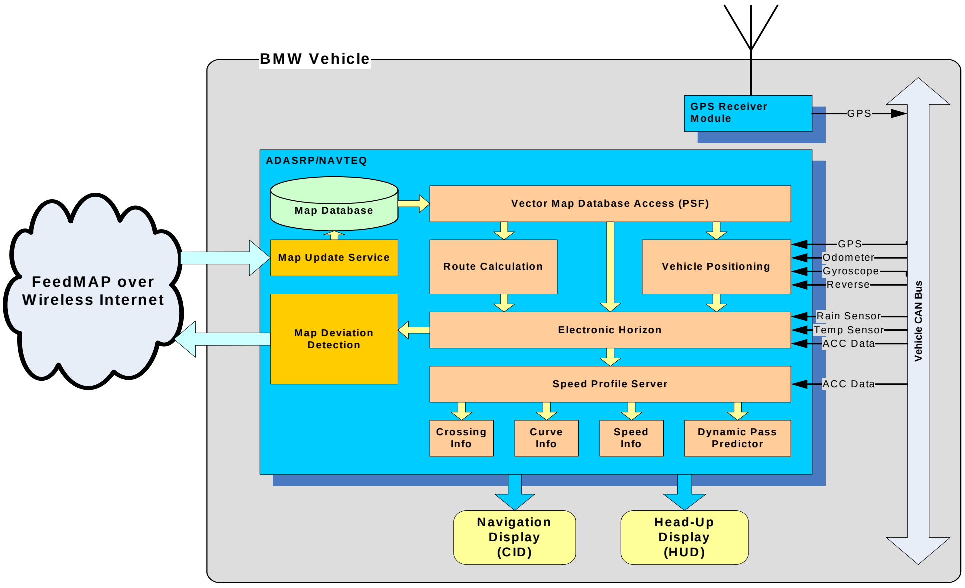

Figure 2: Developed ADASRP platform connected to the BMW sensor CAN box

IV. Application Example: Extending the ADAS Horizon

NAVIGON has extended within the FeedMAP project their ADAS Horizon Provider solution (MapSensor) with FeedMAP client functionality. This application (FeedMAPSensor) was evaluated in a joint test-site with Volvo Technology, and Tele Atlas. The FeedMAPSensor is installed on a Volvo truck, which is equipped with sensors connected to the CAN bus. Such sensors comprise an image lane detection unit, ACC radar, and slope unit. The sensors' information is used to assist the deviation detection algorithms in autonomous detection mode.

The FeedMAPSensor extends the ADAS horizon and the information on the most probable path by means of detected deviations. Additionally, the FeedMAPSensor is capable of receiving incremental map updates from an ActMAP service centre and use them to extend the ADAS horizon. Consequently, ADAS applications using the ADAS horizon information benefit from the FeedMAP concept. Such update and detection information available on the vehicle's CAN-bus can be used to alert the driver about map changes and/or directly can be used by ADAS systems. Hence the overall driving safety is increased, because the map information is up-to-date.

The FeedMAPSensor comprises the manual detection of 4 deviation types and automatic detection of 5 deviation types. For manual deviation detection, a GUI is used that allows the user by "point, click, and select" operations on the map to report: Road Works, Point of Interest, Speed Limit, and Traffic Sign deviations. Although manual deviations detection is of some importance for cases where automatic detection is very complex, the main focus of the FeedMAP project is clearly on the automatic detection of deviations, since this reduces workload and minimizes the risk of disturbing the driver.

FeedMAPSensor automatically detects wrong road geometry, missing roads, changed speed limits, and slope information. The detection of wrong road and missing road deviations are solely based on GPS sensor data. The speed limit deviation detection can be performed in two different modes, either automatic or manual. Automatic detection is based on speed information given by the GPS receiver and additional (optional) radar information about the speed of vehicles in front of the truck.

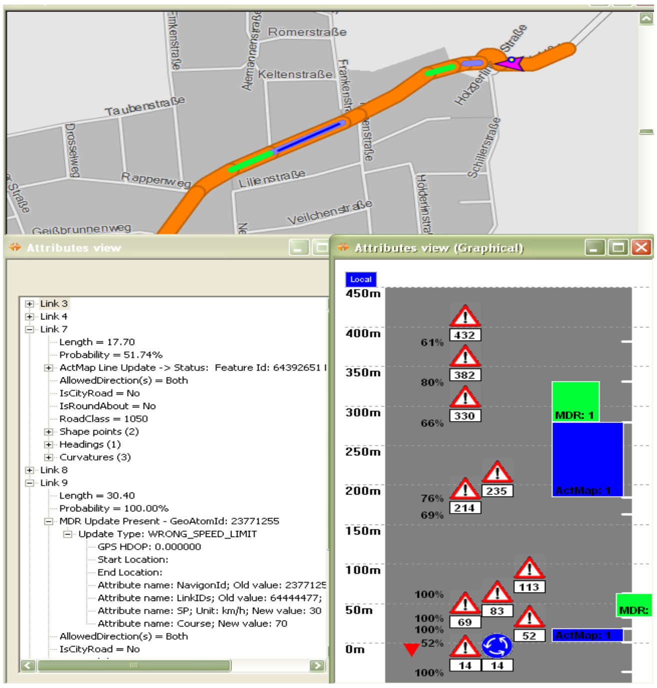

Figure 3 ActMAP Updates (blue), MDR (green), Horizon (orange), attribute and graphical view of ADAS Horizon (left and right)

Since the measured speed information solely based on the GPS information might lead to false assumptions on possible speed limit changes, due to possible congestions or speeding by the driver, the radar information is used to improve the speed limit detection heuristic. The vehicle's speed is compared with speed limit attributes attached to the map and based on different computational models the radar information (read from the CAN-bus) is taken into consideration for estimating new speed limits.

The detection of Missing Roads is also supported and requires a close interaction with map matching components of the core system. Information about the new road's geometry is collected and reported to the FeedMAP Service Centre for further analysis and passed to the map centre for map update creation. Figure 3 shows an example of detected missing roads (in green). Missing road and wrong geometry detection is mainly based on thresholds for the distance between map matched position and GPS position, number of succeeding "spurious" position samples, and maximal distance between sample points.

V. Testing of the FeedMAP framework

The FeedMAP framework is tested and evaluated in five different test sites comprising the different aspects and deviations to be detected (Table 1).

While each test site operates and evaluates its own test, a common concept and terminology expressing quality of the messages generated by the client or by the FeedMAP service centre is being used. While there is still a need to provide further details to the application of the quality parameters in each test site and the specific test, the general terminology and concepts are common. Please note that in this paper only a small subset of quality parameters are presented, for a detailed explanation and comprehensive overview on test results the reader is referred to [6].

All messages generated by the FeedMAP clients and service center (FMSC) need to be compared to those deviations, i.e. discrepancies between the on-board map and the ground truth, which merit a correction in the map database. These deviations are called reference deviations, since they provide the reference against which detection quality is evaluated.

The messages generated in the FeedMAP system are analyzed at the level of the MDR (Message Deviation Report generated by the client) and the MDA (Message Deviation Alert generated by the FMSC).

The total numbers of known deviations that are to be detected are called *reference deviations (TD)*. In case of several loops along a track with deviations, it responds to the number of expected detections or messages for all loops. For instance, Table 2 shows 240 reference deviations for the test performed by DAIMLER (Stuttgart test site). Actually, the track contained 6 deviations to be detected but 40 test runs on this particular track have been carried out.

Specific aspects	Deviations tested
Test site Göteborg **(Navigon, Volvo, TeleAtlas)** • integration with electronic horizon • access to specific in-car sensors • ActMAP updates • Autonomous and driver assisted detection • Data supply from public authorities (static and dynamic)	Wrong Geometry, Missing Road, Wrong/Missing Slope, Wrong/Missing Lane Info, Wrong Speed Limits, New/Wrong Point-of-Interest, New/Wrong Traffic Sign, Missing Road Works
Test site Munich (BMW, Navteq, OBB) • Integration into ADAS Research Platform • Access to specific in-car sensors • Map Update cycle • Client operation on map with deliberately introduced errors • Autonomous and driver assisted detection • Data supply from public authorities	Travel Time, Legal Speed Limits, Road Works, Wrong Geometry, Point-of-Interests
Test site Stuttgart **(Daimler, PTV, NAVIGON, TeleAtlas)** • Autonomous client detection • GPS only and CAN-assisted positioning • Client operation also on 'falsified' map • ActMAP compliant map update cycle	Missing Road, Wrong Geometry, Wrong one way, Wrong Prohibited Turn
Test site Torino (Fiat, Magneti Marelli) • Autonomous and driver assisted detection • Deployment of FM in-car client in embedded environment • CAN-assisted positioning	Missing Road, Wrong Geometry, Wrong one way, Missing guidance
Test site SimCity **(ICCS, PTV, Daimler, Navigon, TeleAtlas)** • Simulation of test drives (error coding in GPS-trace, GPS-error variation) • Operation of FM cycle by TS Stuttgart partners • Central evaluation of tests for different clients and the FM information chain	Wrong Geometry, Wrong Speed limit, Missing Road, Wrong Turn, Wrong one way

Table 1 FeedMAP Test Sites

There is consequently a difference in running a detection only once on one deviation location or repeatedly. Further influencing factors on the detection quality is the reference deviation itself in terms of its location (inner city vs. rural) or its type (manually created by map falsification vs. real world deviation). Comparing results from different test sites and FeedMAP clients is therefore not straightforward. An extensive explanation of the tests and their result is given in [6].

MDRs reported by the detection client are classified as *False Alarm (FA*) if the FMC reports a MDR for a non existing deviation (i.e. there is no deviation, but the FMC reports one), as *Missing Alarm (MA)* if the FMC does not report a MDR for an existing deviation. (i.e. there is a deviation, but no report is generated by the FMC), and as *Positive Alarm (PA)* if the FMC reports a MDR for a location or stretch for which a reference deviation exists – irrespective of the quality of the message content, i.e. the geometric accuracy or the deviation type may be wrong or right.

The total number of Map Deviation Reports (MDRs) reported by a FeedMAP detection client is referred to by the term *Total Alarms (TA).*

As a first qualification of detection, a *Completeness rate (CMPR)* can be defined as *CMPR = PA / TD*. It shows how many of the reference deviations are covered by messages generated – irrespective of the quality of the individual messages.

On a general level, positive alarms (PA) can be separated into messages qualified as valid according to certain criteria (PVA) and those qualified as insufficient or invalid (PIA).

How messages are qualified as 'valid' or 'sufficient' cannot be easily unified across test sites since deviation and test approaches differ significantly, e.g. if only one detection algorithm is operated at a time, no error in deviation type can occur. On the other hand, it can be of interest that a FeedMAP client detects a deviation at a certain location even if it does not detect the correct deviation type. In this case, it would be called a positive alarm but nevertheless an invalid one because of the wrongly detected deviation type.

Therefore, depending on the FeedMAP client implementation (detection algorithms), the testing and evaluation were done according to two approaches: the classification and spatial quality approach. In the succeeding sections of this paper only the classification related to completeness rate, missing alarms, and false alarms are used.

In the *classification quality approach*, no detailed dimensions of 'validity' (semantic quality of reports), except for the deviation type are distinguished. Hence a positive alarm (PA) is said to be a positive valid alarm if the deviation type is detected correctly. The *Classification Completeness Rate (CCMPR)* is defined as *CCMPR = PVA / TD* describing the rate of valid messages related to the total reference deviations.

VI. FeedMAP Test Results

A. *Wrong Road Geometry Detection*

Wrong Road Geometry is a quite common deviation which can be found in real world due to road improvements changing the road geometry (e.g., new roundabouts). The geometry modifications can be short but also very long and can have a small or big distance from the original road. It is therefore difficult to define a threshold for deviation detection able to detect Wrong Road Geometry in all instances. A summary of the test results and the validation is given in Table 2. A comprehensive description is available in [6] and [7].

Test site Munich	***Test site Stuttgart***	***Test Site Stuttgart***	***Test Site Italy***	***Test site Göteborg***
Algorithm: NAVTEQ	Algorithm: DAIMLER	Algorithm: PTV	Algorithm: Fiat/Magn. Marelli	Algorithm: NAVIGON
Sensors: GPS, gyroscope, odometer	Sensors: GPS, gyroscope, odometer	Sensors: GPS	Sensors: GPS, diff. odometer	Sensors: GPS
50 reference deviations	240 reference deviations	35 reference deviations	84 reference deviations	44 reference deviations
CMPR: 84%	CMPR 95%	CMPR 40%	CMPR 85%	CMPR 66%
CCMPR: 64%	CCMPR: 85%	CCMPR: 31%	CCMPR: 63%	CCMPR: 66%
Missing alarms: 18	Missing alarms: 11	Missing alarms: 21	Missing alarms: 13	Missing alarms: 15
False alarms: 6	False alarms: 8	False alarms: 15	False alarms: 115	False alarms: 18

Table 2 Deviation Type Wrong Geometry Detection Results

If the defined threshold is too small, the number of generated false alarms and also the possibility to have wrongly classified alarms increase, while if the threshold is too high, the number of missing alarms will increase.

Even with current state of the art, the test performed show that up to 95% of the 2D geometry could be detected correctly in rural areas and with full range of sensors. On the other hand, 2D geometry detection in urban areas showed reduced performance or increased false alarms rate depending on the sensitivity of the detection algorithm. This is especially the case when only GPS positioning was used in urban areas with detection rate down to 40%.

In the current state of the development of the FMC (including algorithms and sensors), some important shortcomings were experienced especially in dense areas where roads are close to each other and where deviations are relatively short. In urban areas where roads are sometimes very close to each other, the deviation detection is more difficult than outside cities. Also, roundabouts could not easily be detected. The false alarms are mainly due to bad positioning occurring even when GPS HDOP value is good. For instance, this can be the case when strong GPS multi-path is experienced. New positioning algorithms and technologies such as Galileo could improve this issue.

B. *Speed Limit Detection*

Tests at test site Göteborg showed detection rates between 31%-43% for a single car, while test site Munich reported a success rate of up to 74%. Those test sites were designed in a complementary manner with different algorithms, different sensors, and different testing environment. Test results are therefore not directly comparable. However, assuming the most conservative results are realistic, those tests show that it is feasible to detect this deviation using FeedMAP probes. Even if relatively small percentage of map problems is detected, it still translates into large absolute numbers if operated in practice with big number of detection clients. Please note that applied algorithms used standard sensors that can be found in cars today (positioning sensors, radar). With introduction of more advanced systems such as sign post recognition cameras, one can expect the detection rate will be increased dramatically (see Table 3).

Test site Munich	*Test site Göteborg*
Algorithm: ASR (BMW/NAVTEQ)	Algorithms: NAVIGON
Sensors: GPS, gyroscope, odometer, radar	Sensors: GPS, (radar)
50 reference deviations	48 reference deviations
CCMPR: 74%	CCMPR: 31%-43%

Table 3 Deviation Type Speed Limit Detection Results

C. *Wrong One Way Detection*

Wrong One Way is a deviation which is quite easily detected but the generated report often presents a wrong classification type. In particular, in the Italian test site, all the occurrences of the deviation have been detected, but all the generated reports were classified as Missing Road. This is due to the behavior of the map matcher algorithm which up to now computes the possible future paths without considering the prohibited roads. By entering a prohibited road, a detection of a virtually "Missing Road" is generated instead of the wrong one way (see Table 4). This behavior could be corrected with a better detection algorithm checking the existence of the road in the other direction.

Test site Stuttgart	*Test Site Stuttgart*	*Test Site Italy*
Algorithm: DAIMLER	Algorithm: PTV	Algorithm: Fiat / Magn. Marelli
Sensors: GPS, gyroscope, odometer	Sensors: GPS	Sensors: GPS, diff. odometer
80 deviations	30 deviations	17 deviations
CCMPR 98%	CCMPR 77%	CCMPR 100%
Missing alarms: 1	Missing alarms: 7	Missing alarms: 0
False alarms: 1	False alarms: 2	False alarms: 0

Table 4 Deviation Type Wrong One Way Detection Results

D. *Prohibited Turn Detection*

The false alarm rate is very low for prohibited turn detection. In rural areas, especially at ramps, the detection rate and the correctness rate is very high. In urban areas, the detection rate is not so good. However, more work on the map matcher and detection algorithms tested in FeedMAP for wrong prohibited turn could improve these figures. For instance, the map matcher could allow drive/enter all roads but this slows down its real-time processing (see Table 5).

Test site Stuttgart	*Test site Stuttgart*
Algorithm: PTV	Algorithms: Daimler
Sensors: GPS	Sensors: GPS, gyroscope, odometer
31 ref deviations	80 reference deviations
CCMPR: 58%	CCMPR: 100%
Missing alarms: 13	Missing alarms: 0
False alarms: 2	False alarms: 0

Table 5 Deviation Type Prohibited Turn Detection Results

E. *Map Deviation Alert Timing*

In the Test by Simulation on test site Munich, it was found out that, depending of parameters, wrong speed limit MDAs can be generated after around 14-15 hours after receiving the first MDRs.

The large scale simulation testing showed that the average delivery time of an MDA with an acceptable quality is approximately 5 days for all deviation types. This figures show quite promising improvement as compared to state-of-the-art (see Table 6).

Test site Munich	*Test site SimCity*
Deviation type: Speed Limit	Deviation type: All
Samples: 2x50	Samples: ~14000
Assumed Penetration: 1%	Assumed Penetration: 1%
Traffic flow: 300 Vehicles/h	Traffic flow: 300 Vehicles /h
Average Timing: 14-15 hours	Average Timing: 133 hours

Table 6 FeedMAP Service Centre MDA Creation Timing

F. *Increasing Detection Quality by FeedMAP Service Centre Analysis*

The provision of a confidence value with the MDR is a key element to improve the quality of the MDA. Even with low penetration rates of the clients, MDAs could be issued in reasonable amount of time. However, the FMSC is by nature not able to improve the completeness rate (detection rate) from the set of MDRs received.

For Wrong Road Geometry, a MDA generated from a cluster of MDRs was covering 20% more of the extent of the individual reported deviations in terms of geometry. Indeed, different FMC reported on slightly different parts of the actual deviation. The FMSC issued reports with improved geometric accuracy rate of ~8% in comparison to the average of the geometry reported by the MDRs. This means that, in general, the lateral accuracy of the MDA is better than the individual MDRs reported.

In some cases it was observed that, the length of MDAs created by the FeedMAP Service Centre was longer than the actual deviation which leads to slightly worse geometric accuracy. The reason is that cluster includes MDRs that report parts of the existing road before and after the actual deviation. This however should be filtered away in the FeedMAP Service Centre through better tuning.

As it can be seen from Table 7, a cluster should contain at least 400 reports (MDRs) in order to issue a satisfyingly correct MDA, whereby satisfyingly correct MDA is one that in average covered 84% of the deviation and described the deviation with an average accuracy of 13.5m.

Number of (MDR)	*Percentage of Reference Detection of MDA*	*Geodetic accuracy of MDA*
> 1	~33%	~19m
> 40	~61%	~16m
> 100	~65%	~15m
> 300	~67%	~14m
> 400	~84%	~13m

Table 7 FeedMAP Service Centre MDA Quality Results

In general, the FeedMAP Service Centre is able to filter out the random False Alarms generated by the FeedMAP clients. Sometimes, clusters containing only False Alarms can appear in the FeedMAP Service Centre. However, they rarely reach sufficient confidence to be closed. During the tests, MDA have been created from False Alarm clusters. This happens when a systematic False Alarm is generated from a FeedMAP client. In a full scale implementation, the diversity of clients having different detection algorithms should limit this issue. And, again, further tuning of the FMSC will help.

VII. Conclusions

The FeedMAP project has done an extensive testing of the developed framework aiming to validate the technical and commercial feasibility of map data correction by providing a map data feedback loop applied to a map data updating framework using the standardized ActMAP exchange formats and mechanisms.

Overall, the FeedMAP clients and FeedMAP Service Centre show very promising results. No principal barrier could be identified which would hinder or fully impede the implementation of such a system. However, some important shortcomings were experienced especially in dense areas making some types of map deviations very difficult to detect at this stage of the implementation.

All tested components were implemented for the purpose of validation of the concept. The current stage of implementation of the clients and service centers still has significant potential for improvement and fine tuning if they shall yield robust and reliable detections with a reduced False Alarm rate in large scale commercial operation.

As a final remark, the FMSC will obviously not act as a unconditional map update generator. The last verification will always remain to be done by the Map Centers using their other sources of information.

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