Steer-by-Wire in the Context of the Connected Vehicle: Opportunities for Future Steering Innovations

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Abstract. Currently, the application cycle of a steering system goes together with the life cycle of a vehicle application. Significant changes in function and content are typically introduced through new vehicle applications and platform architectures. With the fast development of connected vehicle functions, new chassis applications and innovations can be introduced during the life cycle of a vehicle via over-the-air system updates.

What made the Smartphone so successful that we all have one? A powerful, flexible, software-upgradable platform architecture that comes to life with new downloadable applications is a major part of the answer.

Steer-by-Wire will have the same impact in a connected and software-defined vehicle: Elimination of the I-shaft eliminates constraints in packaging and functionality. It improves new functions like Automatic Emergency Steering and enables functions that we have not yet even thought of but that will develop over the coming years. The steering wheel is transforming into a Human Machine Interface by creating additional degrees of freedom for haptic interaction between driver and vehicle – like fly-by-wire in the aerospace industry.

The connected, software-defined vehicle will feature new software functions, updated over the air over the lifetime of the vehicle, that keep the product portfolio fresh. Therefore, the connected, steer-by-wire–equipped vehicle brings multiple trends together: connectivity and software.

Keywords: connected vehicle, by-wire, safety, multi-modal communication, platform architecture.

P. E. Pfeffer (ed.), *11th International Munich Chassis Symposium 2020*,
Proceedings, https://doi.org/10.1007/978-3-662-63193-5_29

1 Trends and Lessons-Learned in Related Industries

1.1 By-wire

Fly-by-wire was introduced into mass-produced commercial and military planes in 1976. Originally, it was needed to enable novel breakthrough features that otherwise would not have been possible, like the supersonic flights of the Concorde or the stealth of the Lockheed F117. Other benefits followed, including fuel savings and new safety functions via automation. Lessons-learned: By-wire and automation go hand in hand, enabling brand new functionality.

Fig. 1. Early by-wire application examples in aerospace: Concorde, F117 [1]

An equivalent application in automotive steering is the retractable steering wheel in an autonomously driving vehicle. Without by-wire, the steering wheel cannot be prevented from rotating during the storing process (Fig. 2).

Fig. 2. Steer-by-Wire application in automotive

The introduction of automated driving in mass production on public roads will be determined by the pace of legislation, the efforts in validation to make this technology safe for public use, and the cost of the necessary sensor suite. The trend towards the connected vehicle provides a tailwind towards the introduction of Steer-by-Wire (SbW) and will be examined in the following sections.

1.2 Trends in life of vehicle vs. innovation cycles

According to the IHS Markit light vehicle sales forecast [2], the life of vehicle platforms is increasing from one generation to the next. This development is generating higher volumes per platform and therefore economies of scale (Fig. 3).

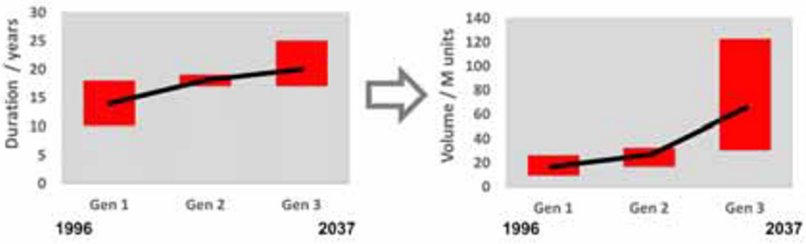

Fig. 3. Duration and production volume of vehicle platforms

At the same time, the vehicle cycles per platform and thus the introduction of new features for the consumer are becoming shorter (Fig. 4).

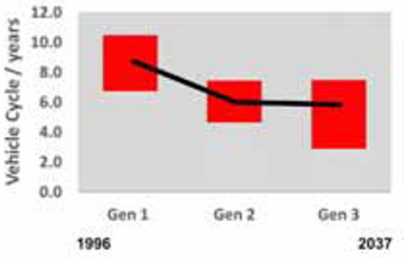

Fig. 4. Duration and production volume of vehicle platforms

This results in an increased "freshness" of the vehicle portfolio, enabled and driven by new software functions (Fig. 5). According to Accenture Research [3], in 2030 software will account for 40% of the total vehicle value.

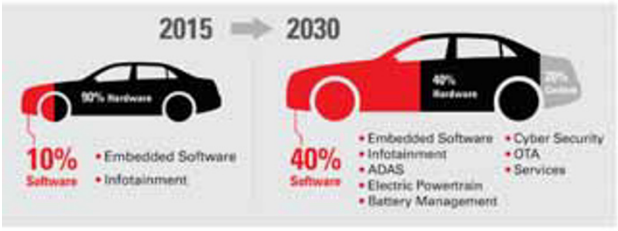

Fig. 5. The software-enabled vehicle

New functions will be launched not only at but also after start of production and can be sold separately during the life of a vehicle platform. Features, including trials, subscriptions, purchases, and on-demand features, can be either activated or downloaded from an App store in the cloud. Example features include drive modes, assist functions, location-based services, and range extension for electric vehicles and are accessible via a User Interface in the vehicle or on a mobile device (Fig. 6).

Fig. 6. Appstore enables feature upgrades

Tesla [4], for example, introduced a number of new and updated features, such as adaptive suspension, auto lane change, power increase, lane departure warning, and auto folding mirrors, in such a fashion. The software updates included beta versions and "sneak previews."

1.3 Lessons-learned From the Mobile App Market

What can we learn from connected, mobile applications in terms of monetization? Previous research [5] identified three phases in the development of the market over the period from 2008 to 2018:

- Experimentation: Mobile device owners discover and experiment with new Apps. Download numbers increase precipitously.
- Adoption: Habits start to form, and users identify their preferred Apps while engagement with the Apps climbs. This phase is characterized by a steep rise in usage of Apps.
- Ubiquity: This phase is characterized by increased consumer spending.

So, the lessons-learned from the mobile App market is that once the consumer became accustomed to the concept of an "App store," the monetization opportunities and thus the revenue for the App providers increased (Fig. 7).

Fig. 7. Downloads, usage, and revenue in the global mobile app market

Consumers try out significantly more Apps than they actually keep on their mobile devices in the long term. Successful Apps are tailored to solving a specific problem for the user, have a lean feature set and great user experience [6] and are continuously replenished with fresh content [7].

Fig. 8. Flawless updates with useful features increase customer loyalty

Another lesson from the mobile App market concerns the architecture of the mobile devices. A standardized, modular, and flexible platform architecture allows features to be more easily integrated into an existing system.

A platform architecture partitions a system into stable core components and variable components. It enables new features to be added or existing features to be removed in tailoring the products to market needs. By promoting the reuse of core components, such partitioning can reduce the cost of variety and innovation at the system level [8].

Upgradability with new software-enabled features drives new E/E architectures also in automotive applications. It consists of multiple tiers, including an actuator tier, Domain Controllers (DCU), and the cloud (Fig. 9).

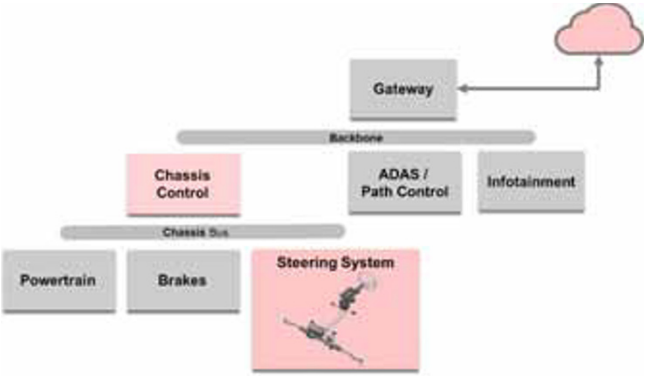

Fig. 9. Simplified view of the E/E architecture enabling new chassis functions

Functions such as time-critical motor controls are located in the Electronic Control Units (ECU) in the actuator tier. Customer-relevant features reside in the DCU and the cloud.

2 Chassis Apps

2.1 Safety

What kind of automotive Apps are consumers willing to spend money on? A 2019 Nexteer survey of 501 people confirmed an interest in safety-related Apps: 85% of respondents like to drive their car, and 77% either have been involved in an accident or are close to someone who has (Fig. 10). Thus, safety is on consumers' minds, but they want to continue to enjoy driving.

Fig. 10. Consumers like to drive but are safety conscious

A majority of the respondents (79%) regularly use Apps on mobile devices (Fig. 11). The familiarity with the concept of Apps will help with the introduction of Apps into cars and for chassis applications and might even be expected by the consumer.

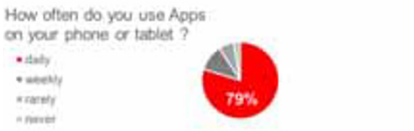

Fig. 11. Consumers are familiar with the concept of Apps

Proposals to pay more for specific safety-related warnings or vehicle stability are met with more mixed results. Among the respondents to the Nexteer survey, 48% said they would be willing to pay for multimodal alerts of a hazardous situation and 52% responded that they would be willing to pay to eliminate the risk of their vehicle sliding or spinning (Fig. 12).

Fig. 12. Consumers' willingness to pay for warnings and stability features

2.2 A consumer input on safety applications

A Lead User analysis [9] provides further insights. Lead Users are consumers who face the needs that will become general needs in the marketplace and who would benefit from a solution. And, more importantly, they have ideas and volunteer them, e.g. by participating in a study and thus being part of the extended product design team [10].

As part of this approach, 1701 contributors interacted with the research team via a web portal. Over 3 stages of interaction, the team identified 30 Lead Users. The ideas generated from this process can be summarized as follows: Consumers are looking for practical helpers that they can experience every day and that give them peace of mind and help them avoid surprises. If a situation should arise that overwhelms consumers, they need the helper to be available at their fingertips (Fig. 13). The solution includes multimodal communication, including visual, acoustic, and haptic communication between the driver and the vehicle.

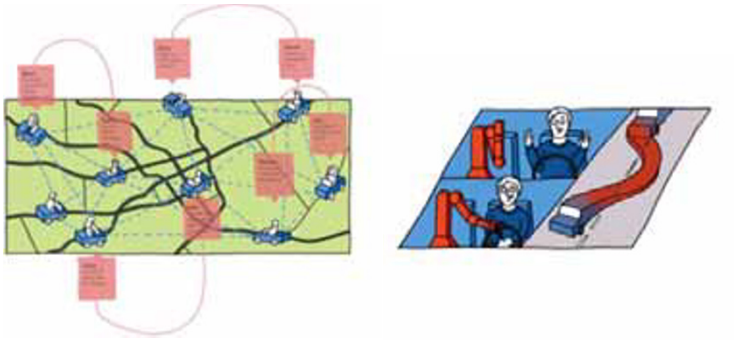

Fig. 13. Practical helpers for peace of mind and as a support net

3 Steer-by-Wire–enabled Safety Applications

3.1 Automatic Emergency Steering and Park Assist

Vehicle-initiated Automatic Emergency Steering (AES) and Park Assist are two functions that benefit from the introduction of SbW. In both applications, the driver can leave their hands on the steering wheel during the maneuver. At the same time, the vehicle communicates its intentions to the driver by giving directional cues via the reduced steering wheel angle (Fig. 14).

Fig. 14. SbW for vehicle-initiated AES and Park Assist

3.2 Shared Vehicle Control

But SbW can do even more to improve the safety of a vehicle. Its strength is the ability to communicate haptic cues to the driver that are independent from the actual steering angle. Thanks to this feature, shared haptic control concepts [11] become feasible and the steering wheel becomes a bi-directional Human Machine Interface (HMI) element.

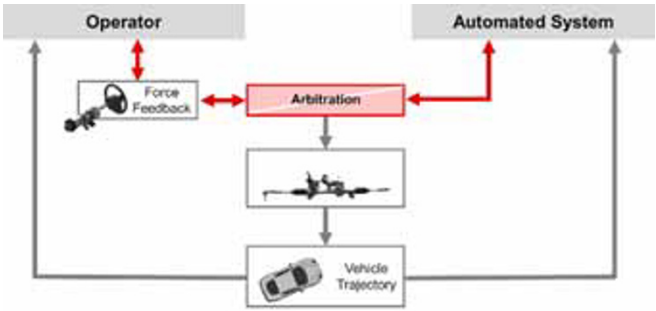

Fig. 15. Shared Vehicle Control enabled by SbW

A study by Nexteer [12] showed that such a control concept can help to manage issues of situational awareness, skills degradation, mode confusion, and workload fluctuation

during the handover from automated to manual driving. These types of applications support keeping vehicle behavior predictable and safe for the average driver in all driving scenarios.

An example is a lateral acceleration limiter to prevent understeer on low friction surfaces (Fig. 16). A crowd-sourced preview of the friction coefficient enables the stability limit to be determined before the vehicle hits an icy patch of road and thus reduces the system's response time. SbW can then be applied to limit lateral acceleration and provide stability control. The driver gets torque feedback that keeps them safe, similar to the feedback with Lane Keep Assist, and prevents them from "fighting" the system.

Fig. 16. SbW can keep vehicle behavior predictable and prevent understeer

As an outlook into the future, shared control algorithms will enable a guided automated driving mode (Fig. 17). Today, guided automated flight controls are applied in the aerospace industry to prevent the pilot from bringing the airplane into an unstable mode.

The character of the vehicle, its feel and behavior become entirely synthetic, i.e. customizable via software. The driver conveys their intent via the steering wheel and brakes, while the automation controls the vehicle in the safest possible way. The steering wheel offers additional degrees of freedom for the haptic communication between driver and vehicle.

This type of application is not yet ready for deployment. However, it was chosen to show that in a connected world, with the appropriate hardware architecture in place, including SbW, functions like this will be available for download and deployment without changing the hardware.

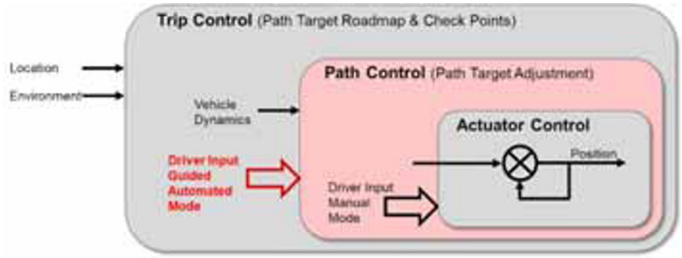

Fig. 17. SbW enables Guided Automated Driving mode

4 Summary

Connected vehicles will offer a new level of experience for the consumer. The vehicle will stay in permanent contact with its environment, the vehicle owner, and the manufacturer. The data and insights from those interactions will result in continuous innovation over the lifetime of a vehicle.

The ability to provide flawless updates of new features over the life of a connected vehicle builds consumer loyalty. Consumers value practical, safety-related features that result in peace-of-mind and real-time support if they should become overwhelmed in a driving situation, and thus these features offer monetization potential.

A standardized, flexible, modular platform architecture, which includes Steer-by-Wire, enables the upgrade and integration of new features that have not yet been developed, without changing the vehicle hardware.

Hence, in a connected, software-defined vehicle, the Steer-by-Wire platform enables unprecedented, future-proof customization and upgradability.

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