ELECTRIC VEHICLES - REVIEW OF TYPE-APPROVAL LEGISLATION AND THE IDENTIFICATION AND PRIORITISATION OF POTENTIAL RISKS

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ABSTRACT

The introduction of electric vehicles provides opportunities for new mobility solutions. The extent to which these opportunities are realised depends on the accompanying regulatory framework. Current regulatory frameworks have developed around the internal combustion engine (ICE) and in response to observed problems - an example being the initial development of the FMVSS. For e-mobility, these frameworks need to be revisited and adapted for the new mobility paradigm. The problem faced by regulators is the accelerated pace of technology change is incompatible with the pace of regulatory development. Although the problems associated with the move to e-mobility are understood, the issue has been how to ensure that the transition to a regulatory framework is conducive to the introduction and continuing innovation in the e-mobility sector whilst avoiding technology lock-in. The approach taken here is to develop and trial a methodology that looks to prioritise the problems and to enable the regulator to focus on development of regulation in parallel to the uptake of e-mobility. The proposed approach consists of three phases. These are: a thematic analysis - to provide a measure of e-mobility development; a functional system breakdown - to identify the areas in which regulation is challenged; and a failure mode effect analysis - to prioritise the development of regulation in those areas in which are found to be deficient.

This work is ongoing and as such only the methodology is described in this paper with the use of exemplars. The work is part of the ENEVATE project, which is a JTS INTERREG IVB funded project.

INTRODUCTION

The pressures of rising fuel costs coupled with the need to meet ever stricter emissions targets, such as those outlined by Europe 2020 (European Commission, 2010), are driving the search for alternative propulsion methods for passenger cars. Of the competing technologies, electric vehicles (EV) seems to be the most viable proposition in the short term, in part due to its use of existing technologies. However, many of these technologies come from vastly different markets, such as mobile computing and smart phones and are being developed at a much quicker rate than is normal in the automotive sector. The regulatory framework that has been put in place is not reactive enough to encompass these new technologies as they come to market, so a new approach is needed.

As yet, the adoption of EVs has been slow, despite the fact that mainstream manufacturers have been producing models for several years. Research by the European Network of Electric Vehicles and Transferring Expertise (ENEVATE) has shown that a major barrier to adoption is the purchase cost – EVs that are currently on the market are too expensive for the average motorist (Davies et al, 2012). Ensuring that regulations do not place restrictions that inhibit new, cheaper and more efficient technologies reaching marketplace will mean that the demand for EVs will be enhanced, as they will become a more realistic alternative to the current internal combustion engine (ICE) powered cars.

Streamlining the type approval process also makes the market more appealing to smaller manufacturers. Those that already produce EVs tend towards lightweight electric vehicles (LEV) that are classed as a quadracycle (European classification L6e/L7e). These are appealing to urban dwellers as they are ideal for city use where space is at a premium and journeys may be shorter. However LEVs do not require the same level of safety testing and they are also lower performance vehicles, which may lead to poor perception of EVs in general by the media and general public.

Initial work has been undertaken in updating the regulatory framework in response to EVs beginning to emerge in the transport mix. In Europe the most notable review of the type approval process was carried out by the UK's Transport Research Laboratory on behalf of the European Commission (Visvikis et al, 2010), whilst in the US the American National Standards Institute (ANSI) Electric Vehicles Standards Panel (EVSP) has produced a standardization roadmap (American National Standards Institute, 2012). Whilst both of these documents give comprehensive reviews of existing standards and where there might be gaps, there is no method of prioritising where effort should be concentrated to achieve the biggest gains and, as a result, accelerating e-mobility.

Currently, regulations are developed in response to problems rather than anticipating them. Further problems arise as there are relatively few EVs currently in use, resulting in limited data with which to detect operational faults.

In order to pre-empt how regulations should be developed and where effort should be targeted, this paper proposes a three stage process to identify and prioritise potential gaps in the regulations.

METHODOLOGY DEVELOPMENT

A new methodology is proposed to both identify areas where problems might arise and prioritise these in order that the greatest gains might be achieved. It will also create a dynamic framework in which to develop regulations in the future. The methodology uses a novel combination of techniques that form a three stage process comprising of a thematic analysis, a functional system breakdown (FSB) and a failure mode and effects analysis (FMEA). The thematic analysis provides the context by exploring the themes surrounding vehicle safety and how related technologies are developing. It does this by examining a variety of qualitative sources of data. A functional system breakdown is then used to decompose the vehicle into sub systems and mission modules, to which the appropriate regulations can be attached. This provides a method of sorting the complex regulatory framework. Critical pathways are then highlighted in the FBS based on the thematic analysis and deficiencies in the current regulations that have been identified. Finally applying an FMEA will allow the deficiencies to be prioritised in terms of severity of failure mode and probability of occurrence of the identified gaps in the regulatory process.

Thematic Analysis

Thematic Analysis is a qualitative research technique focusing on examining and recording themes within a set of data that may come from a variety of sources. These might include interviews with experts and stakeholders, literature reviews, conference proceedings and the media. (for example see Rossen et al, 2012). A lack of empirical data relating to incidents where failures have occurred means alternative sources must be used to gauge safety related issues. An overview on safety aspects and also emerging technology trends can be sought from literature reviews and conference proceedings. Detailed expert opinion can be gained from interviewing stakeholders and industry experts.

The analysis consists of a three stage process of thematizing, data collection and analysing & transcribing, which are described as follows:

Thematizing This bounds the area of the analysis by describing what themes should be included, and those that should not. As the aim is to identify areas where electric vehicles may not necessarily be covered by current regulations, the themes will be the areas of concerns where EV safety may be a potential problem. Hybrid and fuel cell vehicles have not been included, although there will inevitably be some overlaps in technologies that may warrant investigation in order to further streamline the type approval process. Also, charging infrastructure has not been fully included in order to keep the main focus on vehicle technology. Again, this is an important area that should be considered in future studies as it can have major impacts on safety, for example when charging takes place in domestic properties or in public places.

Data Collection The next stage is data collection, in which relevant source material needs to be gathered. As there is little data available on safety issues arising from incidents involving EVs, alternative methods are needed. A more general overview can be gained from scientific literature reviews, conference proceedings and other documents such as roadmaps and policy documents. This can also provide some insight to any new technologies that are currently in development. In order to obtain a more detailed opinion on relevant issues, semi-structured stakeholder interviews should be undertaken. Here industry experts such as legislators, manufacturers and safety testing organisations are asked a series of open questions in order to elicit their opinion, but still retaining some structure and context in order that comparisons can be made between responses. A detailed description of interviewing techniques can be found in Johnson, 2002. By drawing upon networks such as ENEVATE, a wide range of experience and opinion can be gathered. In particular, the work already carried out by ENEVATE on surveying supply chain stakeholders (Pannkoke and Ernst, 2012) can be used to identify emerging technology development trends. This work is ongoing and does not form part of the example described in this paper, but will be reported at the ENEVATE final conference, November 2013.

Analysing & Transcribing After reviewing all the information that has been gathered from various sources, the data is then analysed. This is done by examining the text in detail and highlighting the emerging and recurring themes. By recording the occurrence of each theme, patterns begin to emerge, highlighting where opinion lies with regards to the issues being explored. Themes can also be grouped where similarities occur, and ranked according to how often they are highlighted in order to gauge the importance of a theme.

Functional System Breakdown

Stage two of the methodology is a functional system breakdown (FSB). Today's vehicles are incredibly complex and in most cases regulations only apply to specific parts of the vehicle. In order to make sense of the regulations in relation to the vehicle and highlight areas of concerns, a method of sorting is required, for which FSB is ideal.

An FSB starts with the top level primary function of the system – in this case the vehicle. This is then decomposed into multi level sub systems, such as drivetrain and structures. These are further broken down until they reach mission modules, each of which has its own function such as the battery in and EV or fuel tank in an ICE vehicle. The function of the module missions affects the performance of the sub systems, which in turn determines the operation of the primary function – for example the fuel tank or battery supplies energy into the drivetrain which then powers the vehicle. Some examples and methods of FSB can be found in Stone & Wood, 2000 and Pailhès et al 2011. A basic FSB outline is shown in *Figure 1*

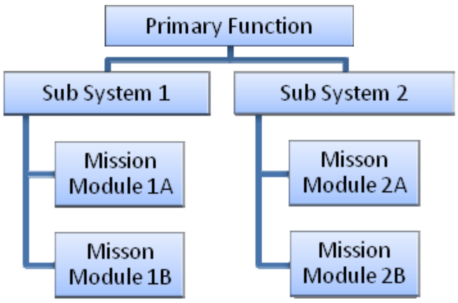

Figure 1 outline functional system breakdown.

The level of detail contained in the FSB can vary depending on the context and it could potentially include the component level as the mission modules. Whilst this might highlight areas where new technologies may appear, it also should not be over prescriptive as tightly specifying components could exclude future innovations.

For this methodology two FSB diagrams should been produced, one for a standard passenger ICE powered vehicle (e.g. European category M_1) and one for an equivalent class EV. For each level in the diagram the appropriate regulations should be identified, where they exist. By comparing the FSB diagrams the areas that require new regulations can be highlighted. In addition the FSB for the EV can been compared with the thematic analysis results. This will further identify the areas where there may be gaps in the regulations. As a result a number of critical pathways can then be devised. These are subsequently used to determine areas of concern and the relevant regulations can be investigated.

Failure Mode and Effects Analysis

The final step is to take an area highlighted by the critical pathways and apply a failure mode and effects analysis (FMEA). This is done in order to prioritise where the most gains can be made and allocate available resources appropriately. An FMEA is more normally used to identify areas of risk or potential failure within a system or process. To do this three criteria are applied: severity, occurrence and detection. Each of these is given a ranking (usually numerical). By multiplying the values a final score is achieved, highlighting the areas that are most at risk to developing a fault. The standard procedure for conducting an FMEA in Europe is outlined in IEC 60812:2006. (CENELEC, 2006). FMEA is routinely used in many industries, including the automotive industry (for example Chrysler et al, 1995). It can also be applied to processes as diverse as healthcare (Latino 2004) and web based systems (Zhou and Stålhane, 2004), which highlights the adaptability of the procedure.

The automotive industry generally uses a scoring system ranging from 1 to 10, with clearly defined criteria to guide the application of the ranking. These will be used for the proposed methodology as they are widely used and understood (e.g. Chrysler et al, 1995). The scores as listed in IEC 60812:2006 for severity are described in Table 1 and scores for occurrence are shown in Table 2.

Table 1
FMEA Severity Scores

Severity	Criteria	Score
None	No discernible effect.	1
Very minor	Fit and finish/squeak and rattle item does not conform. Defect noticed by discriminating customers (less than 25 %).	2
Minor	Fit and finish/squeak and rattle item does not conform. Defect noticed by 50 % of customers.	3
Very low	Fit and finish/squeak and rattle item does not conform. Defect noticed by most customers (greater than 75 %).	4
Low	Vehicle/item operable but comfort/convenience item(s) operable at a reduced level of performance. Customer somewhat dissatisfied.	5
Moderate	Vehicle/item operable but comfort/convenience item(s) inoperable. Customer dissatisfied.	6
High	Vehicle/item operable but at a reduced level of performance. Customer very dissatisfied.	7
Very high	Vehicle/item inoperable (loss of primary function)	8
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves non-compliance with government regulation with warning.	9
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves non-compliance with government regulation without warning.	10

Source CENELEC 2006

Table 2
FMEA Occurrence Scores

Occurrence	Score	Frequency
Remote: Failure is unlikely	1	≤ 0.010 per thousand units
Low: Relatively few failures	2	0.1 per thousand units
	3	0.5 per thousand units
Moderate: Occasional failures	4	1 per thousand units
	5	2 per thousand units
	6	5 per thousand units
High :Repeated failures	7	10 per thousand units
	8	20 per thousand units
Very high: Failure almost inevitable	9	50 per thousand units
	10	≥100 in thousand units

Source CENELEC 2006

The automotive industry also uses a score of 1 to 10 to rank the probability of detection of a given fault, again with defined criteria for each score. However for the proposed methodology, detection relates to whether or not a potential fault in a mission mode is covered by existing regulations. In order to simplify the process, a value of 0 is given if the mission module is covered by a standard and 1 if it is not. The resulting score will then be zero if the module is adequately covered and it will not be included in the final prioritisation. Those that are not covered by existing standards will have a score based on severity multiplied by risk, so in principle those with the highest scores would be given highest priority once the modules are put in ranking order.

One of the drawbacks is that the values used for the ranking may in many cases be subjective, as evidence based on failure rates may not be available due to the small number of EVs currently in use. Where available evidence from other sources may be used – for example, if a technology has been used for a different application then data from this can be used to determine the score. This should only be done with the caveat that automotive use may place different demands on the technology, particularly where safety critical systems such as braking are involved. Expert opinion may also be used; ideally a consensus of opinion should be reached by multiple stakeholders where possible.

EXAMPLE APPLICATION

In order to demonstrate the proposed methodology a worked example has been carried out for this paper. The example has been kept deliberately simple by focusing on one potential area for concern to highlight the methodology rather than the outcome. Work is ongoing by the ENEVATE project team in order to further validate the methodology and develop realistic applications, which will be reported at the ENEVATE final conference, November 2013.

Thematic Analysis

In order to obtain a high level overview of potential areas of concern, data was gathered from proceedings taken from worldwide EV related events from 2010 to present. This gives a broad consensus of areas of concern, not just relating to vehicle technologies and systems but also to the general usage of EVs, with the aim of highlighting where potential failures might arise. A second data set was taken from the standards review undertaken by TRL and the ANSI roadmap. By comparing these two data sets a gap analysis can be undertaken in order to determine any areas that have not been considered by these reviews. The themes that became apparent are summarised in Table 3. Those shown in bold are themes that were not covered by the TRL summary and ANSI roadmap.

Table 3
General Thematic Analysis using Conference Proceedings

Theme	Count
Aftermarket standards	**7**
Battery - recycling and reuse	11
Battery safety - design	2
Battery safety - general	13
Battery safety - misuse	3
Battery Safety - monitoring	3
Battery safety - protection	3
Battery storage	8
Battery testing methods	7
Emergency Response procedures	10
Standards - Charging	12
Standards - electrical safety	7
Standards for batteries	6
Standards for Charging interoperability	9
Standards for retrofit systems	1
Standards for vehicles	9
System integration	**1**
Training for mechanics, salvage operators	**3**
Vehicle - infrastructure interface	**3**
Vehicle crash testing	8
Vehicle Labelling	5
Vehicle testing and compliance	1
Wireless Technology	4

It can be seen from the initial thematic analysis that battery safety, issues around charging infrastructure and battery recycling and reuse are major issues. Emergency response procedures were also seen as important, with issues such as vehicle identification, battery disconnect and personal protective equipment mentioned as problem areas. This applies not just to first responders such as fire service personnel, but also second responders such as recovery teams. Of the issues that did not receive coverage in the standards review and roadmap, the most prominent relates to standards for aftermarket parts, which may also include conversion of ICE vehicles to EV. There were also issues around the vehicle to infrastructure interface. With vehicles increasing using "smart" technology and the possibility of downloading information or software upgrades straight onto the vehicle, there needs to be protection put in place to guard against faults or potentially malicious software becoming embedded in the vehicle's electronic control systems.

A final data set examined vehicle specific topics, so that a comparison to be made with the functional system breakdown. The data used for this was the proceedings of the 22nd Enhanced Safety Vehicle Conference (ESV22). The proceedings of previous ESV conferences were discounted, as EV were not explicitly discussed. The results of the analysis are shown in Table 4.

Table 4
Vehicle Thematic Analysis using ESV22 Proceedings

Theme	Count	Context
Collision	8	Frontal, Rear, side impact, protection zone
Energy Storage	7	Lithium-ION Battery Technology, cause of failure, thermal runaway
Control	4	High Voltage Shutdown System
Occupant	4	Protection from electric component(before and after crash)
Electrical safety	3	Protection from electricity
Leakage	2	Leakage of hydrogen, Battery acid.
Fire	2	Overheating battery or rupture of fuel tank can be source of fire
Pedestrian	2	Warning sound of EV approaching to prevent impact with pedestrian
Abuse	1	Misuse of the vehicle
Structure	1	Battery Pack
Recharge process	1	Recharging battery

The results show that collision and energy storage were the two main issues being discussed by experts in the field at the conference. This was followed by the control system, protection of the occupant from electrical components and electrical safety. Hence, the complete thematic analysis has shown that the patterns suggest collision and energy storage are the areas that attract the most concern, with control also being an important factor.

It should be noted that this is only a small part of the thematic analysis that would be required to conduct a comprehensive review of technology trends and safety issues. Work will continue under ENEVATE in order to obtain a fuller picture by examining a wider range of literature and conducting stakeholder interviews.

Functional System Breakdown

Figure 2 and *Figure 3* shows the functional system breakdown of a standard passenger ICE vehicle and an EV. As the FSB for the whole vehicle becomes increasingly large it decomposes to the lower levels, the figures show only the breakdown for the drivetrain sections for each vehicle. By comparing the two diagrams, there are clearly differences in the drivetrain section, for example the energy storage method for ICE and EV is fundamentally different. An ICE vehicle uses a fuel tank to store the fuel and it is governed by FMVSS 301 Fuel System Integrity. On the other hand, for EVs the energy storage method is a battery, which can be based on various chemistries such as Lithium-ion or lead acid. FMVSS 305 regulates the affects of failure in a battery powered vehicle, by regulating the amount of spillage of electrolyte in the event of a crash and stipulating isolation of electrical components to protect against electric shock. It is important that any such regulation is written independently of issues such as battery chemistry in order that future technology developments are not precluded.

There are several critical paths that could be defined within the EV FSB. From the thematic analysis, the main areas of concern for EV were collisions, energy storage, control system and occupant protection. By following the critical pathways, gaps in regulations which may cause concern are identified. For the purposes of this illustrative example, the critical path relating to the battery has been chosen to demonstrate the proposed methodology, and is shown in *Figure 4*. Here it can be seen that the critical pathway from the mission module (in this case the battery) to the primary function (the EV) takes in several sub systems, namely the battery management system, the motor and the drivetrain. All of these could be affected by a fault in the battery, which in turn could cause the vehicle to malfunction. The regulations that are highlighted by the critical path are shown in Table 5.

Table 5
Critical path for battery mission module

Regulation Number	**Area Regulated**	**Level**
ECE-68	Measurement of the max speed, inc EV	Vehicle
UNECE-100	Electric power trained vehicles	Vehicle
ECE-84	Measurement of Fuel Consumption (Liquid Fuel)	Control
UNECE-85	Measurement of net power	Control
UNECE-GTR5	Technical requirements for on-board diagnostic systems (Currently Diesel Heavy Vehicles)	Battery Management
FMVSS 305	Electric Powered Vehicles, Electrolyte Spillage and Electrical Shock Protection	Battery

Of these regulations several currently only apply to ICE powered vehicles, but relate in some respects to similar functions that are carried out by the equivalent EV mission module, so may have the potential to be adapted. For example, UNECE-GTR5 currently relates to on board diagnostics for diesel powered heavy vehicles, but the regulation states that:

"the gtr has been structured in a manner that facilitates a wider application of OBD to other vehicle systems in the future" (UNECE-GTR5, 2007)

ECE-84 relates to the measurement of fuel consumption, so could also be a useful regulation if applied to EV, as monitoring the amount of "fuel" in the form of charge remaining in the battery is an crucial factor in the operation of the vehicle.

Again this is only a sample of the full FSB that would be required to fully understand the vehicle's systems. A more detailed FSB will be undertaken by the ENEVATE project team at Cardiff University in order to fully explore the potential issues.

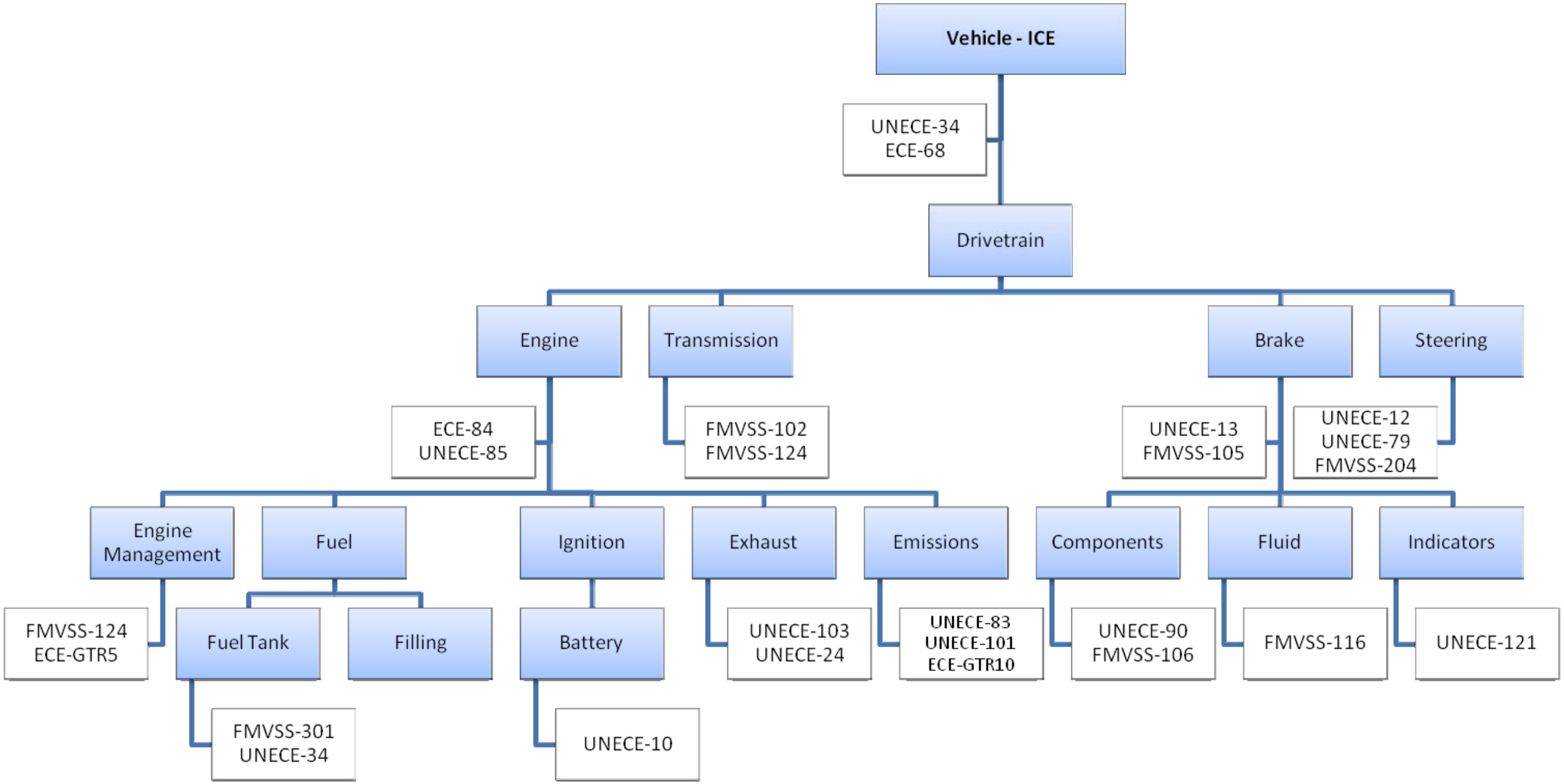

Figure 2 functional breakdown system for a standard passenger ICE drivetrain with relative regulations.

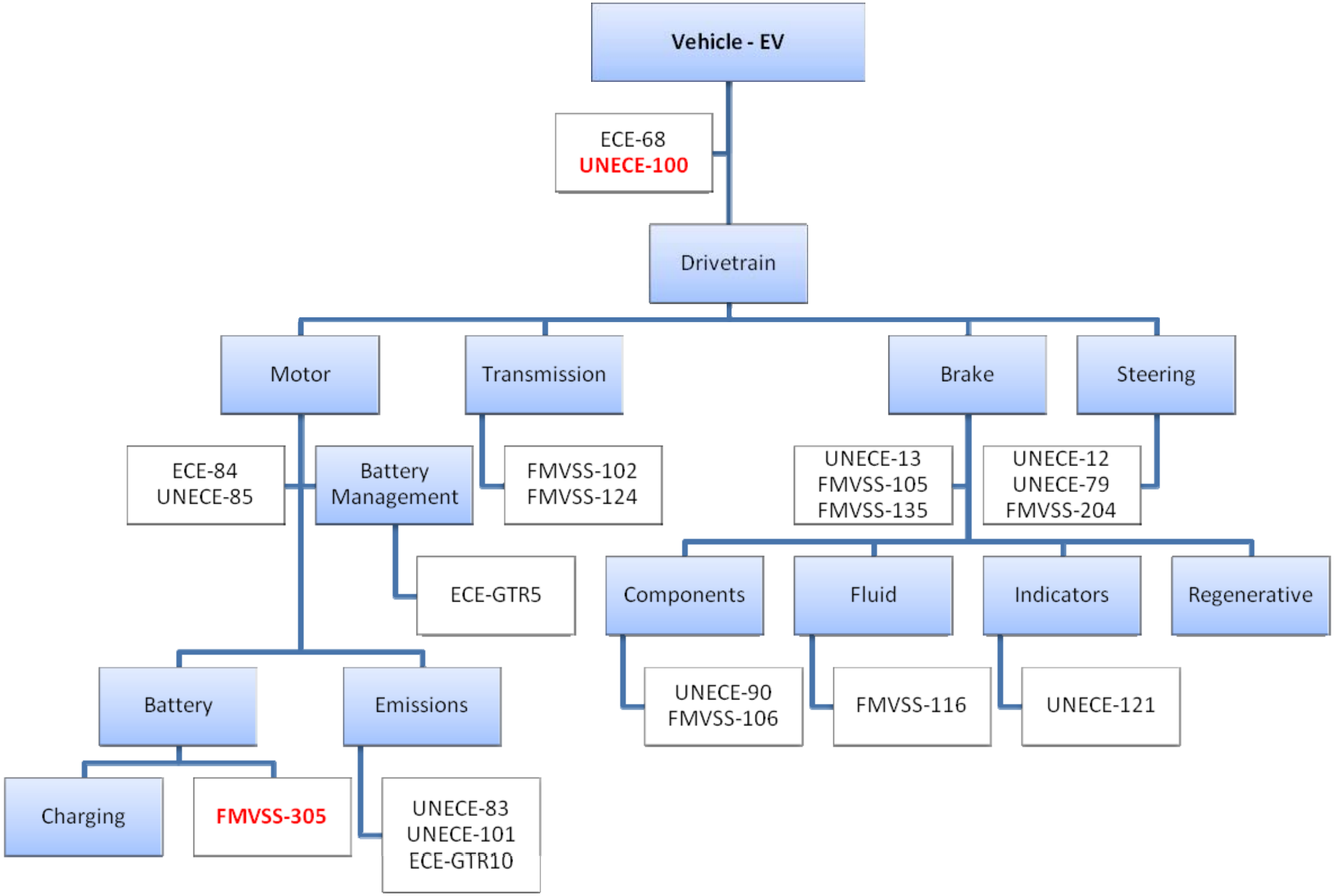

Figure 3 functional system breakdown for electric vehicle drivetrain.

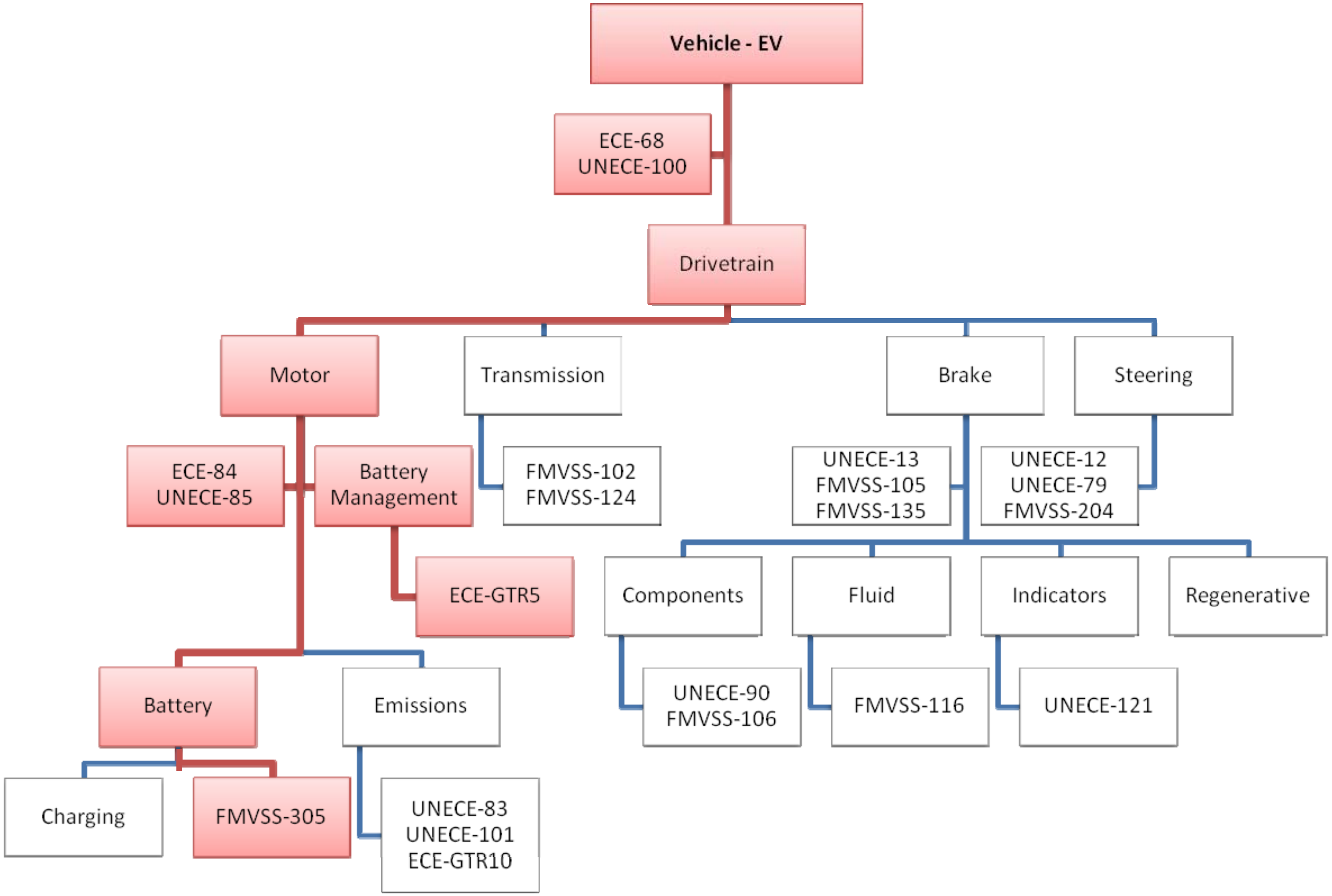

Figure 4 critical path for the battery mission module.

Failure Mode and Effects Analysis

In order to apply the failure mode and effects analysis, some potential failure modes needed to be identified. For the purpose of this illustrative example a list was taken from the battery guide produced by Axeon. This list may not cover all possible battery failure modes, but is used to generate a comparison whereby the modes that are listed can be ranked in order to demonstrate the methodology being proposed.

Once the list of failure modes had been identified the severity and occurrence of each mode was ranked according to the criteria outlined in Table 1 and Table 2. As already described, these values are largely subjective, although evidence has been used to guide the judgements made wherever possible. This was more achievable for the occurrence ranking, as information from other domains could be used for guidance. In many cases the failure mode relates to a high severity ranking as the failure may result in events such as thermal runaway in the battery pack, potentially resulting in fire.

The final stage was to compare the failure modes with the identified standards in order to determine if there was adequate coverage. The failure modes were graded for coverage with 0 or 1 accordingly, in order to rule out those that were already included in existing regulations. The resulting example FMEA is shown Table 6.

From the table it can be seen that some aspects are already adequately covered by regulations. Pressure venting for any gases given off by the battery are covered in UNECE-100 section 5.1.1.2, and fuses are covered by section 5.1.1.3 of the same standard. FMVSS-305 states that if the vehicle is involved in a crash, the battery should not enter the passenger compartment.

Of the remaining failure modes, the highest score has been given to flame retardant cover. There have been some incidents in pure EVs and also hybrid vehicles where vehicles have caught fire (e.g. Smith 2012). This suggests that this is a potential area for concern. Next are cell isolation and shutdown separator followed by current interrupt devises. These are all crucial safety aspects that help protect the battery from events such as thermal runway and short circuit. Whilst these may have been tested in other applications such as mobile phone and laptop devices, the demands placed on a battery by vehicular use may be very different. The final failure modes relate to the battery management system and PCT resistors, which present similar issues.

DISCUSSION

One of the main drawbacks of the regulation process is that effects over time are not taken into account, in particular with regards to battery chemistry and components (Doughty 2012). This can affect the vehicle in two ways. Firstly it can take a period of time for a fault to manifest itself, as was the case with the Volt fire incident, where the vehicle caught fire some weeks after crash testing (Smith 2012). There may also be longer term issues that may arise as the battery degrades after years of use, which would not come to light after short term use of the vehicle. Whilst is may be possible to learn some lessons from other mobile technologies, there may be faults that are specific to the demands of automotive use and safety critical systems. Whilst the proposed methodology provides a prioritisation at a given point in time, it also has the benefit of being easily adaptable into a living document. The process would not need to be started from scratch - by repeating the thematic analysis and updating the initial FSB and FMEA, the resulting prioritisation can be updated as required.

The example in this paper has concentrated on high level regulations that are directly required for type approval such as FMVSS and UNECE regulations. There are many more standards such as SAE and ISO standards that could be used to verify the safety of EV systems and components. The ENEVATE team at Cardiff University will continue to verify the methodology by using a more detailed thematic analysis and FSB coupled with an expanded set of standards and regulations to create a more detailed picture of the current state of the regulatory process.

Table 6
Example Failure Mode and Effects Analysis for Battery Safety Regulation Ranking

Sub System	Mission Module	Severity	Occurrence	Standard	Coverage	Total	Notes
Cell level safety devices	Current interrupt device (CID) - safety components to protect the cell from excessive internal pressure - the CID will break and electrically disconnect the cell	8	2	-	1	**16**	Failure rate ~1:10000 (Doughty 2012)
	Shut down separator: The separator between anode and cathode has the ability to close its pores as a result of thermal runaway	9	2	-	1	**18**	
	Pressure vent	8	2	UNECE-100 (5.1.1.2)	0	**0**	No action needed
	Flame retardant cover	9	3	-	1	**27**	There have been incidents of vehicle fires e.g. Volt (Smith 2012)
External circuit devices	Positive Temperature Coefficient (PTC) resistors (Low power only) exhibit an increase in resistance at a specified temperature. They are suitable for a wide range of applications, in particular including overcurrent protection devices, switches and additionally as heaters	7	1	-	1	**7**	PTCs are used in other applications, lessons learned can be applied to EV application
	Fuses	7	3	UNECE-100 (5.1.1.3)	0	**0**	No action needed
	Cell isolation to prevent a chain reaction of cell events	9	2	-	1	**18**	Some cell elements such as short circuits are difficult to replicate in test environment (Doughty 2012).
BMS Software	The software monitors all key indicators coupled to control actions (e.g. cooling, power disconnect)	7	1	-	1	**7**	ECE GTR5 could cover BMS, but does not at present. BMS used in other applications, but is more complex in EV.
	The hardware provides a fail-safe back-up, including a switch-off in case of software failure	8	1	-	1	**8**	
Battery location	This should be outside the passenger compartment and behind the vehicle firewall	9	1	FMVSS-305 (S5.2)	0	**0**	No action needed

Sub system and mission module data taken from Axeon “Our Guide to Batteries”

SUMMARY

Electric vehicles present new opportunities that need to be managed in a timely manner in order to achieve their highest potential. The mismatch between the rate of change of technology and the time taken to update the regulatory framework as a reaction to new technology and problem areas could hinder the development of new e-mobility concepts. As EVs are an evolving technology it is also crucial that regulations are not specified in such a way that new technologies cannot be used in the future and technology lock-in is avoided.

In order to focus the development of standards in relation to EV a three stage methodology has been described and applied to an example illustrated by the battery and related systems. The thematic analysis provided the context by highlighting discussion on topics relating to battery safety. The functional system breakdown for a conventional ICE powered vehicle and an EV were compared and a critical path devised that showed how battery related issues relate to the vehicle's operation. This also highlighted what regulations were already in place and those that may need reviewing. Finally a list of potential battery failure modes was used to create an illustrative FMEA and prioritise any outstanding issues in order to focus where the biggest gains might be made.

Work will continue to create a more detailed analysis in order to verify the methodology and produce meaningful output. Further results will be presented at the ENEVATE final conference in November 2013.

ACKNOWLEDGEMENTS

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