

TECHNOLOGY NEEDS FOR SAFE ELECTRIC VEHICLE SOLUTIONS IN 2030

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ABSTRACT

Today's society depends heavily on the mobility of people and goods and the need for transport is predicted to grow strongly in the coming decades. Environmental and energy concerns create a strong demand for alternative automotive technologies and in particular for electric vehicles. A serious limitation of large scale introduction of electric vehicles is the limited storage capability for electrical energy of the current generation of batteries and capacitors. Furthermore, there is a strong trend to design significantly lighter vehicles needed to consume much less energy, and to introduce new vehicle architectures due to specific demands of electric vehicles like hub motors, relatively large space needed for batteries etc.

Without new safety technologies there is a large risk that the new vehicle designs will become less safe in case of accidents. In a project recently conducted in Sweden, called SEVS (Safe Efficient Vehicle Solutions), the necessary technologies for the 2030 generation of environmentally friendly safe vehicles have been identified. The SEVS project has resulted in a number of possible societal scenarios for 2030 and a number of future vehicle architectures. Furthermore SEVS has identified the required technological breakthroughs for passenger transport as well as the transport of goods, to realize mass introduction of high efficient and safe electric vehicles on the road in 2030.

This paper will after an overview of the SEVS project focus on a number of safety related technology topics, identified in SEVS, where significant further research is needed, i.e. balance of active/passive safety, light weight design methodology, crashworthiness of future vehicles and "information needs and availability".

An overview of research needs for these topics will be presented.

INTRODUCTION

Today's society depends heavily on the mobility of people and goods and the need for transport is expected to grow even further over the coming decades [1]. Environmental and energy concerns create a strong demand for alternative automotive technologies. An attractive alternative for future motorized transport of persons and goods will be electric vehicles (EV's) and market introduction of a number EV models has started. Most of the EV designs appearing on the market rely largely on existing technologies. For significant breakthrough's in EV's in the longer term however new enabling technologies will be needed.

A serious limitation of large scale introduction of EV's is the limited storage capability for electrical energy of current generation of batteries and capacitors. Furthermore, there is a strong trend to design significantly lighter vehicles needed to consume significantly less energy, and to introduce new vehicle architectures due to demands of EV's (hub motors, relatively large space needed for batteries etc.).

Without new safety technologies there is a large risk that the new vehicle designs will become less safe both in terms of electric and fire safety (high voltage and potentially explosive energy storage systems) and accident safety. On the other hand, new components in EV's might open up for better/other safety solutions than today, if safety is taken on board in the requirements already in the

initial (concept) phase of the vehicle design process.

In a project recently conducted in Sweden, called SEVS (Safe Efficient Vehicle Solutions), the Swedish industrial and research expertise and experience in efficient power trains and vehicle safety has joint efforts to identify the enabling technologies for the generation of safe and green vehicles on the road in 2030. A large number of partners have participated in the project: the vehicle manufacturers SAAB, Volvo Car Corporation and Volvo AB (Volvo Technology) and their supplier Autoliv,; the consultant companies Eteplantech, Semcon and Epsilon; the research institutes SP, Swerea SICOMP AB, Viktoria Institute and the authority VTI. The project has been conducted by the Centers of Excellence SAFER (Vehicle and Traffic Safety Centre) and SHC (Swedish Hybrid Vehicle Centre), which are both related to Chalmers University of Technology in Sweden.

The objective of SEVS was to develop new knowledge to understand the technology, strategies and the principle solutions needed for a new generation of vehicles 2030, which fulfil high standards on both safety and environmental aspects. The level of safety offered to road users should be significantly higher than the level of safety offered by the current generation of ICE-powered vehicles. The new generation of vehicles should address the need for short range (city) as well as long-distance travel either by modular solutions or by having different solutions.

Specific objectives of SEVS were:

1. To identify and analyse the driving forces that shape the future society, and describe four extreme societal scenario's for 2030
2. To identify of a number of promising virtual new vehicle design concepts for 2030
3. To identify the required technological breakthroughs and research needs both for passenger transport as well as the transport of goods to realize mass introduction of high efficient and safe electric (and hybrid) vehicles on the road in 2030.

For passenger cars the target in SEVS was set to reach a reduction of energy consumption by 80% as well as a reduction in fatalities of also 80% by 2030+.

Concerning objective 1, SEVS has resulted in 4 societal scenarios that are illustrated in Figure 1. The scenario process is the result of a detailed analysis of groups of driving forces including demographic trends, life style changes, politics, environmental impact etc... Two of the driving force groups namely "politics" and "personal values" were identified as drivers with the largest

uncertainty and with the largest impact on a future sustainable and safe transport system.

The 4 scenarios shown in Figure 1 have been based on these two groups of drivers. The x-axis corresponds to personal values (in particular concerning travelling) and the outcome of this driving force varies from *no change* (left) to *radical change in transportation patters* (right). The y-axis corresponds to politics (in particular concerning transportation legislation and incentives) and varies from *political passive* (bottom) and *proactive political control* (top). The resulting scenarios in the 4 quadrants are denoted: *Incremental development*, *eco political*, *eco individual and radicalism in harmony*, respectively. For more details on the work done in SEVS related to drivers and scenarios please refer to [2].

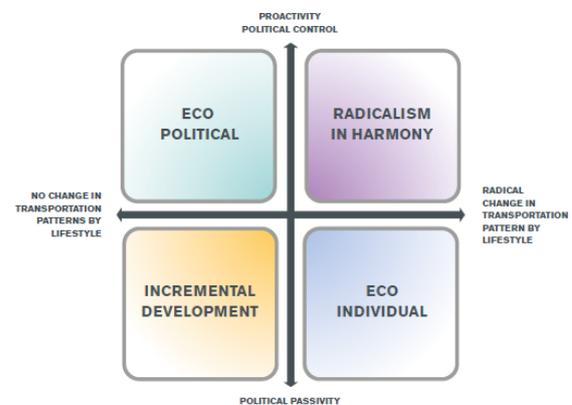


Figure 1. The 4 different societal scenarios resulting from the SEVS project

Concerning objective 2, SEVS produced seven different vehicle concepts (virtual demonstrators) with different placements of electric drive-train components. The concepts included 3 different city movers each linked to a different societal scenario, 2 long distance vehicle linked to 2 societal scenarios and a medium-heavy truck and bus also linked to 2 of the scenarios. Figure 2 illustrates the various concepts as well as their link to the various societal scenarios. The main drivers for the developments of these vehicle design concepts where vehicle safety, lower environmental impact and lower energy consumption, taking the specific characteristics of the 4 scenarios into account. The development of the vehicle concepts influenced also the selection and prioritization of the required technology developments for 2030 (objective 3 of SEVS). More details on the concept development can be found in [2].

This paper will further focus on objective 3 of the SEVS project: the identification of the required technological breakthroughs and research needs for EV's in 2030. In the next section first the process and methodology in SEVS to identify the most important technology topics for EV's in 2030

will be described. Seven of these topics appeared to have a high impact on safety. Out of these seven topics, 4 topics where significant further research is needed, will be presented in more detail namely balance of active/passive safety, light weight vehicle design, crashworthiness of future vehicles and “information needs and availability”.

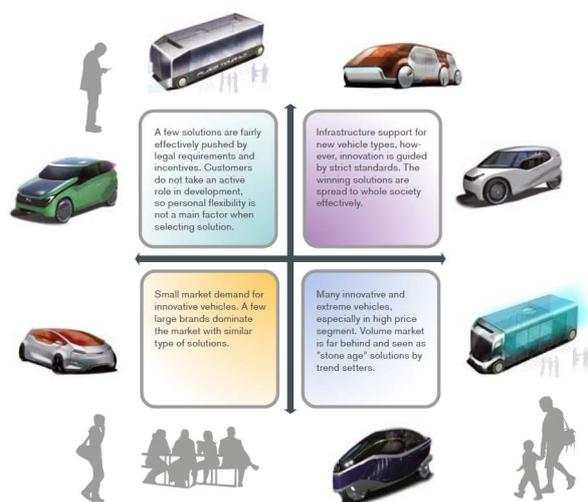


Figure 2. The SEVS project resulted in 7 different virtual vehicle concepts each linked to one of the 4 societal scenarios.

METHOD

The first step in the process of identifying the most important technology research questions was a review of the various technologies needed for electric (and hybrid) and a future outlook of technologies to be developed. The technology area's considered as critical at the start of SEVS for future electric vehicles were:

- Light weight construction
- Batteries
- Sensors, control and communication
- Driveline
- Safety
- Infrastructure

In the next section a short description of these 6 technology areas is presented.

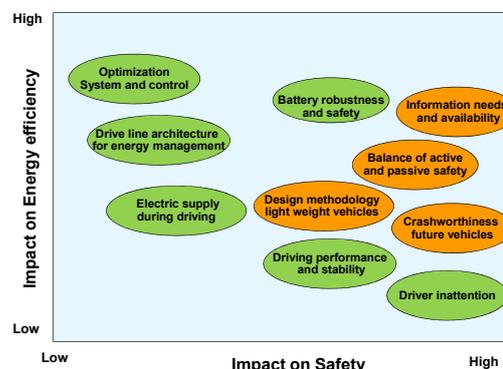
For each of these 6 technology areas a group of experts has reviewed the state of the art for that technology, including its dependency with other technologies, starting with existing technology roadmaps for these areas, interviews with other experts etc... A roadmap of R&D needs for that specific technology was developed and subsequently discussed and finalized in a joint workshop. As a result of this process 6 technology reports have been produced (internal SEVS reports).

The technology teams were also asked to define for their technology field the most important research topics. This resulted in more than 60 technology research topics considered to be of high importance. In a joint workshop involving all experts from the various technology teams the various topics were prioritized concerning their impact on future safe and green transport solutions, keeping the targets set in SEVS for 2030 in mind: a reduction of energy consumption (from well to wheel) by 80% and at the same time an 80% reduction in fatalities. Also an integration and refinement of some of the research topics took place during this workshop.

A further reduction and prioritisation of the research topics took place by:

- (1) Taking into account the priorities resulting from the vehicle concept development task,
- (2) A review of the various research topics by the key organisations involved in the SEVS project. These organisations were invited to identify the areas which were considered most relevant for their organisation in view of the possible transportation needs in 2030 as identified by the 4 scenarios developed within SEVS
- (3) An external workshop with a large number of stakeholders.

This process finally resulted in a list of the 10 most important technology research topics presented in Figure 3 (Top 10 list). The research topics are presented in this Figure according to their estimated impact on energy efficiency (vertical) and safety (horizontal). Seven of the research topics have a large impact on safety and out of these 4 topics (orange in Figure 3) will be discussed in more detail in this paper.



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Figure 3. Top 10 technology research topics prioritized according their impact on energy efficiency (vertical) and safety (horizontal).

TECHNOLOGY AREAS IN SEVS

Lightweight Construction

To meet the demands for lightweight in future electric and hybrid vehicles the use of lightweight metals including aluminium and high-strength steels and non-metals like polymer composites in automotive structures is crucial. Examples of material technologies that need further development before economical application in automotive is possible includes carbon fibre reinforced polymers that present outstanding potential for weight reduction, innovative multifunctional polymer composite materials, providing combined load-carrying and electrical energy storage capabilities and intelligent materials that can optimize their properties in various accident conditions.

Batteries

Future electric and hybrid vehicles will rely on batteries for power support and energy storage. Lithium-ion batteries (like those used in laptops) are today the most volume and weight efficient battery technology for electric energy storage onboard vehicles. However, the adoption of the technology has for several reasons been slow in the automotive industry. The battery chemistry is inherently unstable causing severe concern about the safety onboard a vehicle, especially when subject to external damage. The cost has been (and is still) high, making storage of large amounts of energy onboard a vehicle economically unfeasible. Battery lifetimes substantially shorter than the rest of the vehicle have also been limiting. The technical development is however rapid, and batteries better adapted to the demanding constraints in vehicles are now entering the market, and a further fast development can be expected. Thus, inherently safe batteries, with better lifetimes and at lower costs are to be expected. However, when it comes to energy density only moderate improvements can be expected, at least in a short and medium time frame.

The capacity of the battery will continue to severely limit the electric driving range of plug-in and all electric vehicles. Improvements must therefore rather rely on better integration of the batteries in the vehicles and the development of vehicles with lower total energy demands. Abuse tolerant batteries able to withstand collisions without being damaged are required and this aspect must also be included in the integration of batteries in vehicles.

Sensors, control and communication

A large market growth can be seen for sensors and electronic components leading to increased telematics and vehicle system control possibilities.

This includes navigation systems in combination with digital maps and traffic information and information about adjacent vehicles achieved by radar or lidar (laser based “radar”) and vehicle to vehicle communication. This development is also creating new serious problems in particular concerning reliability and robustness (fault tolerance) of electronic and intelligent (embedded software) systems. Integrating these, up to now, often separate information sources can yield a more reliable, more accurate and cheaper measurement solution for all kind of applications in and around the vehicle and a multivariable reliable system control approach becomes feasible (adaptive systems).

Driveline

The electric or hybrid-electric driveline needs to include safety requirements already in its design and optimization. The type of driveline selected will have fundamental influence on the vehicle architecture and thus on the safety level. Electric motors can be moved to completely different parts of the vehicle and so can the battery and power electronics. Thus the weight distribution and the room for crash structure can be very different from today’s vehicles. Considering safety implications when optimizing the driveline is a necessity in order to find an architecture which has a balance between safety and cost effectiveness and fuel economy.

The driveline can optimize the fuel economy significantly better if it has access to information about surrounding traffic and the road conditions ahead. Knowledge about future accelerations or braking profiles as well as road conditions will allow an optimized use of the energy storage and the different parts of the driveline. The same type of information is also an enabler for many advanced active safety systems, and thus coordinated development of the traffic and road information system may benefit both areas.

Safety

Active safety (accident prevention) will play a much larger role in the future, but further progress in passive safety (injury prevention) will also be necessary, if the target of considerably safer traffic shall be met. Many future vehicles for transportation of people will be smaller and lighter to save energy. To make these vehicles safer to people inside the vehicle (car occupants) as well as to those outside (vulnerable road users) is a challenge, difficult but not impossible. Conventional boundaries between passive and active safety are disappearing rapidly leading to a new, more overall approach to safety.

In future hybrid and electric vehicles, the added flexibility of electric drive actuators can provide more vehicle dynamics functionality. It will be

possible to estimate road surface conditions with less effort. EV's with lightweight design and new vehicle concepts (e.g. low speed city vehicles and modular vehicle combinations) give opportunities to decrease energy consumption and increase active safety. New motion stability problems might arise caused by regenerative braking together with the fast dynamics for low weight vehicles or the complicated dynamics of vehicle combinations. It is also important to consider how existing vehicle dynamics functionality (e.g. ABS, TCS, ESC) can be migrated in a safe way and improved for electric vehicles.

Concerning passive safety many new and improved protection possibilities will become available due to improved pre-crash sensing (of relative speed and direction to impact/impacting objects and identification/classification of impact/impacting object).

The effect of the added battery mass (more severe crash pulses) on the loading of car occupants in frontal and side impacts needs to be taken into account.

Vehicle-to vehicle compatibility for various impact conditions (frontal, side, rear) and for impacts between vehicles of different sizes (truck, SUV, small car) is very important and must be improved.

Infrastructure

A good infrastructure domain is crucial for electric vehicles in particular for fast, safe and efficient recharging of batteries. The infrastructure provides the road authority the possibility to allow for a better and safer traffic situation for low weight, energy efficient vehicles by providing incentives for their use. Possible options are special lanes but also other possibilities will be reviewed. An advanced communication infrastructure (V2I communication) is important both from the safety point of view as for lowering energy consumption, for instance by providing safe and shortest road to the destination information using novel sensors and traffic systems etc...

EXAMPLES OF SAFETY RELATED FUTURE RESEARCH TOPICS RESULTING FROM SEVS

Design methodology for lightweight vehicles

Objective The objective is to develop knowledge and methods to win acceptance and confidence for high performance composites and mix material lightweight design (LWC) solutions in crashworthy automotive applications. Of specific importance are:

- Development of material and structural models of composites for crashworthy LWC solutions related to the adopted manufacturing process, typically comprising forming of the material undergoing mechanisms such as: solid-fluid wet-out, solid consolidation and solidification. The modelling will be developed in a CAE perspective, focusing material and structural properties at failure and energy dissipation, linked to the manufacturing process.
- Testing, validation and further development of CAE methods for high performance composites in the field of crash. This includes evaluating material models and elements for crash CAE. Simplicity in terms of needed material data and methods to obtain material data and mapping of process history is important.
- Development of joining strategies and technologies for mixed materials interfaces like: composite-composite, composite-metal and metal-metal solutions in the context of a LWC electric vehicle 2030.
- Design guidelines for automotive composites comprising thermal insulation, design limitations and affordability issues.

Motivation In many applications, such as the car body structure, it appears that high performance composites is the alternative with the highest potential for lowering weight, while still maintaining the proper crashworthiness. In order to meet the requirements on robust and crashworthy light future electric vehicles based on high performance composite materials or other lightweight materials, the development of material- and structural models for composites is crucial [3]. This concerns both the development of new material- and structural models and the development of design methodologies based on well established models. Focus will be on the material- and structural properties as a result of the manufacturing process. In addition an increased application of a mix of lightweight materials such as carbon fibre reinforced polymers (CFRP) and the light metals aluminium, magnesium and possibly titanium can be expected. These materials have applications in different structures, but there will also be a mix of these materials in the same structure, such as mix material unibodies. This means that robust joining technologies for the new mix of lightweight materials, like adhesive joining, rivets, co-curing and/or bolting, need to be developed. To win acceptance and confidence in the automotive design and engineering process new LWC solutions must be implemented with concurrent design guidelines for integration of LWC materials in the vehicle.

Balance of active and passive safety

Objectives It is generally believed that large improvements of vehicle and traffic safety in the future can be achieved by various new active safety measures. In order to save energy for transportation of people on the roads in 2030+ the vehicles have to be smaller and lighter. This is a challenge for the passive safety. The need of passive safety may increase instead of decrease. New active safety measures will avoid many accidents from happening, but they will not eliminate the risks. Accidents will still take place. Pre-crash sensing systems and other systems (like V2V and V2I communication) for intervention of active safety systems will not be 100 percent reliable. If the speed of a vehicle is high enough a crash cannot be avoided.

The main objective, therefore, is to find the balance between active and passive safety measures for accident and injury prevention for the most common and typical accident situations. These situations have to be defined based upon data from available in-depth accident data bases and, if possible, supplemented with sequences recorded in Field Operational Testing and Naturalistic Driving studies. The objective for each type of accident is to develop a method and to use it to estimate how much various active and passive safety measures (to be defined for each case) for the various types of vehicles in the different traffic environments, as outlined in the four different scenarios in the SEVS project, will reduce the risk for people involved (vehicle occupants and/or vulnerable road users) of sustaining injuries of different severities. What measures will have the greatest potential for improvement of the safety in the four different scenarios? This will be a guide for those working with development of future safe and energy efficient vehicles as well as for those working with road infrastructure and communication (V2V and V2I).

Motivation There is a consensus that future vehicles for transportation of people have to be smaller and lighter to save energy regardless of propulsion system. Smaller vehicles will also have a smaller “foot print”, which will improve the traffic flow. To make these vehicles safer to people inside the vehicle (car occupants) as well as to those outside (vulnerable road users as pedestrians and bicyclists) is a challenge, difficult but not impossible. Active safety (accident prevention) will play a much larger role in the future, but further progress in passive safety (injury prevention) will also be necessary, in order to meet the target of considerably safer traffic. Since vehicles must be affordable there is a great need to also have the economy in mind when developing new safety measures. It is therefore important to study which safety measures (active and/or passive) have the greatest potential to improve the safety in various common and typical traffic

accident situations. Only solutions that are both very safety effective and cost effective will have a chance to penetrate the market.

Crashworthiness of future vehicles

Objectives The objective is to develop knowledge and methods to design the vehicle architecture of future electric small vehicles (City Movers) for an increased protection of its occupants in a crash (in comparison with the protection offered by current vehicle designs) and to protect batteries during a crash in an optimal way. Two areas are of specific importance:

- Protection in frontal impacts. The front end structure should be adaptive to type, severity, and location of impact. It must be compatible in collisions with vehicles of various heights and it should allow the front end structure to easily slip off the other vehicle in a frontal collision.
- The vehicle should offer geometrical compatibility in side and rear-end impacts involving larger and higher vehicles.

Motivation In spite of the large progress in technologies that have become available to help avoiding that an accident would happen, also in the future not all accidents can be prevented and consequently vehicles should be designed in such a way that they offer optimal protection to their occupants in case a crash would happen. This challenge is particular of importance in case of future lightweight and small, green electric vehicles. Smart solutions are necessary to enable lightweight vehicles with reduced carbon footprint and improved safety [4].

The most critical issue for the passive safety of future small cars is the design of the vehicle structure (vehicle architecture). The passenger compartment must retain survivable space for the occupants in any type of accident (front, side, rear, rollover etc.). Geometrical compatibility with other vehicles is important and this compatibility must be much better than today. The challenge for small vehicles is particular also in frontal collisions. The front end structure of future smaller vehicles needs to be more energy absorbing than structures of cars today in order to allow the car to become shorter.

From accident investigations it is known that most vehicles rotate and translate after impact. This lowers the crash pulse in the longitudinal direction of a car compared to an impact without such motions. The structure of future smaller vehicles should be designed in order to optimize these rotational and translational motions.

Information needs and availability

Objectives Research will be based on accident data with the aim to develop understanding of what type of information available to an advanced active safety system could have prevented the accidents. The main objectives are:

- To find what information is necessary for the function of driver independent active safety systems. This information includes knowledge about the state of the own vehicle, other vehicles and pedestrians, the road and its condition etc.
- To find what information is necessary for energy efficient driving. This information includes knowledge about the map, the traffic situation locally and along the route, availability of parking places etc.
- To understand and report the general availability of this information based on fundamental limitations of sensors and radio communication.
- To quantify the limitations of radio communication and satellite bases positioning.

Motivation From a theoretic point of view an automatic driving system can avoid accidents if it has complete knowledge about the local situation. Some of this information is available and used already today. This includes cameras detecting lane marks, radars detecting vehicles etc. The energy consumption can be minimized if sufficient knowledge about the route is available. The local situation influences directly the drive line control. The data collected by the vehicle will be used for information, warnings and active intervention. Inaccurate information and false warnings are confusing and disturbing but an active intervention based on insufficient or erroneous information may in itself cause an accident. The decision making must take this into account. The validity, accuracy and completeness of the information must be a part of the decision process. The possibilities of satellite positioning and vehicle communication in critical safety systems are not well understood yet. The limitations in accuracy and reliability decide for what active systems application is feasible. Some of these limitations concern fundamental problems in wave propagation.

DISCUSSION AND CONCLUSIONS

In this paper the technology research questions defined within the SEVS project as well as the selection and prioritization process leading to these questions is described. Also a brief overview of the work done in SEVS related to drivers and societal scenarios for 2030 as well as the work leading to a number of vehicle concepts for 2030 has been presented.

Focus in this paper is given to the following research questions relevant for green and safe future transportation solutions:

- Balance of active and passive safety
- Design methodology lightweight vehicles
- Crashworthiness future vehicles
- Information needs and availability

In the discussions on research questions also a number of possible research areas of a non-technological nature (societal, political) were identified but not extensively elaborated in SEVS into specific research questions. Examples of such research areas are: expected traffic flows in megacities, special infrastructure for different road users, new business models for mobility, user expectations etc.. Such questions are, even more than most of the technology research questions, heavily depended on future societal and political scenarios. A continuation of the SEVS project is in preparation were both technical and non technical research questions will be addressed in a holistic approach.

ACKNOWLEDGEMENTS

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