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Project report Life on Board

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1. Summary

As traditional mechanical systems are replaced by electromechanical shift-by-wire (SBW) solutions, new challenges arise for both vehicle developers and drivers. The increased degree of freedom in design and functionality can cause situations where selectors and instruments of a familiar system appear alien to the driver. From a safety perspective it was important to understand the relation between features that are technically viable to introduce as support for the driver, to the expected impact on vehicle safety. The purpose with the project was to build knowledge of how new gear shifter concepts would affect usability and hence traffic safety.

Three background related studies and four experimental studies were performed during the project. The results show that there are shifter solutions in production that creates unnecessary distraction and confusion during gear shifts. A normal gear selection differs with 1,42 seconds when average values are compared between a monostable and polystable joystick shifter. The 1,42 extra second demanded by the monostable shifter means reduced possibilities to avoid accidents. A joystick with a polystable J-shape pattern had the highest usability among the compared shifters in the project. Rotary shifters and the use of haptic clues could also be recommended. Another result of the project was three showcase shifters developed by Kongsberg Automotive mounted in a Volvo Concept Car.

The project not only built knowledge but also identified new problem areas. The knowledge gap has grown even though the project started to fill the gap. There is a clear need of continuing the knowledge building initiated through Life on board. Without extensive usability research new gear shifters could cost bad publicity, withdrawn cars, and last but not least, human lives. Therefore, the project parties attempts on applying for a continued project: Life on board 2.0. In the project both continued shift-by-wire challenges and new challenges related to autonomous cars will be addressed.

2. Background

As traditional mechanical systems are replaced by electromechanical shift-by-wire (SBW) solutions, new challenges arise for both vehicle developers and drivers. The increased degree of freedom in design and functionality can cause situations where selectors and instruments of a familiar system appear alien to the driver.

The necessity of actuating a selector arm (joystick) on the transmission with a rod or cable as mechanical linkage has left little room to maneuver when designing the shift pattern (Figure 1). Basically two major patterns previously dominated the market, a straight shift gate with a set of detents to help the driver avoid miss-shifts or a worm/serpentine gate where the detent functionality was replaced by transverse movement between shift positions. Hence, technical limitations streamlined the gear shifter user interface, which in turn meant that a high level of recognition and familiarity was experienced by the driver when handling different mechanical gear shifters. Introducing shift-by-wire technology voids earlier technical limitations. Some limitations are still imposed by legislation but the room to maneuver with user interface design, shift pattern and position in the vehicle is still significant.

Figure 1. A traditional worm gate joystick, a Mercedes ML350 stalk shifter and a Lincoln MCS button shifter.

Moving away from the traditional joystick shifter enables improvements in space efficiency, weight, ergonomics, crash safety, shift quality, functionality and ease of installation. Yet novel designs run the risk of alienating novel users and the functionality might be misunderstood in a stressful situation. Novel designs could increase the risk of distraction in a critical situation and cause miss shifts that lead to unnecessary accidents, accidents that could have been avoided with an intuitive or common shifter. There are also examples of unnecessary accidents that could have been avoided with more intuitive shifter designs.

New York Daily News (Donohue, 2015) describes a fatal accident caused by a miss shift. The driver stopped the car too close to a rail way crossing and the safety gate went down on her car. Witnesses to the accident describes that she went out of the car, tried to remove the safety gate, went back into the car and started to drive forward instead of backwards. The car was hit by the oncoming train and killed the driver and also five train passengers (Figure 2). The car was a Mercedes ML350 with a stalk shifter partly hidden behind the steering wheel (Figure 1) and the car model was new to the driver, which might explain the accidental miss shift. Another example of a gear shift related problem has created large amount of stress for the drivers and costs for Ford but not lead to any fatal accidents, luckily. Ford had to recall 13’500 Lincoln MKC during 2015 because drivers accidently pushed the on/off button when they aimed for the Sport-mode button (Isidore, 2015; Figure 1). The miss shift lead to sudden halts while driving in high speed and put the driver’s in large safety risk.

Figure 2. Accident caused by a miss shift. The accident took the life of six persons.

The new degree of freedom has already started to come into play and the variation in gear shifter concepts, shift pattern and functionality available on the market has significantly increased since the introduction of SBW technology. Uncertainty, misuse and mistakes had also been observed by both KA and VCC during test drives with novel gear selectors, yet no knowledge was available enabling quantifiable predictions on how certain user interface properties affect personal safety. Fitzgerald at BestRide.com (2015) points out; designers inventing new gear shifter concepts should not only focus aesthetic issues but also functionality. The designers should consider situations when “having to get the car moving while a stalker is walking up to the driver’s door or when a runaway cementer mixer is seconds away from crushing the car to a powder”, he emphasize. The problem was that knowledge about which design features that would support the driver in a critical situation and which would distract and confuse the driver was lacking. No guidelines were available. From a safety perspective it was important to understand the relation between features that are technically viable to introduce as support for the driver, to the expected impact on vehicle safety. This knowledge were requested by both OEM:s and sub-contractors.

3. Purpose

The purpose with the project was to build knowledge of how new gear shifter concepts would affect usability and hence traffic safety.

4. Procedure

4.1 Contribution and collaboration

All project parties contributed in the project equivalent to the project plan.
Weekly net-based meetings and larger project meeting, every spring and autumn, were held and lead by Kongsberg Automotive. During larger project meetings, results were presented and research questions for future work were discussed and set. In between the larger project meetings, Kongsberg Automotive and Luleå University of Technology met for workshops when needed. The workshops were either creative or solution oriented or more planning oriented. Workshops were also used for some data collection, i.e. a hazard analysis.

Kongsberg Automotive lead the project and arranged project meetings. Kongsberg Automotive developed all prototypes used in experiments and three concept shifters. Two experiments were also situated in Mullsjö and were performed in collaboration between Kongsberg Automotive and Luleå University of Technology.

Volvo Car Corporation contributed in guidance of research questions. Specific questions were added to meet specific industry interests. Volvo Car Corporation also contributed with a Volvo V60 that was re-build into a concept car. The concept car and showcase shifters were demonstrated during Volvo Powertrain week in 2015.

Luleå University of Technology lead the research performed in the project and arranged workshops. Luleå University of Technology were also responsible for most reports and publications.

4.2 Research procedure

Research questions and design of studies were discussed and decided in consent between the project parties. The initial research questions changed during the project. Some new questions arise and prioritizations were made. The project created knowledge both through background analyses and experimental studies. The background oriented studies included a hazard analyses based on the ISO 26262 method, a trend analyses based on images from the a2mac1.com database, and an international questionnaire. The international questionnaire was sent to the United States, Canada, Brazil, Poland, Sweden and China with 337 responses in total.

Four experimental studies were also performed. One study was performed in field, comparing three productions and one concept car. Three additional laboratory experiments were conducted. Simple desktop driving simulators were used, one with a car racing game and two with the Lane Change Task method. In the first laboratory study nine different shifter concepts with varying patterns and input types were compared. A second laboratory experiment was conducted comparing six different shifter concepts at three complexity levels: In the final experimental study a monostable joystick was used as baseline and compared to four different combinations with functions fragmented to buttons. Figure 3 shows an example of the prototypes used in the laboratory experiments.

Figure 3. Prototypes used in laboratory experiments.

4.2 Concept development

Three showcase shifters were designed and produced based on early research findings. The work was lead and financed by Kongsberg Automotive. Luleå University of Technology contributed during creative design workshops and with usability knowledge. Volvo Car Corporation contributed with a Volvo V60 that was modified.

5. Results

The project goals were met through acquired knowledge that differentiate the level of usability, and hence safety, between different gear shifter features. The results gained in the project create guidelines for a development of safer future gear shifter concept. Yet, there are still many questions that remain. The degrees of freedom in user interface design, brought on by shift-by-wire technology, create many questions and a need for new guidelines and knowledge about usability and the effects on safety. The knowledge building started through this project but needs to be continued. The research findings that will assist future shifter development are presented in short here:

Hazard analysis. The hazard analysis identified 42 hazardous miss shifts and situations that were classified as important to consider in design. Example of situations in which a miss shift could be hazardous would be when driving in, at, or close to crossings, in thigh surroundings, in overtake situations, and in parking situations. Most of the hazards were considered difficult to control by locking functions or automation. Instead the safety goal would be intuitive designs that reduce confusion and miss-use.

Trend analysis. Between 2005 and 2008 there were only joystick shifters, puck shifters and button shifters represented in concept cars according to the A2mac1.com database. A clear decline of the most common joystick shifter and also polystable patterns was noticed after the year 2008. After 2008, concept cars also included monostable patterns, rotary shifters, stalk shifters and shifters with touch control.

International questionnaire. No differences in gear shifter preferences were found between countries. The most common shifter type and placement – a joystick shifter placed in the console between the seats – were also the most preferred, except for Micro cars and Executive cars. A joystick might feel too large in a small car and too common in an exclusive car The RND order of driving modes was only natural for rotary shifters. For button shifters and joystick shifters a DNR order was preferred.

Field study. A button shifter (concept car) and a rotary shifter (Jaguar, polystable) had higher usability than a joystick shifter (BMW, monostable) and a stalk shifter (Mercedes, monostable) compared in the study. The joystick shifter and the stalk shifter needed more instructions and caused more errors. Still, the joystick was the most preferred shifter. The stalk shifter was the least preferred.

Patterns and types. In the study, three shifter concepts resulted in lower performance (i.e. longer gear location times) compared to other concepts. These three shifters were a joystick with monostable and linear pattern, a joystick with toggle function, and a button shifter lacking haptic clues. Due to safety reasons, the shifters could not be recommended. Increased gear location time and increased glances or long glances off road creates unnecessary risk in critical situations and violates safety. The most preferred shifter, which also got the best performance results, was a rotary shifter with haptic clues.

Complexity. The patterns and types-study raised questions about complexity level. The previous study only included RND in the patterns. In the complexity study three levels of complexity were compared: RND, RNDM, and PRNDM. As could be expected, task completion time increased with increased complexity. Only two shifters were unaffected by increased complexity, a polystable joystick (J-shaped) and a polystable rotary shifter. In general, polystable shifters, both joystick and rotary, had higher usability than monostable and toggle shifters. The task completion time for a monostable joystick were in average 1,42 s longer compared to a polystable joystick at a complexity level including PRNDM. The effect was large enough to significantly reduce the driver's possibilities to avoid an accident in a hazardous situation. As concluded in the previous study, monostable and toogle functions could not be recommended due to safety concerns.

Fragmentation. In this study a monostable joystick was research further with drive modes fragmented to buttons. Five combinations were compared: no buttons, a P button, a M button, both P and M buttons or P, N, and M as buttons. The hypothesis, that a monostable joystick could be simplified with functions fragmented to buttons, was rejected. Fragmentation increased rather than reduced complexity when combined with a monostable joystick.

5.3 Effects on safety

The difference in gear selection time between different gear shifters would have an impact on accident risk in a critical situation. One such situation would be when a driver should enter a larger road and an oncoming car forces the driver to stop the entering and reverse the car away from harm. Findings in the project shows that the time to select reverse and move out of harm would differ depending on the type of gear shifter installed in the car. With a polystable joystick (P-R-N-D-M, J-shape) the preventing action would take 4,18 s in average. However, if a monostable joystick (P-R-N-D-M, J-shape) was installed, the action would take in average 5,60 s instead. That means, with a monostable joystick the shift would take 1,42 s longer than with a polystable joystick. The actions to detect harm, brake, accelerate, and reverse the car out of harm were included in the calculations and estimated to 2,1 s. Figure 4 illustrates what the difference in time would mean in terms of distance needed to the oncoming harm in order to avoid an accident. The monostable joystick would require a distance of 35,4 m longer to the oncoming harm than a polystable joystick to avoid a crash. This example illustrates that prolonged gear selection times creates additional risks and violates safety. Moreover, in a real situation, stress and fear would most likely reduce the driver's cognitive skills and even longer reaction times could be expected. Therefore, the gear selection time do matter and legislations should be considered.

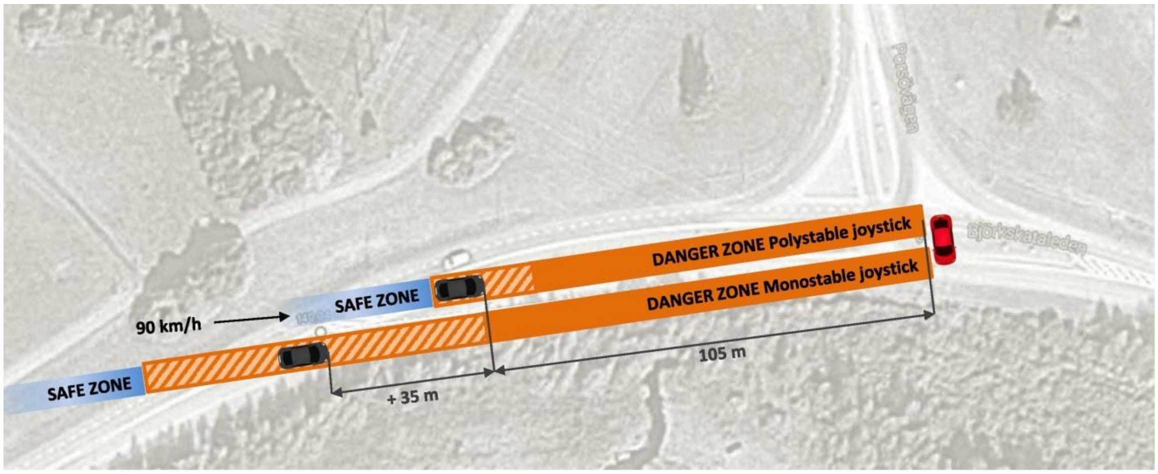

Figure 4. Distance needed to oncoming harm to avoid accident. The striped areas represent the variance of participant results. A monostable joystick creates a more dangerous situation than a polystable joystick.

Cognitive load and stress might also cause confusion and a miss shift. If the driver would make a wrong selection, for example select drive (D) instead of reverse (R), the time to avoid the accident and the distance needed to the oncoming harm would increase to approximately the double. Figure 5 illustrates a situation with a miss shift at a rail way crossing, similar to the accident described in the background. With an oncoming train in a speed of 200 km/h, the driver would need a distance of approximately 311 meters to have time to reverse from harm with a monostable joystick. If the driver would make the same mistake as in the accident and select drive instead of reverse and then change to reverse, the distance needed to the train would increase with approximately 319 meters. The driver in the train accident, mentioned in the background, did not have enough time and distance to correct her miss shift. The confusion of gear modes took the life of six persons. This example illustrates the need of intuitive designs that reduce the risk of confusion. For example, a DNR order instead of RND would better correlate to the car movement. However, previous experience might also matter. These questions remain and needs to be further studied.

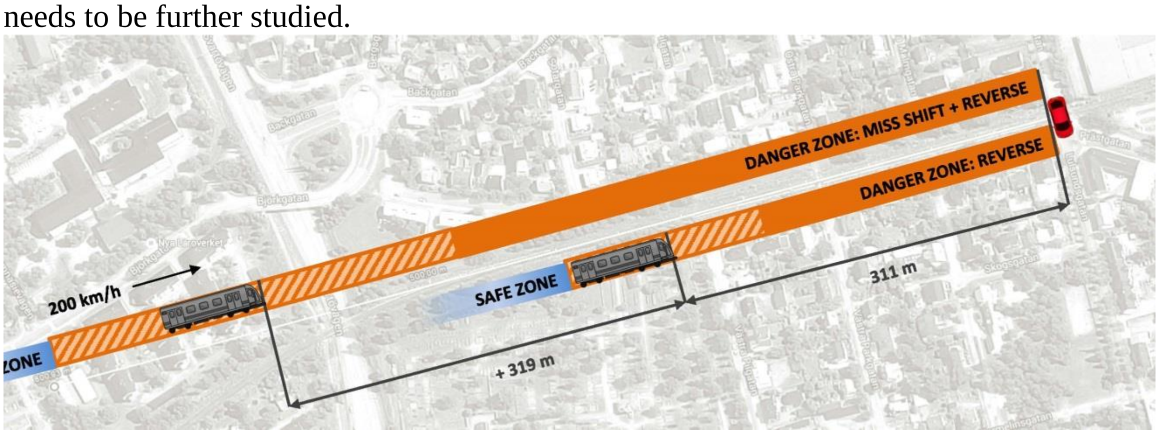

Figure 5. Distance needed to oncoming harm to avoid accident with a monostable joystick. Difference between a correct shift compared to a miss shift and correction. The striped areas represent the variance of participant results. During a miss shift, a distance less than 481 m to the train will end in a fatal crash.

5.4 Three concept shifters

Based on early research findings in the project, three concept shifters were developed. All project parties took part in the development through workshops and discussions lead by Kongsberg Automotive. Several sketches were made and the final concepts were developed by Kongsberg Automotive at a TRL-level 6. The concepts could not be presented as images here due to patent writing. In short, the three concept shifters were one joystick shifter, one rotary shifter and one button shifter. The joystick shifter got interactive information intended to reduce memory load and miss shifts. The rotary shifter was combined with buttons intended to reduce a common noticed miss shift and memory load. Finally, haptic clues were used in the button shifter concept with intention to make the buttons easier to locate without taking eyes off road. The concepts were demonstrated and tested during real driving at Volvo Powertrain week 2015-09 (Figure 6).

Figure 6. The three concept shifters were displayed and tested during real driving at Volvo Power Train week.

5.5 Contribution to FFI goals

- The knowledge built in the project was beneficial for the industry already during the project. Kongsberg Automotive can testify to the great demand for project learning experiences noticed in contact with companies. Hence, the knowledge building has put the industry parties in a stronger position on the market.
- The project has provided clear guidelines that increase the industry's knowledge of secure user interfaces. The knowledge will be used and be of benefit when future gear selector are developed.
- Project results enable a development of future gear shifter generations built on safety and contribute to reduce unnecessary accidents. That in turn prevents the strong Swedish brand of safety from being jeopardized.
- The project has demonstrated good cooperation between industry and universities to which all parties have benefited. One result is thus a strengthened network and a desire for continued cooperation exists.
- The project has given the Academy the opportunity to strengthen the industry influence in education through student assignments related to the project. Three courses have been linked to the project.
- The project has also given the Academy the opportunity to publish research results of high international value.
- The project will lead to an application for a continuation project.
- At least one patent are processes as a result of the project. The process does not have an patent number yet.
- At least three academic publications are expected to be published as a direct result of the project.

6. Dissemination and publication

6.1 Communication of knowledge and results

Several car developers over the world have shown interest in the project and follow the knowledge building with great interest. The trend towards more and more non-traditional gear shifters based on shift-by-wire technology creates a request for safe design guidelines. Shift-by-wire technology creates new opportunities to save space, integrate functions or build stronger brand identities. However, no brand would gain from increased accidents and complaints. The results provided by the project will therefore be of great value for Volvo Car Corporation, Kongsberg Automotive and their partners. The results will also be spread worldwide through research publications and research conferences after the project.

The project parties would like to continue the knowledge building through continued collaboration in research projects. Volvo Group has also showed interest in joining the collaboration.

6.2 Publications

Several publications will be published as a result of the project. The project results were evaluated as important at a high and international research level. During the project data collection and research was prioritized. Manuscripts are in preparation and will be submitted after the project. The field study was presented as a poster at HFES Europe Chapter in the Netherlands, 2015. A folder presenting the results was also printed and used as hand-outs at Volvo Powertrain week, at the HFES conference, and in contact with other industries.

7. Conclusions and future research

The introduction of shift-by-wire technology creates many new opportunities regarding changed shifter designs. There are also several incentives to change the design and one is to save space. Knowledge of how and if the shifter could be changed without violating safety was lacking. The project started to build knowledge that could save many lives. The results show that there are shifter solutions in production that creates unnecessary distraction and confusion during gear shifts. A normal gear selection differs with 1,42 seconds when average values are compared between a monostable and polystable joystick shifter. The 1,42 extra second demanded by the monostable shifter means reduced possibilities to avoid accidents. A joystick with a polystable J-shape pattern had the highest usability among the compared shifters in the project. Rotary shifters and the use of haptic clues could also be recommended.

The project also identified additional variables and possibilities that could ease usability and reduce confusion. Feedback in terms of haptic clues and information displays are believed to help the driver to identify different shift modes and build a correct mental model of the system. There are also interesting and untested shifter patterns that the project had to save for later projects. Moreover, development in the car industry towards more integrated functionalities and self-driving cars adds new challenges and risks. The gear shifter could get an extended role as input device during autonomous driving. However, there is no known research yet that could guide such a development. The knowledge gap has grown even though the project started to fill the gap. There is a clear need of continuing the knowledge building initiated through Life on board. Without extensive usability research new gear shifters could cost bad publicity, withdrawn cars, and last but not least, human lives.

The project parties attempts on applying for a continued project: Life on board 2.0. In the project both continued shift-by-wire challenges and new challenges related to autonomous cars will be addressed.

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