Adaptive speed recommentation in FeedMAP: Real Time Map Information with Map Deviation Detection for Advanced In-Vehicle Applications

Sinisa Durekovic[1], Jan Löwenau[2], Andreas Wilde[3], Maxime Flament[4]

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.

INTRODUCTION

In addition to the surveys, mapmakers rely on road authorities and user feedback to detect the latest changes in the road network. The FeedMAP project will study the commercial and technical feasibility of map deviation feedback. In order to improve the flow of user map feedback, the FeedMAP concept uses all vehicles equipped with a digital map for deviation detection, i.e. to check if the maps are indeed accurate and complete.

The project is developing a framework that will detect map anomalies when cars happen to come across a faulty map attribute and that will quickly update the maps of all other vehicles using a standardised mechanism for delivering incremental map updates as developed in the ActMAP project.

FeedMAP's main focus will be on static and semi-static changes to the road network. In addition, real-time status of reports on events such as traffic jams or accidents can be verified and returned to the information source.

Figure 1 depicts the overview of the architecture of the ActMAP – FeedMAP framework:

[1] NAVTEQ, Otto-Volger-Str. 1, 65843 Sulzbach, Germany, e-mail: sinisa.durekovic@navteq.com
[2] BMW Group Forschung und Technik, Hanauer Str. 46, 80992 Munich, Germany, e-mail: jan.loewenau@bmw.de
[3] BMW AG, 80788 Munich, Germany, e-mail: andreas.wilde@bmw.de
[4] ERTICO SCRL, 1050 Brussels – Belgium, email: m.flament@mail.ertico.com, www.ertico.com

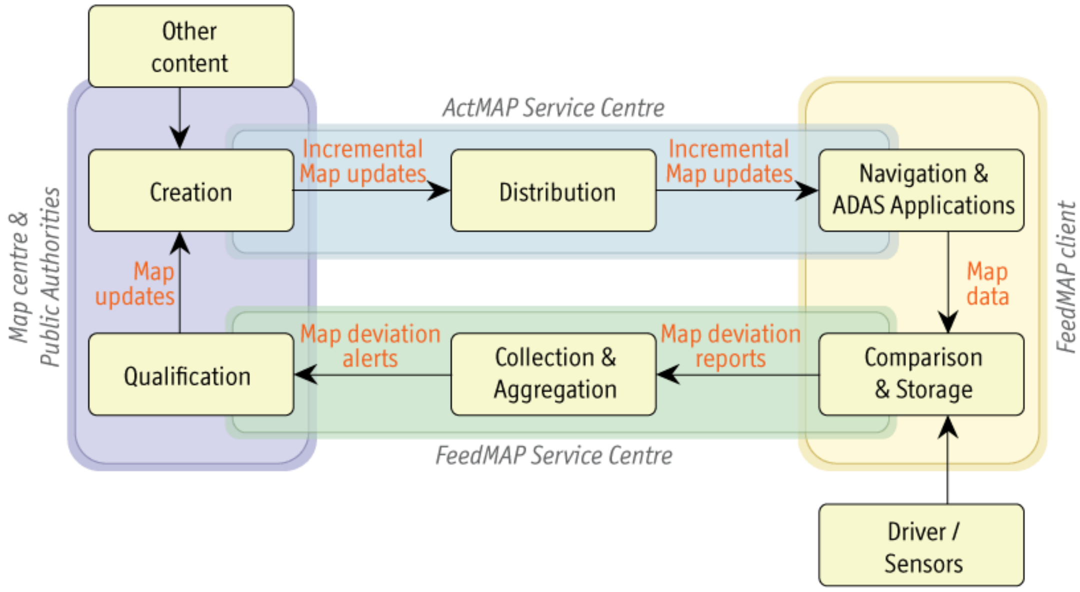

Figure 1. ActMAP-FeedMAP framework

It is comprised of four parts:

- The in-vehicle FeedMAP client – detecting potential map deviations by comparing up-to-date maps to environment sensor information (driven by car industry and equipment providers),
- The FeedMAP service centre – aggregating map deviation reports in a statistical manner from multiple in-vehicle FeedMAP clients and issuing of map deviation alerts with reliability measures (driven by FeedMAP service providers),
- The map centre – qualifying deviation alerts, integrating with map production work flow and generating map updates (driven by map providers, road authorities and other content providers),
- The ActMAP service centre – distributing map updates through the ActMAP service centres consolidated with the FeedMAP specifications (driven by service providers).

ADAPTIVE SPEED RECOMMENDATION

The BMW application “Adaptive Speed Recommendation” (ASR) is a typical example of ADAS applications whose usability heavily depends of the correctness of the map data. The Adaptive Speed Recommendation Info function provides additional, detailed information on the stretch of road the driver is currently covering. To provide this helpful support, a traffic sign graphics in the instrument cluster – head up display and navigation display - in the cockpit informs the driver of the speed limit at his current location (see Figure 2).

Figure 2. BMW Vehicle used in the FeedMAP framework

Adaptive Speed Recommendation is extended with Map Deviation Detection, Reporting and Dynamic Map Update capabilities and it is now active part of the ActMAP-FeedMAP chain.

ASR Method

To calculate recommended speed at each moment, the following road characteristics are taken in account:

- Curves
- Legal Speed Limits
- Crossings
- Roundabouts

As such, ASR system combines Curve Information, Speed Limit Information and Crossing Information ADAS functions in one application.

ASR will warn the user of the need to slow down before the vehicle reaches the point where speed must be reduced. For instance, the ASR may display the information about speed limit 50-300 meters ahead of the actual Speed Limit traffic sign. The exact distance depends of the several factors such as Current vehicle speed, Vehicle braking acceleration (deceleration), Driver reaction time, etc. Of course, if the system calculates that present speed does not violate current or future legal speed limit, no information will be shown.

The special care is taken to properly calculate the maximum allowed speed on the curves. Current curve radius data from the vector map database is not always precise enough. In addition, speed in the curve will depend of many other factors as well: number of lanes, width of the road, overall road surface condition etc. While algorithm will calculate allowed curve speed based on the available curve radius, all other relevant road attributes from the vector map database will be used to increase or decrease that estimate.

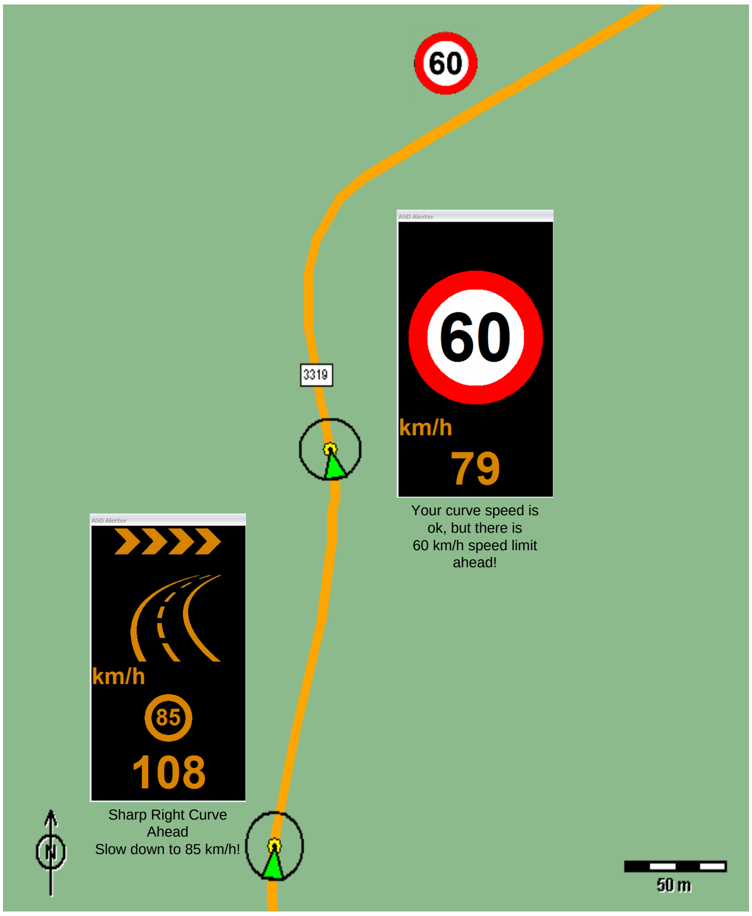

Figure 3. Information inside the BMW Vehicle

The ASR system will monitor actual driven curve speed, compare this value with previously calculated recommended speed and use that data in the calculation of the speed recommendation for the next curve. In other words, system will learn from the driver to offset the vector map data inaccuracies and road characteristics not present in the database (most important: road surface condition).

ELECTRONIC HORIZON

The “road ahead” concept is basically entity called Most Probable Path (or Most Likely Path) derived from Electronic Horizon (a.k.a. ADAS Horizon, Extended Driver Horizon).

Electronic Horizon is an extract of the digital map around the current vehicle position. For the each street segment, probability of driving trough this segment is assigned.

Most Probable Path is a connected set of segments, starting with the one where vehicle is located, and following the segments with the highest probability (see Fig. 4).

Figure 4. Electronic Horizon (orange) & Most Probable Path (blue)

SPEED PROFILE

The Most Probable Path (MPP), base for the calculation, is a curve in two-dimensional space. For the purpose of the ASR, however, it can be assumed that MPP is 1-dimensonal line. The start of that line corresponds to the current vehicle position. Length of the line is same as length of the Most Probable Path.

For each point of the MPP line, the maximum recommended speed of the vehicle at that point can be assigned. For the moment, we will leave open the method how this speed is calculated.

We can take the MPP line as x-axis of the graph, and draw the maximum speed along the y-axis. Let's call this graph Speed Profile (see Fig. 5).

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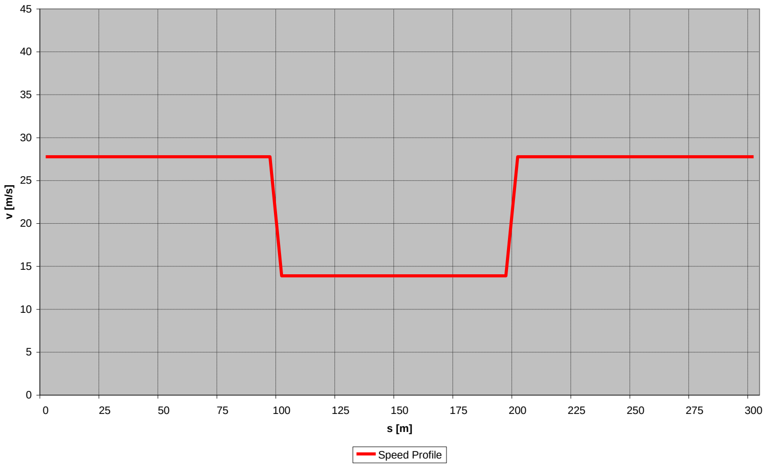

Figure 5. Speed Profile

Above Speed Profile in Figure 5 describes the real world situation where

- Current legal speed limit is 100 km/h (27.78 m/sec).

• 100 meters from current vehicle position, new legal speed limit of 50 km/h (13.89 m/sec) is introduced.

• Speed limit of 50 km/h is valid for 100 meters; therefore it is in effect between 100m and 200m from the current vehicle position.

• After that, legal speed limit is 100 km/h again.

BRAKING PATH

In the ASR system, the following assumptions will be taken as starting point in developing the physical model describing braking path (see Figure 6).

• Vehicle is traveling with some constant speed v_0 (commonly expressed in meters per second).

• After the speed information is issued, driver will wait for t_r seconds before applying brake.

• Braking will cause constant deceleration of the vehicle a ($a<0$). Of course, this acceleration is expressed in meters per seconds squared.

Under that conditions, the speed of the vehicle as function of time t will be expressed as

$$v(t) = \begin{cases} v_0 & 0 \le t \le t_r \\ v_0 + a(t - t_r) & t_r \le t \le t_d \end{cases}$$

To calculate the time and the speed for the "Most Probable path" the well-known formulas are used.

$$v(s) = \begin{cases} v_0 & 0 = s(0) \le s \le s(t_r) \\ \sqrt{2as - 2at_r v_0 + v_0^2} & s(t_r) \le s \le s(t_d) \end{cases}$$

For the $v_0=25\ m/s$ (90 km/h), $a=-2m/s^2$ and $t_r=2.5\ sec$, the speed along the (Most Probable) path looks as follows:

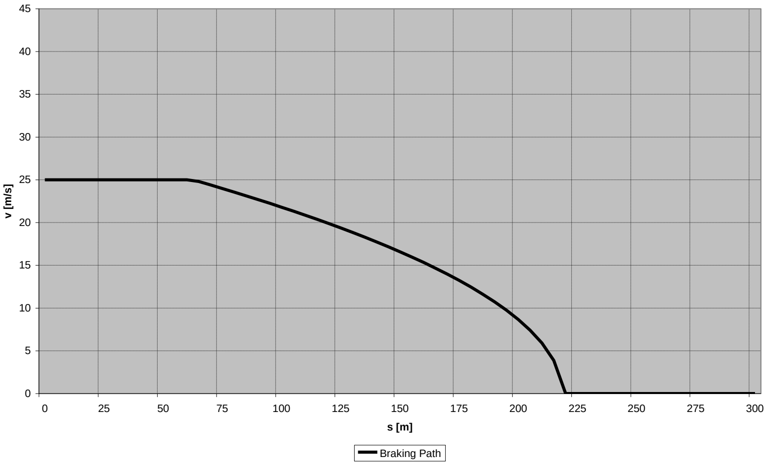

Figure 6. Braking distance

SPEED INFORMATION

If we combine Figure 5 and Figure 6, we can immediately find out that driver of the vehicle traveling with $v_0=25\ m/s$ (90 km/h) will have not enough time to slow down to obey 50 km/h speed limit in 100 meters (see Figure 7).

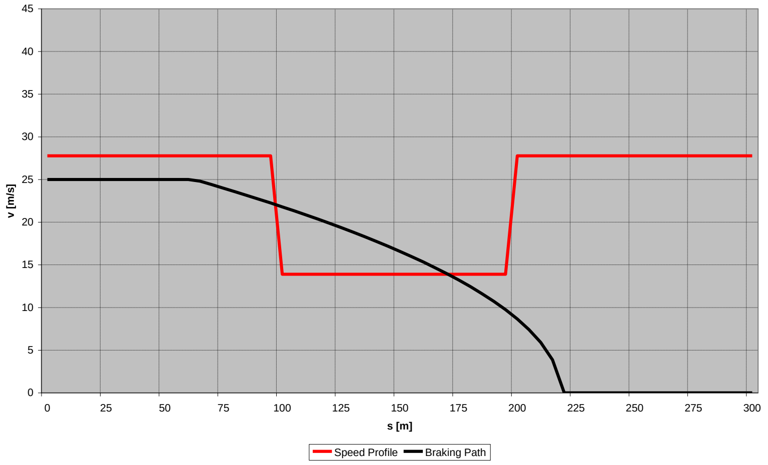

Figure 7. Speed information

If, however, initial speed $v_0=20\ m/s$ (72 km/h), and rest of the conditions are the same ($t_r=2.5\ s$, $a=-2\ m/s^2$), the legal speed limit will be obeyed.

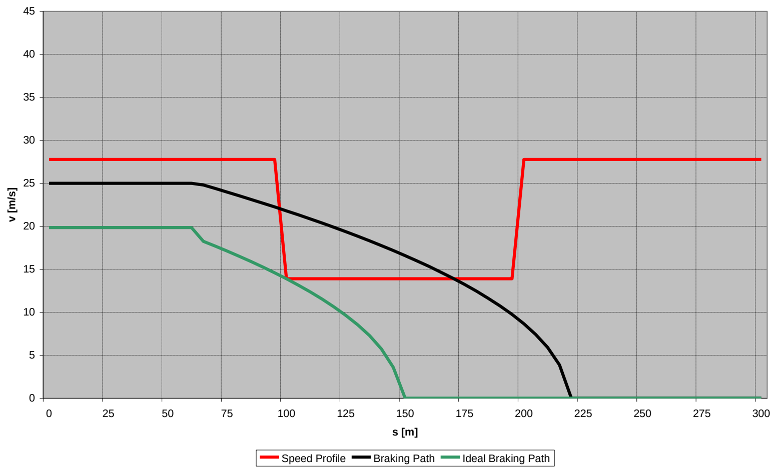

Figure 8. Speed information slowing down

In this particular case, Speed Profile Server system should issue a information to the driver that he should slow down (see Figure 8).

DETECTION OF EXCESSIVE SPEED

To recognize situation where current vehicle speed is too fast for the speed profile of road ahead, we will define the function $v_0(s, v_s)$. This function specifies maximum speed at point $s=0$ which ensures safe braking to speed v_s at point s after reaction time and deceleration rate is taken into account.

If $v_0 \le v_0(s, v_s) \quad \forall s \quad 0 \le s$ it can be said that vehicle is driving at safe speed. Otherwise, information must me issued to the driver.

In other words, ASD will warn the driver of speeding if $v_0 > \min\limits_{0 \le s} v_0(s, v_s)$

Variable v_s is in fact function $v_s(s)$, the Speed Profile described before.

It is important to check the minimum $v_0(s, v_s)$ for the whole path ahead of the vehicle and not only for the first instance where braking speed exceeds speed profile. In that way, exact maximal speed on $s=0$ can be calculated. For instance, in our standard example $v_0=25\ m/s$ (90 km/h), $a=-2\ m/s^2$ and $t_r=2.5\ sec$, but there is legal speed limit of 70 km/h 100 meters ahead but 50 km/h after additional 50 m (150 m from the vehicle), the Speed Profile/Braking path graph is

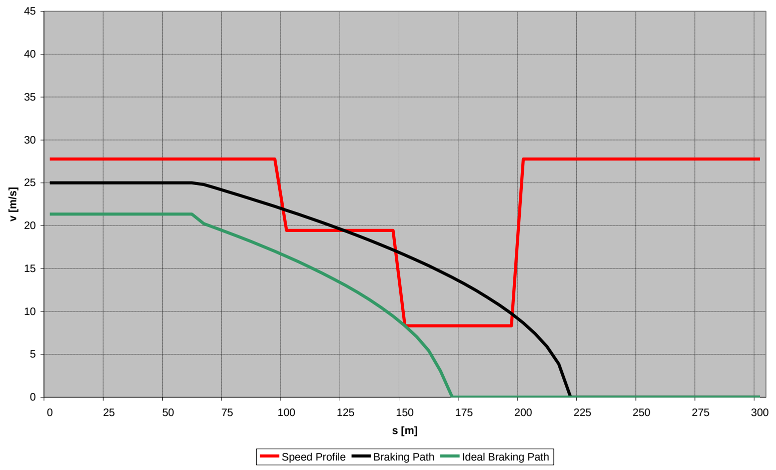

Figure 9. Speed Profile/Braking path graph

Instant slowing down from 25 m/sec to 23 m/sec will be enough to obey first speed limit of 70 km/h 100 meters ahead, car will be still too fast to obey second speed limit of 50 km/h 150 meters ahead. Therefore, in ideal case car must immediately slow down to 21 m/sec (see Figure 9).

Function $v_0(s, v_s)$ can be derived from the well-known equations as

$$v_0(s, v_s) = \begin{cases} v_s & 0 = s(0) \le s \le s(t_r) \\ at_r + \sqrt{v_s^2 + a^2 t_r^2 - 2as} & s(t_r) \le s \le s(t_d) \end{cases}$$

For our second sample (two legal speed limits, see Figure 10), the graph of this function will be

Figure 10. Speed Profile/Braking path graph with two speed limits

Minimum of the function $v_0(s, v_s)$ ASR will take as the maximum recommended speed at point s=0.

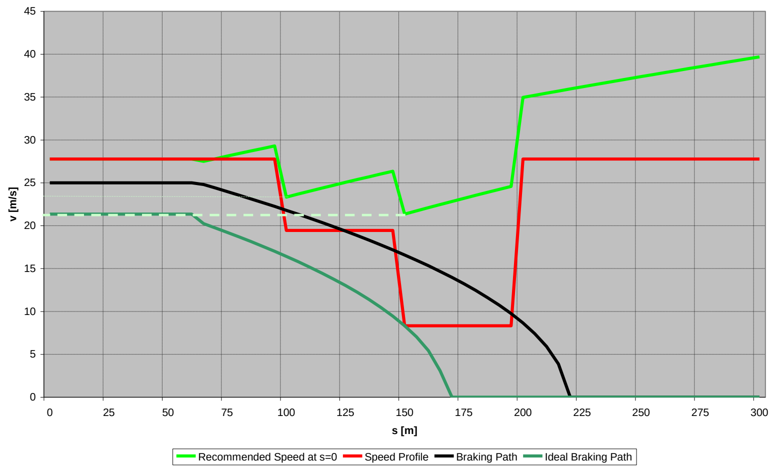

Figure 11. Result of the integrated speed information system

If the Speed Profile is defined not only by taking in account Legal Speed Limit, but also recommended speed at normal and priority crossings, roundabouts and curves, result is integrated speed information system.

ASR IN FEEDMAP LOOP

Since quality of ASR results heavily relies on quality of Digital Map Data, it is obvious that this application will benefit from up-to-date map content provided by FeedMAP loop.

Opposite is true as well: Adaptive Speed Recommendation system plays critical role in implementations of many car-speed related map deviations.

Simplest example is the FeedMAP algorithm for detection of issues with Legal Speed Limit data in the Digital Map.

DETECTION OF INCORRECT LEGAL SPEED LIMIT

To detect wrong Legal Speed Limits, system will monitor speed recommended by ASR system and actual driven speed**.**

If driver drives faster, and since Legal Speed Limit is part of ASR calculation, one can conclude that actual Legal Speed Limit is higher than one stored in the digital map.

More complex case is if, along single segment, driver is significantly slower than legal speed limit.

First of all, output from ACC radar can be checked to find out if slow vehicle is present in the front. If this is the case, no conclusion can be reached.

If, however, no cars are in front, driver may simply follows ASR recommended speed that tells him there is crossing or sharp curve ahead. Again, digital-map legal speed limit may be correct.

When ASR calculates that driver can be faster, and if there are no cars in front, most probable reason why driver is driving slowly is because he/she saw the actual legal speed limit sign. Under this assumption, FeedMAP client that uses ASR will generate Map Deviation Report about probable wrong Legal Speed Limit.

CONCLUSIONS

At the conference the final version of BMW's ADAS solutions concerning the FeedMAP framework are presented.

Potential fields of deployment as, for example, precision navigation and ADAS applications (as shown in Figure 2) are demonstrated. Implementations of applications are showcased and the benefits of using the framework are explained. Driver assistance systems heavily rely on remote sensing for road traffic situation perception. The concept of advanced vehicle navigation extends the driver's visual horizon to an electronic horizon with a much larger range. The ability to combine dynamic data (such as vehicle data) and map data (such as the roadway geometry from a vehicle navigation system), provides the means for a driver assistance system to generate a "clear" picture of the current traffic scene.

BMW has proven by series applications, that the integration of advanced vehicle navigation in driver assistance systems can bring substantial benefits in terms of reliability, robustness, increased functionality, fuel efficiency, active safety and performance. Driver assistance products using map databases as an additional source of information will most likely be introduced in phases. The ASR is based on available GPS technologies and common map databases designed for driver assistance systems. Even with the quality of navigation data available today, BMW's ASR system can be enhanced by dynamics, which adapt to the situation, providing even more benefit for the customer. By using ASR in dynamic situations a safer, more comfortable and superior driving is achieved.

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