SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

CALIBRE PROFESSIONAL SERVICES ONE PTY LTD
Level 2, 50 St Georges Terrace, Perth, Western Australia 6000
PO Box Z5426, St Georges Terrace, Perth 6831
+61 8 9265 3000 | ABN 55 150 624 356 | www.calibregroup.com

CALTPT-NTR-001-18

Monday, 4 June 2018

Mr Paul Retter AM
Chief Executive Officer and Commissioner
National Transport Commission
Level 3/600 Bourke Street Melbourne VIC 3000

Calibre Group Submission to the National Transport Commission: Safety Assurance for Automated Driving Systems - Consultation Regulation Impact Statement (RIS)

Reference:

A. NTR Consultation Regulation Impact Statement dated May 2018

Dear Mr Retter,

Calibre thanks the National Transport Commission for the opportunity to provide industry comments for the Safety Assurance for Automated Driving Systems Consultation Regulation Impact Statement - May 2018 (Reference A).

As you are aware, Calibre has extensive contemporary experience with automated and semi-automated driving systems, including recent involvement in an autonomous freight railway project. We have utilised this experience, along with our wider expertise, in our commentary where possible.

Some areas that we have raised commentary may require interaction directly between the NTC and Calibre due to the confidentiality arrangements we remain under; and we always welcome the opportunity to undertake a face-to-face discussion with your team.

We do look forward to ongoing engagement on this or parallel projects, and once again thank you for your kind consideration.

Our point of contact for such matters is:

Arran Bollard

Group General Manager Integrated Projects

M: 0428 144 043

E: Arran.Bollard@calibregroup.com

A: Ground Floor, 545 Queen Street, Brisbane, QLD 4000

Please do not hesitate to contact either Arran or myself for further information or clarification.

Regards

George Nuich

Executive General Manager – West

Professional Services

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CALIBRE GROUP SUBMISSION TO THE NATIONAL TRANSPORT COMMISSION:

SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS) MAY 2018

Reference:

A. NTR Consultation Regulation Impact Statement dated May 2018

As per the Consultant Regulation Statement May 2018 (Reference A), the following comments are associated with the Safety Assurance for Automated Driving Systems Document as performed by Calibre personnel.

1. Section - Executive Summary: (page 1/136)

1.1. General

Comment 1

Within the first sentence of the first paragraph, there appears to be typo and that the following word "breaking", should be re-written as "braking".

Comment 2

Within this remit Calibre recommends the inclusion of technology enabled vehicle active safety systems such as Driver's Vigilance Systems (e.g. in car driver's vigilance systems whereby an in-house camera watches the driver's eyes for fatigue and then takes some safe action like reducing the speed etc). Some reference material is provided at Annex A.

Comment 3

It states within this section:

"mobility benefits but potentially introduce new road safety risks".

Perhaps this should detail items like the following: lane changes, road workers, roadside breakdowns, emergency lane non-existent?

Comment 4

Option 1 would appear to be the least safe as there are already many car manufactures already have safety driving functions even in low cost vehicles which are enhanced as price increases, selling points!

Calibre recommends Option 4 because it is the best option but will have time schedule problems and cost associated with the delivery of this option.

Calibre notes this option will need time to create an overall governing body and dependant on whether it covers state or nationwide and how it relates to the various state governments in order to push through regulations.

By having a primary safety duty this could be a composition of ISA and supplier for the vehicles or commercial operators performing this duty of care for the safety of their fleet in operation.

Comment 5

Option 1 would still have to have government oversight as to the adherence to any road safety regulations being enforced upon car manufacturers.

1.2. Safety Assessment Criteria: (page 2/136)

Comment 6

Calibre recommends that for the First and Third criteria the current safety standards (statutory and regulatory frameworks and requirements as currently in use at the state and federal level) should be specified here.

Comment 7

For the Fourth criteria, what are the current laws that are associated with any ADS? Calibre recommends these should be referenced here.

Comment 8

For the Fifth criteria would the automation be between cars that have ADS and the emergency services also for all road coverages that the ADS would be deployed are there valid mobile communications coverage?

Calibre recommends that this be the case.

Comment 9

For the Sixth criteria, would the level or minimal risk be managed by SFAIRP as is done in the railway industry under the Office of the National Rail Safety Regulator (ONRSR) Guideline "Meaning of duty to ensure safety so far as is reasonably practicable - SFAIRP" dated July 2016 and enacted under the Model Rail Safety Bill 2006 which was used for Calibre's automation safety development?

We also refer to incorporation of NTC's "National Guideline for the Meaning of so far as is Reasonably Practicable (SFAIRP)" dated 2007 (https://www.ntc.gov.au/Media/Reports/(50087412-21D3-ECFD-FFCB-CF1129CFF06A).pdf).

Calibre recommends that this be the case.

Comment 10

For the Seventh criteria, will the ADS be part the mandatory Road Driving Licence Test?

Calibre highly recommends this is the case.

Comment 11

For the Eighth criteria, will the systems updates be done in real time? Calibre highly recommends this is the case.

Will it cover car user/system functions which may imply more dynamic risks?

Calibre highly recommends this is the case.

Dynamic updates are not recommended by Calibre based on our recent experience with an autonomous freight railway project. Updates, whilst performed remotely, were still done on static locos with a rigid process in place to check that the update was successful from a combination of on-board communications and checks on the loco themselves. This cannot be guaranteed on road vehicles due the nature of operations and human interactions. Dynamic updates if done whilst road vehicles are on the move, and because they represent vehicle safety systems, could cause accidents if updates were incorrectly applied.

Comment 12

For the Ninth criteria, does this cover State or National wide road coverage?

Calibre highly recommends this is the case.

Comment 13

For the Tenth criteria, this should refer to the contemporary (and any 'under development") statutory, legislative and industry standards in Australian and internationally.

In rail ADS, Calibre included incorporation of the European and RISSB Cyber Security Standards: EN 50159 and ISO/IEC 62443 etc.

Comment 14

For the Eleventh criteria, does this cover public and / or law enforcement and emergency services training and education?

Calibre highly recommends this is the case.

Comment 15

For the criteria about data recording and sharing, will this be nationwide(?) and what securities will be in place for each state within Australia? Calibre believes Standard Data Protections laws would need to be enforced. Please see following website for guidance; but we note it may be different between the various states, and therefore more research is advisable here: https://www.oaic.gov.au/privacy-law/privacy-act/.

1.3. Assessing the reform options: (page 2/136)

Comment 16

For the level and nature of the risks posed by automated vehicles, Calibre recommends this should be work-shopped by the relevant SMEs within the car industry.

Comment 17

For the criteria for the framework to be worldwide Calibre recommends this should not be the subject of this paper. As each country enforces different levels of road safety and road rules even driving on opposite sides of the road, this would therefore probably not be attainable. Calibre recommends that the Australian position should recognise overseas frameworks, but focus on local needs and requirements.

Comment 18

For the impacts on the options, Calibre recommends these would need to be reviewed by safety competent personnel; and utilising an independent and transparent vessel to remain bias free.

Comment 19

Calibre agrees Option 4 is the best option but will have time schedule problems and cost associated with the delivery of this option. This option will need time to create an overall governing body and dependant on whether it covers state or nationwide and how it relates to the various state governments in order to push through regulations. Next by having a primary safety duty this could be a composition of ISA and supplier for the vehicles or commercial operators performing this duty of care for the safety of their fleet in operation.

Comment 20

Option 3 has insufficient data for conclusion as costs may be reduced by having industry car suppliers bear the costs of administration. Calibre recommends that this be the case.

Comment 21

Option 2 has insufficient data for conclusion as Calibre understands there are no existing regulations associated with ADS?

1.4. What is the preferred option? (page 3/136)

Comment 22

The statement for ensuring that automated vehicles entering Australia are reasonable safe, is not exactly true unless the laws are changed for obtaining a license and that there are other safety systems in place to account for lane changes, no emergency lanes, road workers and accidents etc.

Comment 23

The statement for providing users with reassurance that automated vehicles are safe would require a nationwide campaign.

This was recommended for the level crossings on an autonomous freight railway project, but was not taken up by the client. However WA has already run a road safe campaign for another safety issue on the roads, please see following web link: https://www.perthnow.com.au/travel/driving/silent-killer-wa-campaign-targets-driver-fatigue-ng-b88783412z.

Comment 24

For the statement:

"It is possible that the relative benefits and costs of the options will change as the future unfolds and existing uncertainties become resolved"

Calibre recommends this should not be the case as all uncertainties about safety functions introduced via ADS must be clearly investigated and resolved prior to entry into the Australian market overseas.

Comment 25

For the statement

"This Consultation RIS tests this preferred option under a range of different deployment scenarios. The RIS also sets out the relevant conditions under which other options might perform better."

Calibre recommends would have to be assessed; again utilising an independent and transparent vessel to remain bias free.

2. Section – 1 Context: (page 4/136)

Comment 26

Within the key points for the statement

"Automated vehicles will soon be available for commercial deployment in Australia."

Is incorrect as there are numerous vehicles whilst not fully automated are semi-automated that present known current road safety risks and should be work-shopped as soon as possible to improve road safety. Please refer to recent presentations from the ATSB and Roy Hill used in the RISSB Safety Conference in Sydney 2018 at Annex B and Annex C.

Calibre's view is that land-based fully automated and autonomous vehicles will eventually be available for commercial deployment in Australia (with airborne systems already operating in commercial service) and therefore safety should be work-shopped in the near future to prepare for their emergence. However, there are numerous vehicles that are not fully automated, semi-automated / semi-autonomous which present known current road safety risks and Calibre recommends this should be work-shopped as soon as possible to improve road safety improve road safety today.

2.1. Section – 1.1 Introduction – what are automated vehicles? (page 4/136)

Comment 27

Within the first sentence of the first paragraph, there appears to be typo and that the following word "breaking", should be re-written as "braking".

Comment 28

From the statement within this section:

"after-market devices or software upgrades that add automated driving functions to existing vehicles"

Calibre believes this may not be the general case as there would probably have to be some hardware updates added to vehicles with the appropriate cabling which may give rise to other risks during and after software upgrades.

Comment 29

For the statement within this section:

"However, the supply and use of automated vehicles also raises new risks."

Calibre believes the document should mention some such risks as how are lane changes performed, how are dynamic changes to the traffic performed, how are road workers or emergency services provided for?

2.2. Section – 1.2.1 Road crashes in Australia: (page 5/136)

Comment 30

From the statement within this section:

"There is currently no nationally consistent road crash injury data in Australia due to state/territory methodological differences;"

Calibre considers this statement may be in conflict with the previous two statements

"Human error and dangerous human choices cause up to 94 per cent of serious crashes (National Highway Traffic Safety Administration, 2015, p. 1). In 2017 there were 1,225 deaths on Australian roads from 1,131 road crashes (BITRE, 2018, p. 1)"

Calibre recommends that this be looked at for consistency by NTC.

Comment 31

From the statement within this section:

"costs to individuals and their families associated with death or rehabilitation and care"

Calibre questions whether there is / will be / needs to be special insurance allowances for ADS vehicle drivers, for instance provisions under the Motor Accident Commission Act 1992 - South Australia and the associated Regulations which may impact costs?

2.3. Section – 1.2.2 Benefits and risks of automated vehicles: (page 5/136)

Comment 32

From the following statement within this section:

"research suggests that, overall, automated vehicles are expected to improve road safety, travel times, highway and intersection capacity, fuel efficiency, emissions per kilometre,"

Calibre's autonomous freight railway project experiences and data analysis indicates there could be an average 20% faster journey time, which would lead to larger returns on benefits and reduction of fuel costs as automated vehicles would be driving at the optimum efficiency.

Unfortunately Calibre cannot provide the autonomous freight railway project data and analysis on safety improvements from automated vehicles due to commercial restrictions.

Comment 33

From the following statement within this section:

"the uptake of complementary innovations such as connectivity, electrification and sharing mobility."

Calibre recommends consideration of including other forms of energy that be employed here such as optimal renewable energy (solar) collection and utilisation, hybrids and other fuels (gas, hydrogen etc) to reduce environmental impact and which may sway consumers to go for these types of vehicles.

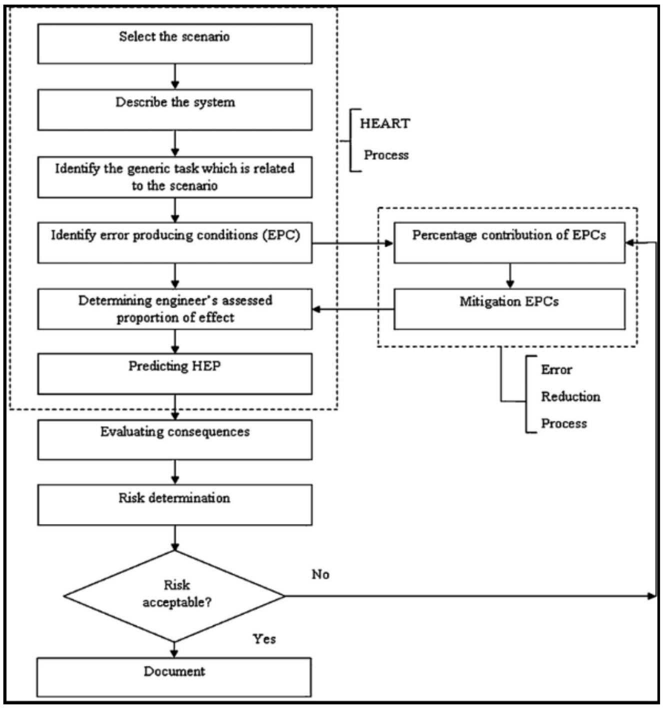
Comment 34

From the following statement within this section:

"For example, safety engineers anticipate that systemic technical errors, or failure to properly maintain and service the ADS, could become significant hazards, akin to human error (Kira, 2017, pp. 7, 17)."

Is this the only human factors reference to be applied?

Calibre recommends consideration of HEP based upon HEART methodology (see http://www.hse.gov.uk/research/rrpdf/rr679.pdf as a reference)? For example:



2.4. Section - 1.2.3 Regulatory environment: (page 6/136)

Comment 35

From the following statement within this section:

"the operation and roadworthiness of vehicles and driver licensing."

Calibre is unsure whether this currently includes ADS? If not, Calibre recommends this needs to be simultaneously addressed.

Comment 36

From the following statement within this section:

"Current Australian transport legislation assumes there is a human driver. It does not provide for an ADS to be in control of the vehicle, rather than a human driver."

Unless fully automated vehicle service is fully regulated and monitored, there will always be some human interaction within the vehicle being driven.

2.5. Section - 1.2.4 National reform program for automated vehicles: (page 6/136)

Comment 37

From the following statement within this section:

"Changing driving laws to support automated vehicles:"

From the timescales and milestones provides, Calibre questions if this could meet the *May 2018* Council requirements?

This is just an observation for consideration; Calibre has no position or recommendation at this time.

Comment 38

From the following statement within this section:

"Automated compulsory third party insurance review: Reviewing motor accident injury insurance schemes to identify any eligibility barriers for occupants of an automated vehicle, or those involved in a crash with an automated vehicle".

For Insurance purposes who pays(?): i.e. individual driver or vehicle manufacturer. Also who assigns blame in the event of an accident e.g. software / hardware design failure versus human failure? Calibre believes this may prove legally contentious and requires specialist and careful consideration?

Comment 39

For the following statement within this section:

"Regulating government access to C-ITS and automated vehicle data: Developing options to manage government access to cooperative intelligent transport systems (C-ITS) and automated vehicle data that balance road safety and network efficiency outcomes and efficient enforcement of traffic laws with sufficient privacy protections for automated vehicle users. We will submit recommendations to the Council in May 2019."

Calibre recommends this should include capacity planning and predictive analytics including predictive network capacity? This was a key driver for the capacity future-proofing and capital investment planning of an autonomous freight railway project.

Comment 40

From the following statement within this section:

"Exchange of Vehicle and Driver Information System, could capture essential information about the ADS. The NTC notes that detailed work will be undertaken by a national registration working group in 2018 to finalise new registration fields."

What is the approval change notice for updating the DIB? Whilst Calibre is not aware of standards associated with such notices, we recommend a review of the following website:

https://infrastructure.gov.au/vehicles/mv_standards_act/.

2.6. Section - 1.2.5 for automated vehicles project: (page 9/136)

Comment 41

During the consultation paper for June 2017, was there any discussion around the Safety Integrity of any automated functions / systems and if so what standards were they assigned to?

Calibre recommends utilisation of ISO 26262 (Automotive Safety Integrity Level) and Functional Hazard Assessment (FHA) is defined in ARP4761.

Comment 42

For the following statement within this section:

"The safety assurance system is part of the broader national reform program for automated vehicles outlined above. Importantly, the safety assurance system is being developed in conjunction with the changing driving laws reform project which, among other things, will specify the situations in which an ADS may drive a vehicle in place of a human driver. Driving laws will only be changed to allow this when the approach to safety is clear. This will provide certainty that allowing an ADS 'driver' will not result in unsafe vehicles operating on public roads."

In order to accomplish this road safety standards Calibre highly recommends this must include an approach to safety target levels in which to specify a level of safety integrity level that once specified in a standard can be used for all vehicle manufacturers that want to design, build, commission and sell within the Australian market.

2.7. Section - 1.2.6 Design features of the proposed safety assurance system: (page 10/136)

Comment 43

For the following statement within this section:

"3. ADSEs (such as manufacturers) will be required to submit a Statement of Compliance that demonstrates how each of the agreed safety criteria has been managed. A Statement of Compliance must be submitted and approved before the relevant ADS or function can be introduced into the market."

What type of compliance is sought here, safety, EMC/EMI etc?

Calibre recommends utilisation of ISO 7637 Road vehicles -- Electrical disturbances from conduction and coupling and the following references at Annex D, Annex E and Annex F.

Comment 44

For the following statement within this section:

"6. All in-service modifications to the ADS that have a significant impact on safety performance or material compliance with the original safety assurance system approval, including over-the-air software updates of the vehicle, are anticipated to require approval by the safety assurance system before that significant modification is introduced into the market."

Does this imply various Safety Risks which could result in death?

Comment 45

For the following statement within this section:

"initial safety assurance – which involves the ADSE demonstrating compliance against a set of safety criteria for an ADS type on a case-by-case basis"

What regulatory framework/standard body decides any safety criteria? For example is there an equivalent to RISSB?

2.8. Section - 1.2.7 International developments: (page 11/136)

Comment 46

For the following statement within this section:

"Most national governments agree each jurisdiction must resolve automated vehicle safety regulation at a domestic

level. International standards are only expected to address the technical components to be incorporated into any domestic regulatory process. There is no emerging international consensus on how to assure the safety of automated vehicles, or the role of government to assure the safety of automated vehicles."

Calibre recommends that Australia develop a national standard which will initially provide the technical input to road regulations can also help create these road rules dependant on the tolerable hazard rates associated with each automated driver function driving the priority of where rules should be specified and clearly defined in the first place.

Comment 47

For the following statement within this section:

"Critically, the design of the safety assurance system should enable industry to demonstrate safety by referencing approvals, tests or validation processes undertaken by other national governments if the standards and processes are commensurate with the safety expectations and requirements in Australia. In this regard, safety regulation in Australia can align with a diverse range of safety assurance processes in other countries wherever possible."

Is there currently a Regulatory Roads body that oversees the safety assurance process within the automobile industry within Australia and if so what workshops have already been performed about standardisation?

This is just an observation for consideration; Calibre has no position or recommendation at this time.

2.9. Section - 1.3 About this consultation Regulation Impact Statement: (page 12/136)

Comment 48

For the following statement within this section:

"The Office of Best Practice Regulation advised the NTC that a Council of Australian Governments RIS would need to be completed prior to the Transport and Infrastructure Council making a decision on the appropriate form of safety assurance for automated vehicles."

Does this Office incorporate the SFAIRP practices as performed for the railway industry (also refer to Comment 9 on Page 2)? If not, Calibre highly recommends they conform to them at some time in the future.

2.10. Section - 1.4 Key terms and concepts: (page 14/136)

Comment 49

For the following statement within this section:

"Level 3: Conditional automation, The ADS undertakes the entire dynamic driving task for sustained periods in defined circumstances. The human driver does not have to monitor the driving environment or the ADS but must be receptive to ADS requests to intervene and any system failures."

Calibre recommends that a Drivers Vigilance (or equivalent) system is needed to ensure Driver is awake at all times to interact with the ADS.

Please also refer to our comments at Comment 2 on Page 1.

Comment 50

For the following statement within this section:

"Level 4: High automation, The ADS undertakes the entire dynamic driving task for sustained periods in some situations, or, all the time in defined places. The human driver does not have to monitor the driving environment and the driving task or to intervene when the ADS is driving the vehicle."

Calibre considers this may conflicts with the idea of the driver not needing to monitor or intervene as the following statement

"Level 5: Full automation All aspects of the dynamic driving task and monitoring of the driving environment are undertaken by the ADS. The ADS can operate on all roads at all times. No human driver is required."

As it implies there will be roads and areas of roads where Level 4 cannot be sustained thereby implying that there needs to be an interaction between the Driver and ADS when coming into and out of these sections.

Calibre recommends this needs to be clearly defined in this section.

3. Section 2 - Problem Statement and Need for Government Intervention (page 16/136)

3.1. Section - 2.2.2 Evidence of automated vehicle safety risk: (page 17/136)

Comment 51

For the following statement within this section:

"Scenario 3: Vehicle owner does not accept over-the-air software update Deepa drives a vehicle that is capable of operating at high automation. She receives a notification that a safety critical software update to the ADS is available and should be installed. Deepa decides not to accept the update and the ADSE does not take any action to manage the risk."

Calibre recommends there should be another scenario where the user accepts the download but an analysis must take into account that the update has not been done successfully and / or the download has corrupted the ADS systems making it unstable whilst traveling on the roads.

3.2. Section - 2.3 Lack of consumer confidence in ADS safety may reduce or delay their uptake: (page 23/136)

Comment 52

For this section has fraudulent use of ADS fake components being considered here?

This is just an observation for consideration; Calibre recommends this be considered.

3.3. Section 2.4.1 - Consultation questions

1. To what extent has the consultation RIS fully and accurately described the problem to be addressed? Please provide detailed reasoning for your answer.

2. What other factors should be considered in the problem statement? (page 22/136)

Comment 53

For Question 1, there needs to be more information on what types of ADS are currently available and what are in the pipeline in the next 2-3 years in order to give emphasis on the exact nature of the risk.

For Question 2, perhaps state what other countries that have ADS have similar road laws/risks as to Australia.

3.3.1. Section 2.5 - Consultation questions

3. Has the consultation RIS provided sufficient evidence to support the case for government intervention? What else should be considered and why?

4. To what extent have the community and industry expectations of a regulatory response been accurately covered? (page 23/136)

Comment 54

For Question 3, more evidence of safety risks not particular associated with road safety that has occurred due to non-government intervention in an monitoring capacity may add weight to the need for this on the introduction of ADS vehicles to our roads.

For Question 4, has there been a nation-wide survey for this request? If not, Calibre recommends this occur.

4. Section 3 - Options to Address the Problem (page 24/136)

4.1. Section - 3.1 Introduction: (page 24/136)

Comment 55

For the following statement within this section:

"The safety assurance system applies both at 'first supply' of an ADS and while it is on the roads ('in-service'). The ADSE will be responsible for initial and ongoing adherence to their Statements of Compliance."

Calibre recommends this cover infrastructure with respect to roadside communications and cyber security.

4.2. Section - 3.3.1 Description of the option: (page 26/136)

Comment 56

For the following statement within this section:

“This includes new national vehicle standards (ADRs) to align with evolving international automated vehicle standards”

Calibre recommends it would be helpful to list some of these emerging standards.

Comment 57

From the statement from within this section:

“followed by a revision (ADR 90/01) in late 2018 to align it fully with the current level of international standards as developed through the UN”

What are the current international standards developed through the UN?

This is an observation for consideration; Calibre recommends these be referenced in the document.

4.3. Section 3.4.2 - Safety assurance system specific offences and compliance and enforcement measures: (page 30/136)

Comment 58

Within this section it seems that the risk of ADS equipment being replaced by an inferior cheaper parts (e.g. replica or “pattern” parts rather than OEM parts) has not been included which may introduce risk.

Calibre recommends that the safety assurance system specific offences and compliance and enforcement measures specifically mention and deal with non-OEM / certified parts – much like the aerospace industry requirements.

4.4. Section - 3.5.2 Primary safety duty: (page 31/136)

Comment 59

For the statement within this section:

“A primary safety duty would provide an overarching and positive general safety duty on the ADSE to ensure the safety of the ADS so far as reasonably practicable”

Calibre believes this may infer that the Australian SFAIRP legislation / guidelines apply.

Calibre recommends this be clarified clearly.

Calibre recommends that the Australian SFAIRP legislation / guidelines apply.

4.5. Section - 3.5.3 How it would work: (page 32/136)

Comment 60

The introduction of the ATSB should be the investigating agency when investigating an accident, which currently covers aviation, maritime and railways that could also add the roads to their portfolio.

4.6. Section 3.5.4 - Consultation question

5. Are the four options clearly described? If not, please elaborate. (page 32/136)

Comment 61

The layout of the options are different from each other with some headings included and some not with some different headings being included in the 4 options thereby leaving the easy understanding between them not as clear as could be with each option not covering all the topics of the others in chronical logic order.

5. Section 4 - Proposed safety criteria for the Statement of Compliance (page 33/136)

5.1. Section - 4.3.1 Safe system design and validation processes: (page 34/136)

Comment 62

This section should also include a V-Model for software design, development, verification and validation.

It should also include the use of requirements management to progress the safe design.

5.1.1. Section - 4.3.3 Human-machine Interface: (page 34/136)

Comment 63

For the following statement within this section:

"requesting that the human driver take back control of the vehicle with sufficient time for the human driver to respond."

Calibre's view is this may not be practicable as this would imply that each human driver needs to be trained to respond in this event which may not take place when vehicles are sold or exchanged.

Calibre does not have an alternative option at this stage, but recommends this be looked at in depth.

Comment 64

For the following statement within this section:

"This could include monitoring by the ADS of human readiness to take back control and alert systems where such readiness is not apparent"

Calibre considers this would imply that a camera alertness vigilance system (or equivalent) needs to be employed which would have to be integrated with the on-board ADS sub systems which has inherent risks.

That being said, Calibre recommends this be incorporated (see Comment 49 on Page 8).

5.2. Section - 4.3.5 Interaction with enforcement and other emergency services: (page 35/136)

Comment 65

For the statement within this section:

"The applicant should also demonstrate how it may facilitate police access to this information in real time at the roadside"

Calibre recommends the recording device need to be crash and fire proof (e.g. "black box") if police / coronial / judicial (etc) evidence needs to be obtained.

5.3. Section - 4.3.6 Minimal risk condition: (page 35/136)

Comment 66

For the statement within this section:

"The applicant must demonstrate how the ADS will detect that it cannot operate safely and ensure a minimal risk condition is reached."

Calibre recommends that the what happens in degraded modes of operation and what implied risks are realised during these degraded modes of operation needs to be identified.

5.4. Section - 4.3.7 On-road behavioural competency: (page 35/136)

Comment 67

For the statement within this section:

"The applicant must demonstrate how the ADS will appropriately respond to foreseeable and unusual conditions that may affect its safe operation."

Calibre recommends this must this take into account the scenario of other road users that do not have and ADS

> Roads & Highways > Railways > Maritime Ports > Airports > Intermodal Hubs > Intelligent Transport Systems
Transport Assets That Perform for the People They Serve

system engaged and may change lanes, brake or swerve abruptly.

5.5. Section - 4.3.8 Installation of system upgrades: (page 35/136)

Comment 68

For the statement within this section:

"This includes ensuring safety-critical system upgrades to the ADS are installed and do not result in the operation of an unsafe ADS."

Calibre recommends that for safety purposes, any updates should not be done when vehicle is moving.

5.6. Section - 4.3.9 Testing for the Australian road environment: (page 36/136)

Comment 69

For the following statement within this section:

"The applicant must demonstrate how it has considered the Australian road environment in designing and developing the ADS."

Calibre recommends that there should be a requirement specification that includes all the environment criteria for Australia which the suppliers would have to conform with.

5.7. Section - 4.3.11 Education and training: (page 36/136)

Comment 70

The following statement within this section:

"facilitating the maintenance and repair of an ADS, including after a crash before it is put back in service."

Calibre recommends that protocols must be in place to ensure that correct parts have been fixed / replaced and safely tested prior to allowing vehicle to go back into operation with ADS engaged. This has various inherent risks, such as faulty and or sub-standard spare parts could fail to protect safely, badly written software code onto spare safe components not designed and approved to recognised safety standards due to cost of production etc.

5.8. Section 4.4.3 - Consultation questions

6. Are the proposed safety criteria and obligations on ADSEs (detailed in chapter 4 and Appendix C) sufficient, appropriate and proportionate to manage the safety risk?

7. Are there any additional criteria or other obligations that should be included?: (page 37/136)

Comment 71

For Question 6, could be improved with more overseas data. This is just an observation for consideration; Calibre has no recommended data available but is aware it exists.

For Question 7, within Section 4 Calibre highly recommends there should be a criteria to prevent alteration to the stored recorded data which may be used in court.

Comment 72

For Question 7, Within Section 4 Calibre highly recommends there should be a criteria for the handling of such safety related data from the ADS through to evidence for court proceedings.

Whilst Calibre does not have example criteria available, we highly recommend this is the subject of further research and identify the following web link as a potential start point: http://www.mondaq.com/australia/x/675064/data+protection/New+Australian+mandatory+data+breach+laws.

6. Section 5 Method for assessing the options (page 38/136)

6.1. Section - 5.2 Impact categories and assessment criteria: (page 39/136)

Comment 73

Calibre recommends this should mention police and emergency service impacts of how they are alerted in the first place to an accident, this may be through an automated ADS system upon detection of a crash.

Comment 74

For the following statement within this section:

"2. Uptake of automated vehicles – the potential benefits of automated vehicles such as improved road safety, mobility, freight productivity and reduced road congestion cannot be fully realised without the uptake of automated vehicles into the Australian vehicle fleet."

Calibre recommends the inclusion of fuel efficiency and hence reduction of environmental carbons be stated within this bullet point.

6.2. Section - 5.2.1 Choice of road safety assessment criteria: (page 41/136)

Comment 75

For the following statement within this section:

"We assess each of the four options against nine road safety assessment criteria."

Calibre believes this may conflict with the following Section - 4 Proposed safety criteria for the Statement of Compliance Key points. The NTC proposes 11 principles-based safety criteria as part of a safety assurance system.

Calibre recommends this be clarified.

6.2.1. Section Consultation question 8

Do you agree with the impact categories and assessment criteria? If not, what additional impact categories or assessment criteria should be included? (page 43/136).

Comment 76

The answer to Question 8, is that Criterion "e" seems to be contradictory if a vehicle with an ADS is allowed to enter even when the ADS has not been approved or there is insufficient infrastructure may infer safety risks and more costly to validate once in country if there are some design issues with the software functions in that instance.

6.3. Section - 5.3 Individuals and groups likely to be affected: (page 43/136)

Comment 77

For the following statement within this section:

"Table 5. Affected individuals and groups, Road users, including vulnerable road users such as cyclists and pedestrians."

Calibre recommends this include motorbike riders and the risks imposed by their potential interaction with vehicles that have ADS engaged.

6.3.1. Section 5.3 - Consultation question

9 Has the consultation RIS captured the relevant individuals or groups who may be significantly affected by each of the options? Who else would you include and why?: (page 44/136)

Comment 78

For the following statement within this section:

"Has the consultation RIS captured the relevant individuals or groups who may be significantly affected by each of the options? Who else would you include and why?"

Calibre recommends this include motorbike users and interactions with automated and passive railway level crossings with vehicles using ADS systems.

7. Section - 6 Assessment of the Options (page 46/136)

7.1. Section - 6.2 Road safety impacts: (page 46/136)

Comment 79

For the following statement within this section:

"The US Department of Transport attributes the cause of 94 per cent of all crashes to 'human choice'."

Calibre recommends it might be better to reword "Human Choice" to "Human Error" as we do not believe people "choose" to crash and this is not exactly stated in Appendix G

7.2. Section 6.2.1 - Consultation questions

10. Does our analysis accurately assess the road safety benefits for each reform option? Please provide any further information or data that may help to clearly describe or quantify the road safety benefits. 11. What additional safety risks do you consider the primary safety duty in option 4 would address compared with option 3?: (page 50/136)

Comment 80

The primary safety duty for option 4 should include the introduction and adherence to new road safety standards, they should also be responsible for road safety awareness campaigns nationally.

7.3. Section 6.3.1 - Consultation question

12. Does our analysis accurately assess the uptake benefits for each reform option? Please provide any further information or data that may help to clearly describe or quantify the uptake benefits: (page 50/136)

Comment 81

Yes with the available data for assessment purposes.

7.4. Section - 6.4.1 Assessment of options against regulatory costs to industry: (page 51/136) assessment criteria

Comment 82

For the following statements within this section:

"Option 1 requires that ADSEs seek exemptions from the ADRs.

ADSEs would also be required to register automated vehicles as nonstandard vehicles without defined and certain processes." and "The administrative costs of option 1 are uncertain because there would be no defined standards for which an ADS would be assessed against.

This would make the application process uncertain and potentially costly for industry."

Why would there be no defined processes due to the fact that the vehicle manufacturer will need certain processes in order to allow goods into Australia and these goods must be produced to some country standard where they came from for the basic safety principles for Australian citizens (example of this occurred when the two wheeled surf boards were allowed in from China which then caught fire on several occasions that they were banned from being allowed on aircraft).

This is just an observation for consideration.

7.5. Section 6.4.2 - Consultation questions

13. Does our analysis accurately assess the regulatory costs to industry for each reform option? Please provide any further information or data that may help to clearly describe or quantify the regulatory costs.

14. Are there any specific regulatory costs to industry that we have not considered?: (page 54/136).

Comment 83

Calibre recommends that administration costs been considered with respect to any safety accident investigation body needing to be set up as part of the regulatory duties to oversee the safety enforcement of the road regulations.

Comment 84

Calibre recommends the production of a Risk Model in which to govern the industry with respect to the addition of the new ADS manufacturers and their products.

7.6. Section 6.5 Regulatory costs to government impacts: (page 54/136)

Comment 85

For the following statement within this section:

"The regulatory costs to government impact category recognises that a safety assurance system would have upfront and ongoing costs to government. These costs need to be proportionate to the benefits. 35"

Calibre recommends that the support note "35" should also contain the number of automated vehicles involved in an accident as part of any ongoing costs to be monitored.

7.7. Section 6.5.1 Assessment of options against regulatory costs to government assessment criteria: (page 55/136)

Comment 86

For the following statement within this section:

"There is significant uncertainty around other potentially significant government costs. These include monitoring, investigating and enforcing in-service safety incidents. However, these activities could also be costed and recovered through fees and charges. Currently, there is insufficient information to estimate these costs."

Calibre believes there should be current data on general road accidents and some overseas data on accidents with automated road vehicles that could be used as an initial basis when added with a Risk Model could provide some approximate costs associated with this area of government assessment.

7.8. Section 6.5.1 - Consultation question

15. Does our analysis accurately assess the costs to government for each reform option? Please provide any further information or data that may help to clearly describe or quantify the costs to government. (page 56/136)

Comment 87

It is not clear from the table 10 within this section is proposing a National Governing body or assuming each state will provide their own regulatory bodies which may have risks associated with producing standards and laws in which to accept and govern the use of automated vehicles within Australia.

Calibre recommends a superordinate National Governing body.

7.9. Section 6.6.1 - Consultation question

16. Does our analysis accurately assess the flexibility and responsiveness for each reform option? Please provide any further information or data that may help to clearly describe or quantify the flexibility and responsiveness of the options. (page 57/136)

Comment 88

Calibre believes there should be some thought on the dependence on ADS with respect to the network infrastructure as safety is paramount on the GPS location positioning systems as the use of the ADS may have to take into account the various speed restrictions and diversions throughout a journey.

8. Section 7 - Summary of Assessment and Preferred Option (page 58/136)

8.1. Section 7.2 Impacts of options under various automated vehicle uptake scenarios: (page 60/136)

Comment 89

For the following statement within this section:

"40 Commercial operators could offset these costs against savings from reduced costs for human drivers."

The addition of fuel savings due to automated driving should also be a factor for commercial operators moving to ADS vehicles.

Comment 90

For the following statement within this section:

"With an increasingly shared vehicle fleet, the overall number of registered vehicles would fall, but each vehicle would travel more kilometres each year. This could present risks to in service performance, which are only addressed under options 3 and 4. In-service performance is most comprehensively addressed by option 4 because the primary safety duty provides for new risks that were not identified in the Statement of Compliance."

Calibre believes that the costs could be offset with the introduction of an e-safety certification each year in order for a vehicle to remain roadworthy in which ADS could be revalidated.

Comment 91

For the following statement within this section:

"41 This is based on the current number of new vehicle applications of around 400 per year."

Is this applications based upon vehicles with ADS or partial ADS systems embedded or just standard vehicle applications? This requires clarification.

Calibre recommends the source for this assertion be provided.

8.2. Section 7.3.1 - Consultation questions

17. Do you consider the relevant factors and conditions for government in choosing an option to be valid? Are there any factors and conditions you do not agree with? 18. Do you agree with our view on the relevant factors and conditions for government in choosing an option? (page 65/136)

Comment 92

Yes for both questions.

8.3. Section 7.4 - Consultation questions

19. Has the consultation RIS used an appropriate analytical method for assessing the benefits and costs of the options? What else should be considered?

20. On balance, do you agree that the preferred option best addresses the identified problem? If not, which option do you support?

21. How does your choice of option better address the problem than the preferred option? (page 66/136).

Comment 93

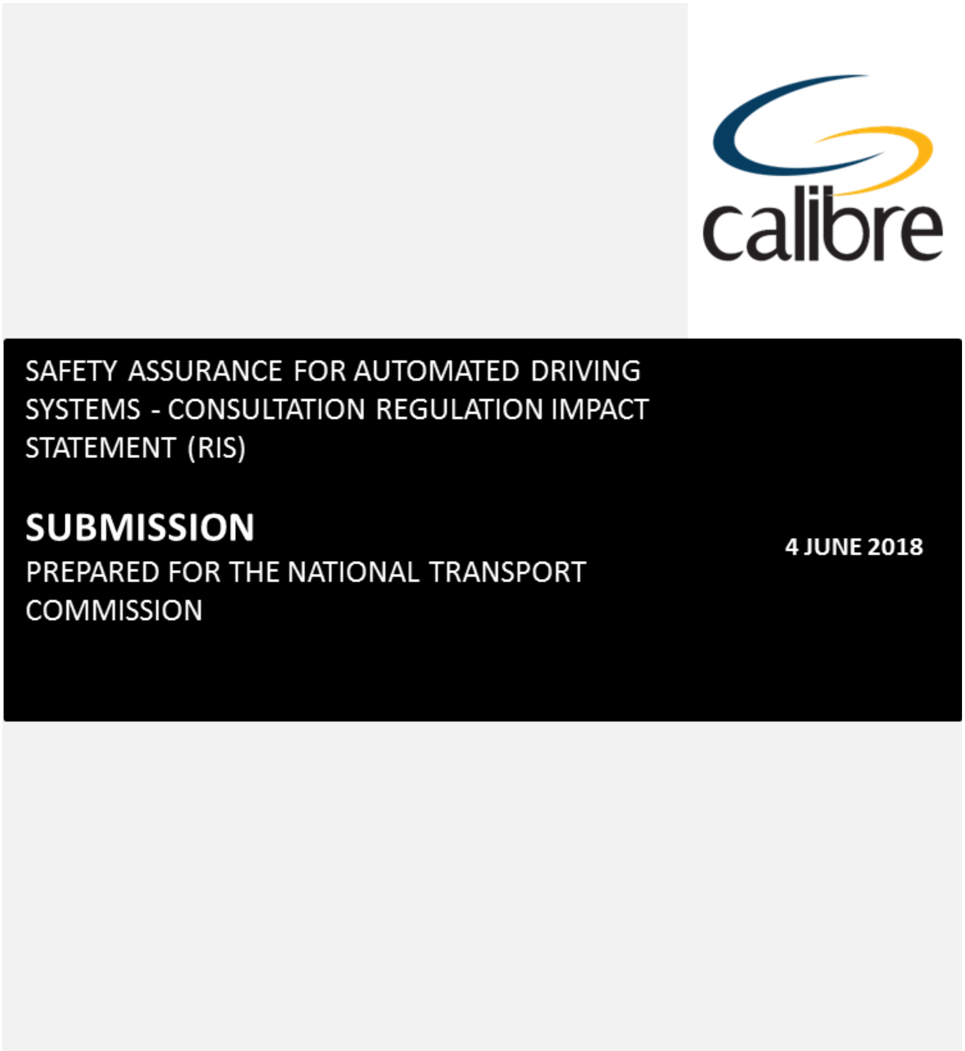
For question 19, most of the analysis is good but would be better to have included more overseas research and analysis as ADS vehicles have already been introduced in other parts of the world and going on some fact-finding missions would improve this paper.

Calibre believes that to make the introduction of ADS vehicles into Australia safe then there needs to be a nation-wide regulatory body that can legalise road safety standards and ensure overall compliance to these standards.

This body like other regulatory bodies within Australia could aid the safety of Australians within the country and could liaise with the ATSB in order to achieve the complete safety lifecycle.

Annex A to
Calibre Group Submission to NTC
4 Jun 18

Example Vehicle Active Safety Model


SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

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A Vehicle Active Safety Model: Vehicle Speed Control Based on Driver Vigilance Detection Using Wearable EEG and Sparse Representation

Zutao Zhang,[1,*,†] Dianyuan Luo,[2,†] Yagubov Rasim,[2] Yanjun Li,[2] Guanjun Meng,[1] Jian Xu,[3] and Chunbai Wang[4]

Felipe Jimenez, Academic Editor

[1]School of Mechanical Engineering, Southwest Jiaotong University, Chengdu 610031, China; meng_guanjun@my.swjtu.edu.cn
[2]School of Information Science & Technical, Southwest Jiaotong University, Chengdu 610031, China; luodianyuan@my.swjtu.edu.cn (D.L.); rasim_yagubov@hotmail.com (Y.R.); liyanjun@my.swjtu.edu.cn (Y.L.)
[3]The Psychological Research and Counseling Center, Southwest Jiaotong University, Chengdu 610031, China; xujianlm@gmail.com
[4]The Department of Industrial & Manufacturing Systems Engineering, Iowa State University, Ames, IA 50011, USA; chbwang@iastate.edu
[*]Correspondence: zzt@swjtu.edu.cn; Tel.: +86-135-5120-4769
[†]These authors contributed equally to this work.

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Abstract

Go to:

In this paper, we present a vehicle active safety model for vehicle speed control based on driver vigilance detection using low-cost, comfortable, wearable electroencephalographic (EEG) sensors and sparse representation. The proposed system consists of three main steps, namely wireless wearable EEG collection, driver vigilance detection, and vehicle speed control strategy. First of all, a homemade low-cost comfortable wearable brain-computer interface (BCI) system with eight channels is designed for collecting the driver's EEG signal. Second, wavelet de-noising and down-sample algorithms are utilized to enhance the quality of EEG data, and Fast Fourier Transformation (FFT) is adopted to extract the EEG power spectrum density (PSD). In this step, sparse representation classification combined with k-singular value decomposition (KSVD) is firstly introduced in PSD to estimate the driver's vigilance level . Finally, a novel safety strategy of vehicle speed control, which controls the electronic throttle opening and automatic braking after driver fatigue detection using the above method, is presented to avoid serious collisions and traffic accidents. The simulation and practical testing results demonstrate the feasibility of the vehicle active safety model.

Keywords: wearable electroencephalographic, vigilance detection, vehicle active safety, vehicle speed control, sparse representation, brain-computer interface

1. Introduction

Go to:

A growing number of traffic accidents have become a serious social safety problem in recent years. One of the main factors has been the obvious drop in the driver's perceptual senses, such as feeling, recognition, and automobile control abilities, as they feel sleepy. Statistics show that the leading cause of fatality and injury in traffic accidents is the driver's diminished vigilance level [1,2]. Analysis of literature suggests that driver vigilance contributes to approximately 43% of vehicle crashes and 27% of near crashes [3]. Fatal crashes reported from Washington D.C. indicate that driver fatigue caused a large proportion of crashes (*i.e.*, 10% in 2005 and 16% in 2009, for total 5474 fatigue-related fatalities in 2009) [4]. In Europe, statistics report that about 10% to 20% of all traffic accidents are caused by driver's fatigue due to a diminished vigilance level. The National Sleep Foundation (NSF) reported that 51% of Americans have driving while feeling drowsy and 17% admit that they had actually fallen asleep [5].

Technologies such as pretension seat belt, airbag, antilock brake system, traction control system, and electronic stability programs, can protect people in collisions only to a certain extent. It is important to develop systems that actively detect a driver's level of vigilance and control the vehicle speed when he is driving fatigued. Over the past several decades, many researchers have focused on driver's vigilance detection. They solved this problem by sending a warning to driver when the driver appears drowsy. Nevertheless, these technologies are not helpful in the control of vehicle because the majority of drivers believe that they are able to control the vehicle. However, they actually are not. With increasing vehicle speed, the dynamic vision, vision of the driver in motion, and dynamic vision field (vision field of the driver in motion) decrease. Generally, dynamic vision is 10%–20% lower than a static vision. For instance, when vehicle speed is 60 km/h, the driver can see traffic signs within 200 m. When vehicle speed is up to 80 km/h, the driver can only see traffic signs within 160 m ahead. Therefore, it is necessary and efficient to control the vehicle speed or decelerate to prevent a collision when the driver is drowsy.

1.1. Driver Vigilance Detection Technologies

Currently, technologies of detecting driver vigilance are developing rapidly. The most popular approaches are classified into three categories [6,7,8]. The first category focuses on the movements of the vehicle [9], such as detecting the lane departure, steering wheel movement, the pressure of driving pedal. If the movement of the vehicle is abnormal, the driver is regarded as drowsy. Although this technology provides a noninvasive way for correcting the driver, it is difficult to construct a common model for drowsy driving due to variability of an in dividual's driving behavior and changes of road circumstances.

The second category analyzes the changes of driver's physical behaviors [10,11,12,13,14,15], such as eye tracking, yawning, percent eye closure (PERCLOS), blink frequency, nodding frequency, face position, and the inclination of the driver's head. In literature [10,11,12,13,14,15], measuring eyelid movement, face expression and head pose using video cameras are effective ways o driver vigilance detection based on machine vision and computer hardware technologies. The use of multiple visual parameters and the information fusion of various driver facial visual cues, were used to model driver vigilance and to predict driver fatigue [14,15]. Usually, in such an algorithm, a video is used to analyze and classify the vigilance level of the driver. Video is susceptible to environmental and driving conditions such as light conditions, glasses worn by the driver, and so on. Furthermore, false estimation can also be caused by variability of the driver's behavior, such as sleepiness with eyes open.

The last category is the physiological signal [16,17,18,19,20,21,22,23,24,25,26,27,28] for driver drowsiness detection, using electrocardiosignal (ECG), electrooculographic (EOG), electroencephalographic (EEG), and heart rate variability (HRV). These systems are more reliable because physiological drowsiness signs are well known and rather similar from one driver to another. EEG is always regarded as a "gold standard" of vigilance detection. In [16], Šušmáková described the relationship between human sleepiness and EEG. It indicated that some existent rhythm components, theta (4 Hz–8 Hz), alpha (8 Hz–14 Hz), and beta (14 Hz–34 Hz) in EEG had a close relationship with the driver's vigilance levels. There is a positive correlation between the power of theta or alpha rhythm and drowsiness, and a negative correlation between the power of beta rhythm and being awake. In this category, the first and most important part is the acquisition of EEG of driver. However, the traditional laboratory equipment is too large and troublesome to use. To extend the application of EEG to the drowsy driving field, many researchers began to develop portable equipment for EEG collection. Lin *et al.* have designed a series of wearable BCI systems in [17,18] to detect driver vigilance. Their system possesses three functions. The first function is EEG acquisition and amplifying, and the second function is data transmission implemented in CPLD (complex programmable logic device), *etc.* The third function is vigilance detection implemented in OMAP (open multimedia architecture platform), *etc.* In literature [19,20,21], Rodger *et al.* had also made significant improvement of interface neuro-physiological behavior performance over existing techniques, which authors proposed a NeuroIS

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knowledge discovery approach, a study on emotion and memory, improving memory, and software training results for BCI systems. Independent component analysis (ICA), wavelet, and filters are usually used in interference removal. Next, a vigilance detection algorithm is implemented to distinguish different states of the driver [4,22,23,24,25,26,27]. In [4], the author explores many experimental results to verify the relationship between EEG power spectrum density (PSD) and drowsiness. The power of alpha and beta rhythm in an alert state is greater than in a drowsy state. The power of the theta rhythm in an alert state is lower than in a drowsy state. In [22], Jung *et al.* proposed a model of estimating alertness based on EEG power spectrum as early as 1997. In their paper, principal component analysis (PCA) is used for EEG feature extraction, and artificial neural networks (ANN) are used to establish an alertness model. The results show that continuous, accurate, noninvasive, and nearly real-time estimation of vigilance levels using EEG is feasible. In [23], as a kind of EEG feature, power spectrum density is extracted to construct a drowsy model for vigilance classification. Yu *et al.* use continuous wavelet transform (CWT) to extract the rhythm features of EEG and use sparse representation classification to accomplish the classification task in [24]. To enhance the performance of sparse representation classification, k-singular value decomposition (KSVD) proposed by Aharon, *et al.* in [25] is explores. A multi-channel EEG signal model during a working memory task was presented in literature [26]. In [27], a mobile healthcare device for dirver vigilance detection using wavelet-based EEG and respiration signals was presented. The driver's health condition was analyzed from evaluating the heart rate variability in the time and frequency domains. In [28], a new evaluation model of driver fatigue is established with integration of four fatigue-based indicators with a dynamic Bayesian network (DBN). The results show that it is more accurate to evaluate driver fatigue than the sole EEG-based indicator. The difficulties of these physiological signal measures as on-road driver vigilance detection monitors are in how to obtain EEG recordings comfortably under driving conditions and classify the driver drowsiness with so many EEG signals. Nevertheless, the physiological signal measures are believed accurate, valid, and objective in determining driver vigilance.

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1.2. Vehicle Speed Control Algorithms after Driver Vigilance

After the driver is drowsy, some proposed systems give warnings to the driver in order to avoid traffic accidents [9,15,17]. Despite warning of fatigue driving, most drivers believe they can drive safely. Under the circumstances when the driver's response and vigilance continue to slow down, the vehicle active safety strategy is an important optional system that provides speed control in order to prevent traffic collisions. Adaptive cruise control (ACC) and stop-and-go strategies are related to vehicle speed control. The former is mainly involved in the inter-distance control on the road where the automoble drives at a constant speed, whereas the latter deals with vehicle commuting in municipal areas with frequent stops, decelerations, and accelerations [29]. In [30], Li proposed an active control strategy to keep vehicles away from possible collisions owing to distracted driving or drivers' attention. In [31], the literature examines drivers' adaptation using a conceptual model of adaptive behavior. In [32], Zhang *et al.* present a reversing speed control for vehicle safety. The final simulation and experimants show the validity of the vehicle reversing speed control. McCall *et al.* proposed a novel safety system to reduce rear-end collisions based on predictive braking assistance in [33]. In [34], Keller *et al.* present a active pedestrian safety system that fuses sensors, state analysis, decision support, and autombile control. In [35,36], Naranjo *et al.* proposed an ACC system that was used for vehicle safety. The related work treats the vehicle speed control by environment perception [37], road condition detection [38,39], and driver active state detection [40].

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Despite the success of the existing approaches/systems for driver vigilance detection and vehicle speed control, a variety of factors still challenge researchers. Much research has been conducted on driver vigilance detection systems, focusing on the following three main problems: (1) how to find a higher-reliability and lower-cost comfortable wearable EEG system that are currently widely used to get the EEG signal of driver; (2) how to detect and recognize the driver fatigue from so much data; and (3) how to apply the vehicle speed control algorithm after driver fatigue detection using the above method in preventing collisions. Until now, few have investigated deeply and systematically vehicle active safety technology based on vigilance detection using wireless wearable EEG signals. The existent lane departure warning system and vehicle collision warning system are established on the driving state and environment to avoid collision. It is imperative to take measures to reduce collisions based on the study

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of the driver's vigilance state using EEG signals. In this paper, we introduce an active safety method for vehicle speed control based on driver vigilance detection using wearable EEG and sparse representation. A homemade eight-channel low-cost comfortable wearable brain–computer interface (BCI) hardware system is developed to collect the EEG signal of driver. We can transmit the data of BCI hardware to a personal computer (PC)/field-programmable gate array (FPGA)/digital signal processor (DSP) via a Bluetooth interface. Then wavelet de-noising and down-sample algorithm are utilized to enhance the quality of EEG data and Fast Fourier Transformation (FFT) is adopted to extract the EEG power spectrum density (PSD). Sparse representation classification combined with KSVD is, firstly, implemented in PSD to estimate the driver vigilance level. After driver vigilance detection and recognition, a novel vehicle speed control strategy will make a decision to decelerate or brake. The results of the practical test and simulation show the feasibility of the proposed vehicle active safety model.

The rest of this paper is organized as follows. In Section 2, the general system architecture is presented. Section 3 focuses on low-cost wearable BCI system for EEG collection using our homemade eight-channel BCI system. Sparse representation classification for vigilance detection is described in Section 4, and vehicle speed control strategy is proposed in Section 5. The system simulation and validation are reported in Section 6. Finally, some conclusions are given in Section 7.

2. System Architecture

Go to:

The general architecture of our system shown in Figure 1, includes three major steps: (1) a wearable BCI system for EEG collection; (2) driver vigilance detection using sparse representation classification combined with KSVD; and (3) a vehicle speed control strategy.

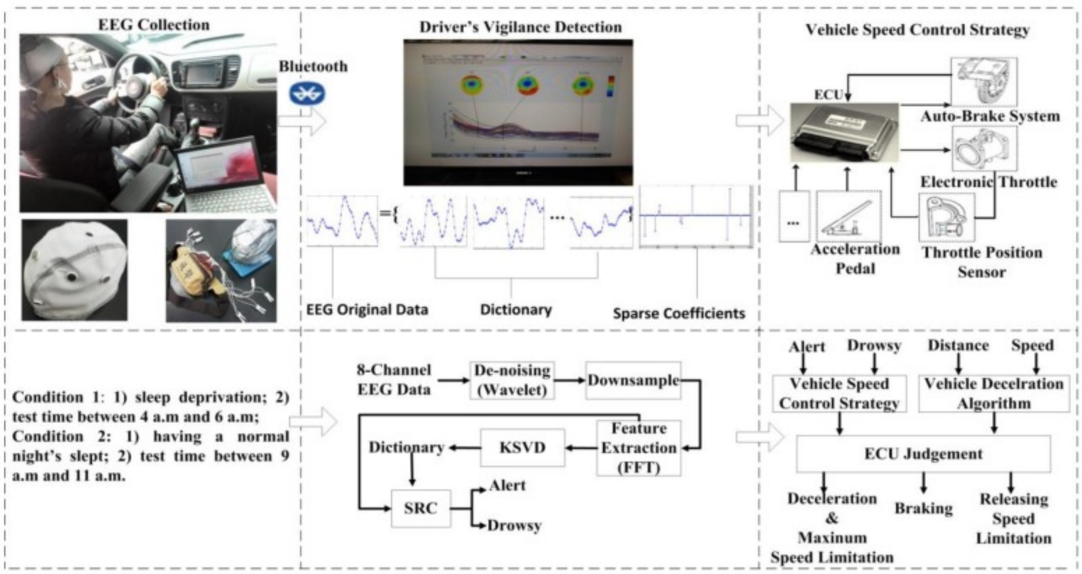

Figure 1

Flowchart of the proposed vehicle active safety model.

In the first step, when a driver is driving, a homemade eight-channel wearable BCI system is used to collection the EEG signals of the driver and then transmits its recorded data to PC/FPGA/DSP via a Bluetooth interface. Our BCI system consists of eight stainless steel dry electrodes. It incorporates the use of a wearable EEG device to record EEG signals from the head region of the driver. To extend the application of EEG to the drowsy driving field, the portable system is developed for EEG collection with all of the chips (including Bluetooth model and batteries) in a small bag. In order to acquire the data from different vigilance levels, we set the experimental conditions as the left of Figure 1. In this paper, we define two vigilance levels: alert and drowsy. In our experiment and simulation, we use a PC

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to process simulation data. The improved versions will be completed in the later experiment using DSP or FPGA.

The second step is driver's vigilance detection using sparse representation classification combined with KSVD. As shown in the middle block of Figure 1, after the EEG original data is collected using our eight-channel wearable BCI equipment, de-noising is implemented to remove some interference using wavelets. Then the data is down-sampled to 128 Hz in order to reduce the computation load. PSD is extracted as a feature of each state using FFT. Sparse representation classification combined with KSVD is implemented in PSD to estimate the driver's vigilance level, and the dictionary is prepared before classification and is trained using KSVD.

The final step is the vehicle speed control strategy in the right block of Figure 1. Despite the success of the existing approaches/systems for driver vigilance detection and ACC system, there are few studies about vehicle active safety technology based on vigilance detection that are deeply and systematically based on vigilance detection using wireless wearable EEG signals. In this paper, an active safety strategy for vehicle speed control based on vigilance detection using EEG and sparse representation is developed.

After driver vigilance detection, a vehicle speed control strategy determines what steps it takes to control the speed of vehicle as shown in Figure 1. According to the following car speed and distance detected by a binocular camera system, the vehicle deceleration model gives a safe deceleration method in the course of speed control. After the driver continues drowsy driving, the electronic control unit (ECU) receives the driver vigilance detection information from the second step and automatically controls vehicle speed. When the driver is detected in deep drowsiness, the ECU will control the throttle opening and auto brake to make the car decelerate or brak slowly to reduce the accident rate.

3. Wearable BCI System for EEG Collection

Go to:

EEG data is very important to our driver vigilance detection. The basic scheme of our EEG-based BCI system is proposed as in Figure 2. The wearable BCI system consists of EEG cap, reference electrodes, and a processing model as shown in Figure 2a. In Figure 2b, the positions of eight dry electrodes installed in EEG cap are corresponding to the cerebrum areas of O1, O2, C3, Cz, C4, P3, Pz, and P4. The installation positions on the head have a close relationship with driver vigilance level detection. In our system, the wearable EEG cap is suitable to comfortably collect the driver's brain signal data. It has eight single-channel EEG collection modules. As shown in Figure 2c for a single module, the structure has a five-part structure: (1) a stainless steel dry electrode; (2) TGAM module (the chip used to process EEG signal); (3) Bluetooth module; (4) reference electrode, and (5) battery module. The EEG signal is obtained by the stainless steel dry electrodes firstly, and then amplify and filter by the ThinkGear asic module (TGAM) model with the hardware filtering 3 Hz to 100 Hz and sampling rate of 512 Hz. Next, the EEG signal is transmitted to our PC via Bluetooth. The reference electrode provides reference potential for our stainless steel dry electrode. The system is powered by eight 3-V DC batteries. Figure 2d shows the processing module, including TGMA, Bluetooth, and batteries installed into some boxes, which are designed by *SolidWorks* software and manufactured by a 3D printer. At last, all chips of TGAM, Bluetooth, and batteries are arranged into a bag shown in Figure 2a to make our equipment more wearable. Although there are many commercial solutions, in our paper we want to design a low-cost wearable EEG system for our research. The cost of our homemade wearable EEG system is very cheap. Although it is not the cheapest, we think our homemade wearable EEG system has cost advantages compared with some of the commercial solutions. At the same time, the homemade wireless wearable EEG system is necessary for our future research. Our research is vehicle safety and the speed control module needs some interface via EEG. Our homemade wearable EEG system can meet our requirements.

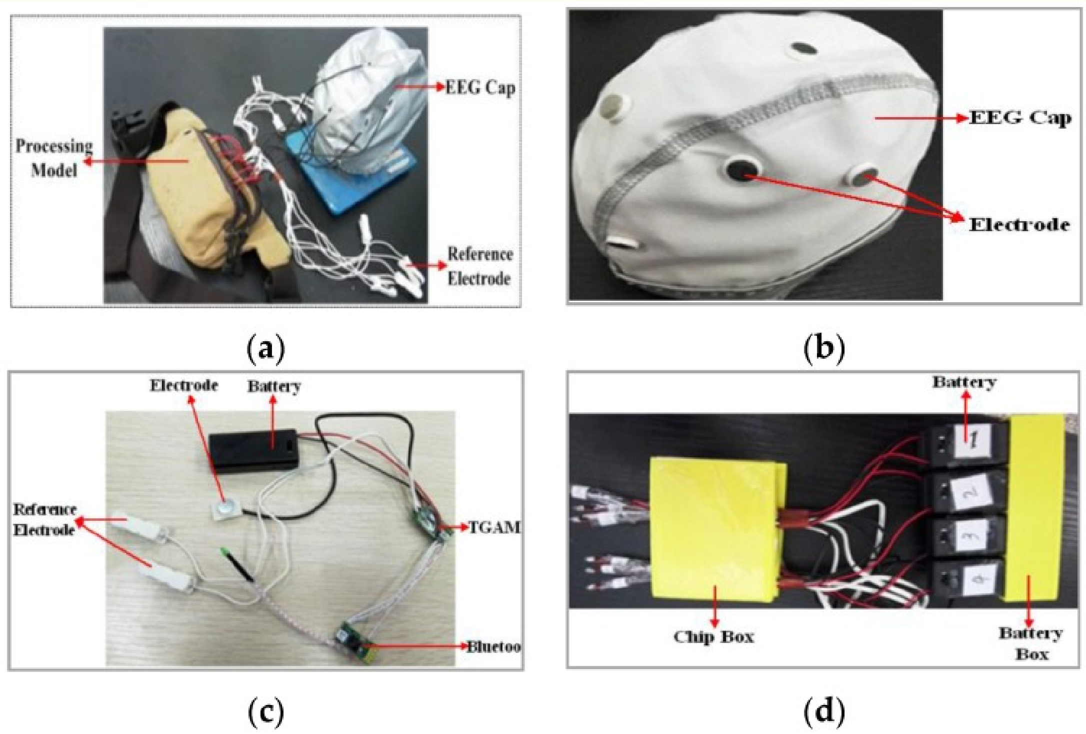

Figure 2

Fabrication of our proposed wearable BCI system. (**a**) Wearable BCI system; (**b**) Electrode cap; (**c**) Single-channel wearable EEG collection module; (**d**) The processing module.

To improve the efficiency of our homemade wearable BCI system in data acquisition accuracy, a 64-channel EEG provided by BRAIN PRODUCTS (BP) was used in our previous study and analysis, in the course of which we have a clear understanding about drowsiness-related EEG signals. As shown in Figure 3, the commercial BP system consists of BrainCap, BrainAmp, and the Recorder Analysis Software. In Figure 3a, BrainCap is an EEG acquisition cap with 64 channels and high-quality Ag/AgCl sensors. BrainAmp is used to amplify the EEG signal in Figure 3b. Recorder is software used to view, accept, reserve, and process EEG signals.

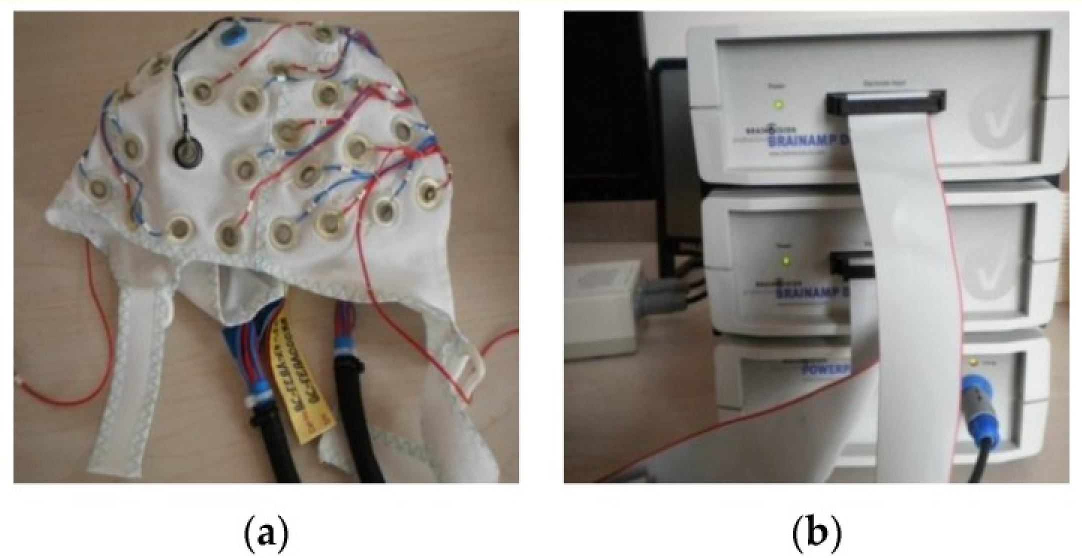

Figure 3

BP equipment in our previous study for comparison. (**a**) BrainCap; (**b**) BrainAmp.

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In this paper, we acquire EEG signal from both equipments. We called the signal set $\mathbf{Set}_{ijk}$, where i = {BP, wearable homemade BCI system (HBS)} indicates the type of apparatus, j = {*a*, *d*} shows the state of subject (*a* is the state of alert, *d* is drowsy), and k = {O1, O2, C3, Cz, C4, P3, Pz, P4}, representing the number of channels.

4. Driver Vigilance Detection

Go to:

After we get the EEG original signal, data processing is processed using MATLAB R2012a in three main steps described as follows.

4.1. Data Preprocessing

This process contains de-noising and downsampling. Discrete wavelet transformation (DWT) is an excellent time-frequency analysis tool in various fields of signal processing, for example, for de-noising of EEG. In this paper, we explore the application of the wavelet de-noising method for EEG signals according to its multi-resolution for the non-stationary EEG signal. A six-layer decomposition of db5 wavelet is implemented in the original EEG signal to get the sub-bands' wavelet detail coefficients (D_i, i = 1, 2, 3, 4, 5, 6) and approximation coefficients (A_i, i = 1, 2, 3, 4, 5, 6). The decomposition space tree and frequency range are shown in Figure 4. The range of EEG frequency is from 0.5 Hz to 50 Hz. By reconstructing the decomposition coefficients of d3, d4, d5, d6, we can extract the useful EEG signal and remove some low frequency and high frequency interference, as mentioned above.

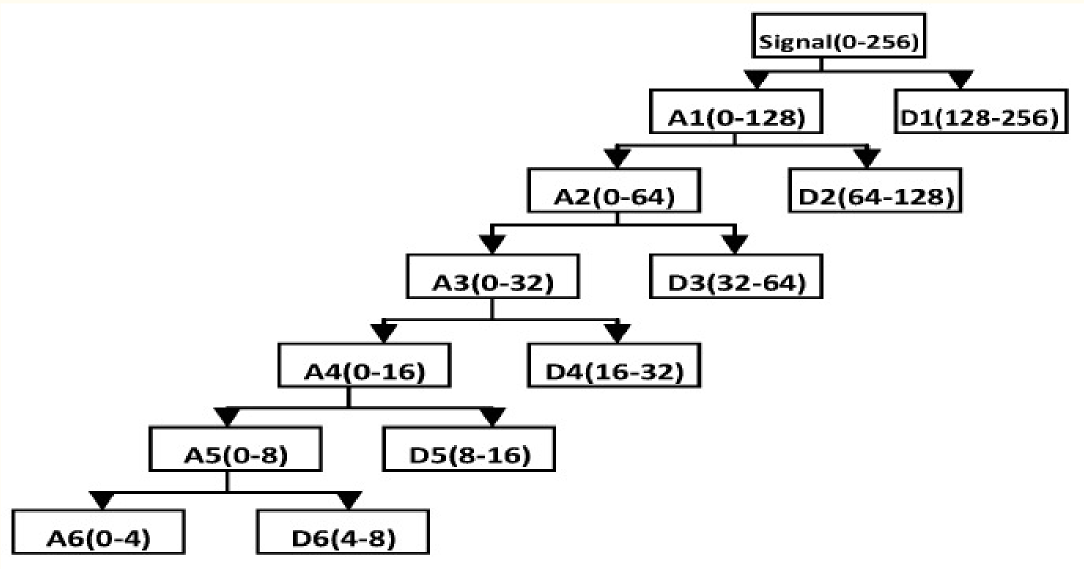

Figure 4

Decomposition space tree and frequency range of wavelet transform.

In addition, $\mathbf{Set}_{HBS}$ is downsampled to a sampling rate of 128Hz and $\mathbf{Set}_{BP}$ is downsampled to a sampling rate of 100 Hz to reduce the computation load.

4.2. Feature Extraction

It is very important to know the relationship between EEG and drowsiness for feature extraction. Firstly, $\mathbf{Set}_{BP}$ is analyzed using eeglab v12.0.0.0b (toolbook) of *MATLAB* to reveal the features of the

EEG. Figure 5 shows the power scalp topographies of some frequency components in the states of (a) alert and (b) drowsy.

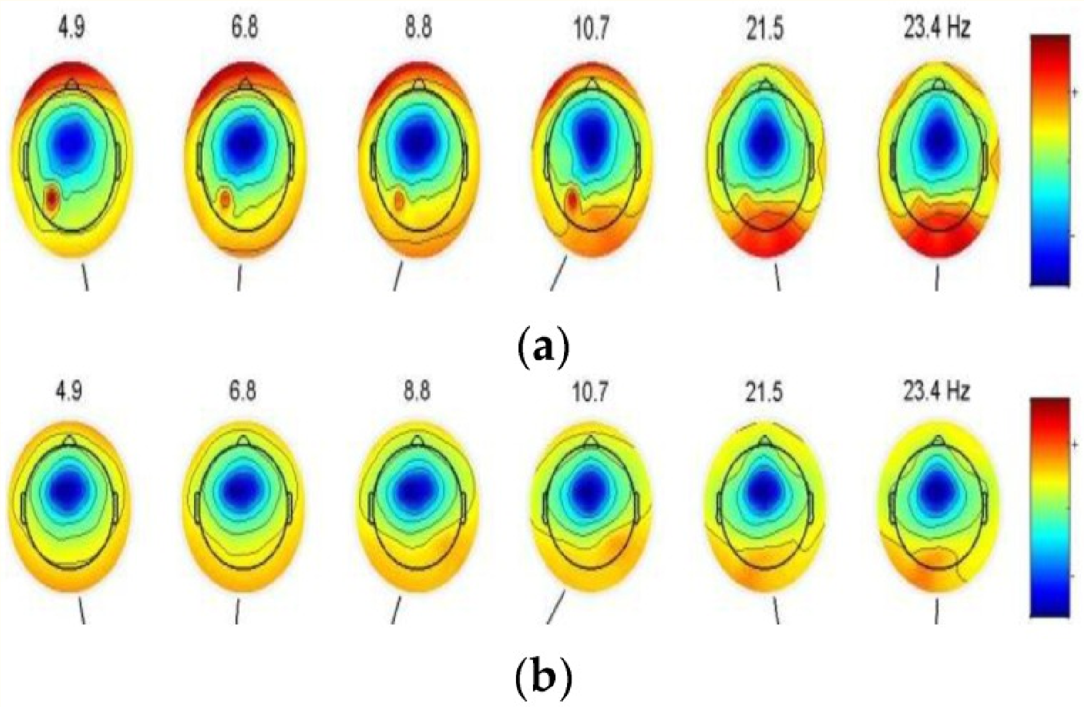

Figure 5

Power scalp topographies of some frequency components. (**a**) Power scalp topographies of the alert state; (**b**) Power scalp topographies of the drowsy state.

In Figure 5, we can observe many significant differences of the frequency distribution on the scalp. In the alert case, the more low frequency components are found in the area of the forehead, the more high-frequency components are distributed in the area of occipital. In the case of drowsiness, low-frequency components and high-frequency components in the area of the forehead and occipital region are approximately uniform. We can distinguish between different states from two areas of occipital and forehead using power spectral density of different frequency components. Since the signal in the forehead area is susceptible to the eye movement artifacts [18], the PSD of the occipital area (O1, O2) is adopted to distinguish between the two states. Then, the feature of the EEG signal at time *t* was the average PSD of the previous *s* s and *t* s. The PSD of each second is calculated using a 128-point FFT and then converted into a logarithmic scale. Next, a Rectangle Window is used to extract PSD of *theta*, *alpha*, *beta* rhythms, reported as the significant index for the driving error. At last, we stack the feature into a feature set **F**.

4.3. Driver Vigilance Detection Based on Sparse Representation Classification Combined with KSVD

Driver vigilance detection is the most important part in our vehicle active safety model. The sparse representation classification algorithm, one of the most popular classifiers used in pattern recognition in recent years, is used for the problem of vigilance classification. Moreover, KSVD is utilized to learn an over-complete dictionary for each level of the vigilance state. Meanwhile, L_0 minimization is used in solving the sparse representation problem. A minimal residual method is engaged to solve the classification problem for driver vigilance detection. In this paper, the sparse representation classification combined with KSVD is firstly introduced to implement in PSD to estimate the driver vigilance level. Although other algorithms have been used previously for the same task, we want to try to construct a novel algorithm for driver vigilance detection using sparse representation classification and KSVD.

4.3.1. Sparse Representation

In a sparse representation model, an EEG feature $\mathbf{y}$ ($\mathbf{y} \in R^p$) belonging to the set of $\mathbf{F}_{ijk}$, can be represented as a linear combination of atoms from an over-complete dictionary $\mathbf{DIC} = [\mathbf{d}_1, \mathbf{d}_2, \ldots, \mathbf{d}_w]$ ($\mathbf{DIC} \in \boldsymbol{R}^{p\times w}$, $w > p$), as Equation (1), where $\mathbf{d}_w$ is the atom of the dictionary, w is the number of atoms, and p is the length of $\mathbf{d}_w$:

$$\mathbf{y} = \mathbf{d}_1\alpha_1 + \mathbf{d}_2\alpha_2 + \ldots + \mathbf{d}_w\alpha_w = \mathbf{DIC}\alpha \tag{1}$$

where $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_w]$ is the sparse coefficient matrix, which only in a small fraction are non-zero. The optimum solution of sparse coefficients can be formulated as Equation (2), which denotes a L_0 minimization problem:

$$\alpha' = \arg\min\|\alpha\|_0 s.t. DIC\alpha = y \tag{2}$$

Here $\|\alpha\|_0$ is the number of non-zero coefficients in $\boldsymbol{\alpha}$. $\boldsymbol{\alpha}'$ is the approximate value of $\boldsymbol{\alpha}$. Orthogonal matching pursuit (OMP) is used to solve the L_0 problem. Then we can get approximately reconstructed signal via Equation (3):

$$y' = DIC\alpha' \tag{3}$$

4.3.2. Dictionary

From the sparse representation model mentioned above, the dictionary plays an important role in the process of sparse decomposition and signal reconstruction. To match each state, w features are randomly selected from each $\mathbf{F}_{ijk}$ to stack into dictionary $\mathbf{DIC}_{ijk}$. In order to avoid dictionary redundancy, KSVD is used in our paper to learn an over-completed, but small, dictionary. Two-thirds of each $\mathbf{F}_{ijk}$ are used to train and update the atoms of $\mathbf{DIC}_{ijk}$. Then we can get an excellent sparse decomposition performance at the corresponding state.

4.3.3. Sparse Representation Classification

To extend the application of sparse representation, sparse representation classification was first proposed by Wright *et al.* for face recognition in [41]. In the case of vigilance detection, we will introduce a SRC model as follows. Here, $\mathbf{DIC}_a = [\mathbf{d}_{a1}, \ldots, \mathbf{d}_{aw}]$ represents the dictionary of alert state and $\mathbf{DIC}_d = [\mathbf{d}_{d1}, \ldots, \mathbf{d}_{dw}]$ represents the dictionary of alert or drowsy. We form these two sub-dictionaries as $\mathbf{DIC} = [\mathbf{DIC}_a\ \mathbf{DIC}_d]$. In this way, a test sample y can be represented as Equation (4):

$$y = DIC\alpha = \sum d_{a1}\alpha_{a1} + \cdots + d_{aw}\alpha_{aw} + d_{d1}\alpha_{d1} + \cdots + d_{dw}\alpha_{dw} \tag{4}$$

By combining Equations (2) and (3), we can get the sparse coefficient $\alpha' = [\alpha_{a1}, \ldots, \alpha_{aw}, \alpha_{d1}, \ldots, \alpha_{dw}]$

So, $\boldsymbol{\alpha}'_a = [\alpha_{a1}, \ldots, \alpha_{aw}, 0, \ldots, 0]$ can be regarded as the sparse coefficients under $\mathbf{DIC}_a$, and $\boldsymbol{\alpha}'_d = [0, \ldots, 0, \alpha_{d1}, \ldots, \alpha_{dw}]$ can be regarded as the sparse coefficients under $\mathbf{DIC}_d$. The class of $\mathbf{y}$ is calculated by Equation (5) and is determined by the minimal residual of $\mathbf{y}$ and its reconstructed signal y' under coefficients of α_a and α_d:

$$class(\mathbf{y}) = \operatorname{argmin}_x residual_x \|\mathbf{y} - \mathbf{DIC}\boldsymbol{\alpha}'_x\|_2 \tag{5}$$

where x = $[a, d]$.

If the driver is alert, the non-zero sparse coefficients will concentrate on these sections corresponding with $\mathbf{DIC}_a$. Then the residual in the condition of α_a is smaller than in the condition of α_d in theory. We can determine what state the driver is in. After that, our proposed vehicle speed control strategy receives the driver's vigilance level to determine when and how we should decelerate our vehicle speed to ensure safety.

5. Vehicle Speed Control Strategy

Go to:

In this section, a novel safety strategy of vehicle speed control, which controls the electronic throttle opening and automatic braking after driver fatigue detection using the above method, is presented to avoid serious collisions and traffic accidents. As shown in Figure 6, if the driver's drowsiness is confirmed, the algorithm gives different operating commands, including deceleration and braking. The ECU receives these operation commands and controls the vehicle to avoid traffic accidents. Auto-braking and deceleration, a vehicle deceleration algorithm based on the car following security distance model, and the relationship between vehicle speed is presented in this section.

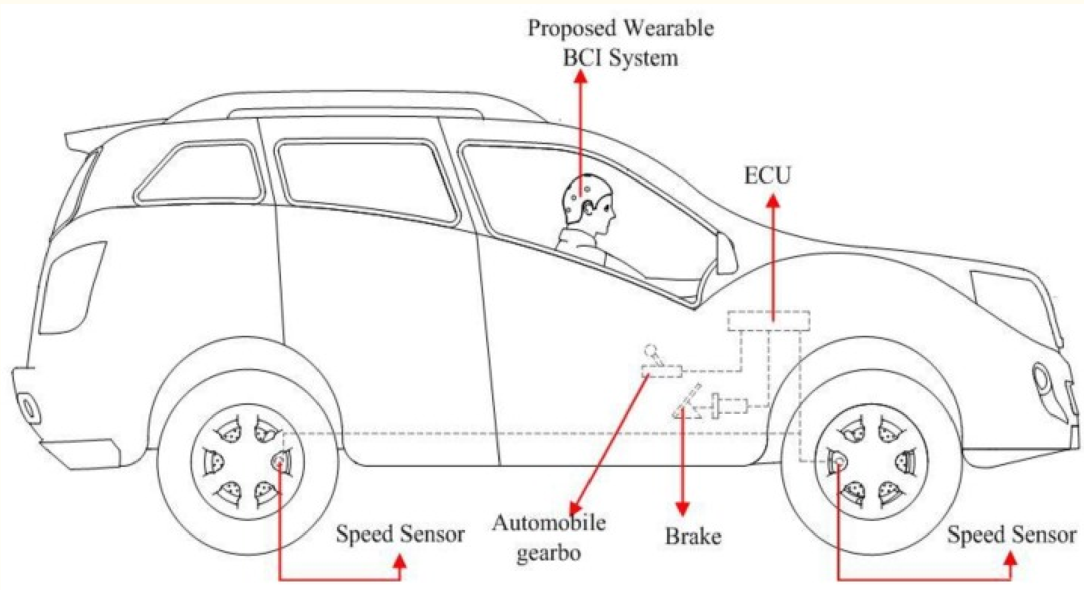

Figure 6

Prototype of proposed vehicle speed control strategy.

Different operations are used to prevent traffic accidents from happening in different circumstances. For example, immediate braking is used under emergency situations. In those cases, the accelerator is cut off and the braking system begins to work automatically. In other words, at that moment, an acceleration pedal operation will be replaced by an automatic braking operation, as in the right block of Figure 1. Speed control is used in the whole driver vigilance detection process to get an appropriate speed of the vehilce.

5.1. Vehicle Deceleration Algorithm

In this subsection, we analyze the vehicle deceleration algorithm. Due to the danger of sudden deceleration, the first and most important part in our vehicle speed control strategy is the safety of deceleration. However, this poses two challenges, one of which is how we can determine the speed difference (ΔV) between initial speed and end speed after deceleration. Another is to choose a proper accelerometer to avoid rear-end collisions in the course of deceleration. From the theory in [42], we have the relationship between accidental risk and speed, as shown in Figure 7. We find that the accidents occurring in the case of moderate or high speed driving are more severe than in the case of low speed.

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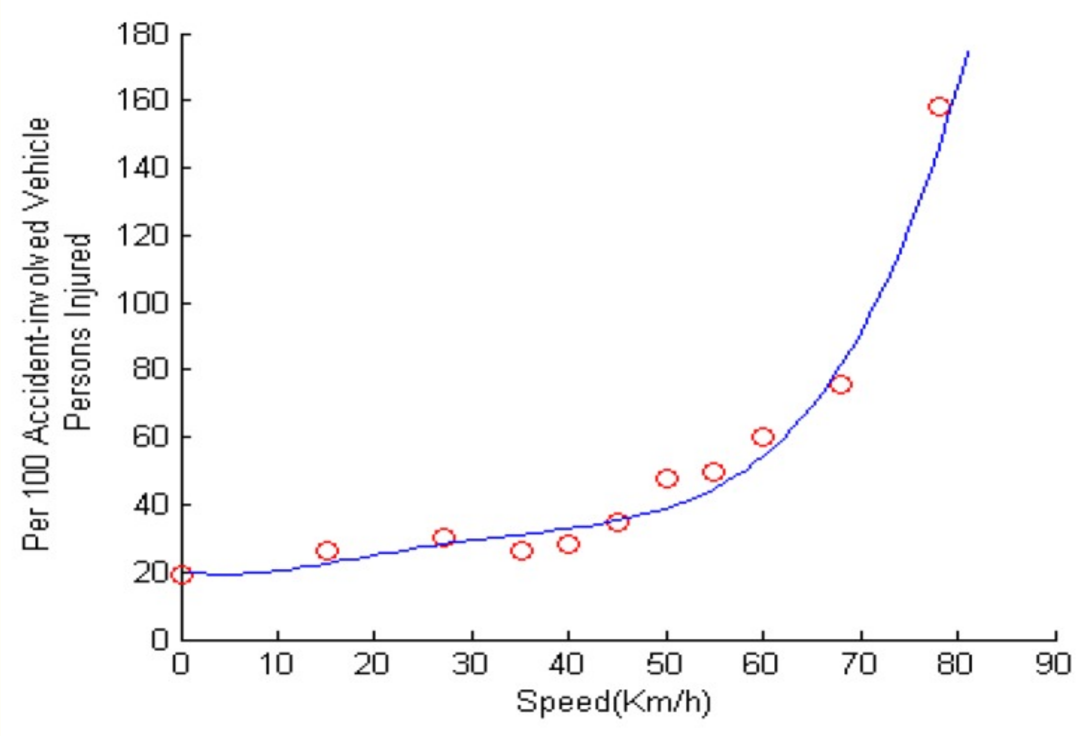

Figure 7

Relationship between accidental risk and speed.

Another study from Joksch [43] indicates that the relationship between the speed difference and probability of fatality in Figure 8. This means that we should keep the speed difference with other vehicles less than 20 km/h as much as possible. Thus, it is proper to choose ΔV = 20 km/h to reduce the speed of vehicle in the case of drowsiness. Additionally, a car-following safety distance model is adopted to calculate an accelerometer to avoid the rear-end collision in the course of deceleration. Some parameters are defined as follows:

- t_1: The driver reaction and brake coordination time of following vehicle;
- t_2: The acceleration increase time of following vehicle;
- t_3: The uniform deceleration time of following vehicle;
- $t_{following}$: The total time of following vehicle deceleration;
- v_{21}: The initial speed of following vehicle;
- v_{22}: The final velocity of following vehicle calculated by $v_{12} = v_{21} - 20$ Km/h;
- s_1: The distance traveled by the following vehicle during $t1$;
- s_2: The distance traveled by the following vehicle during $t2$;
- s_3: The distance traveled by the following vehicle during $t3$;
- $s_{following}$: The distance traveled by the following vehicle during the whole process;
- a_m: The maximum accelerometer of the following vehicle;
- v_{11}: The initial speed of the front vehicle;
- v_{12}: The final velocity of front vehicle calculated by $v_{12} = v_{21} - 20$ Km/h;
- a_f: The accelerometer of the front vehicle;
- D_{min}: The minimum safety distance of the front-following vehicle after deceleration;
- L: The needed distance of front-following vehicle before deceleration; and
- s_{front}: The distance traveled by the front vehicle during the whole process.

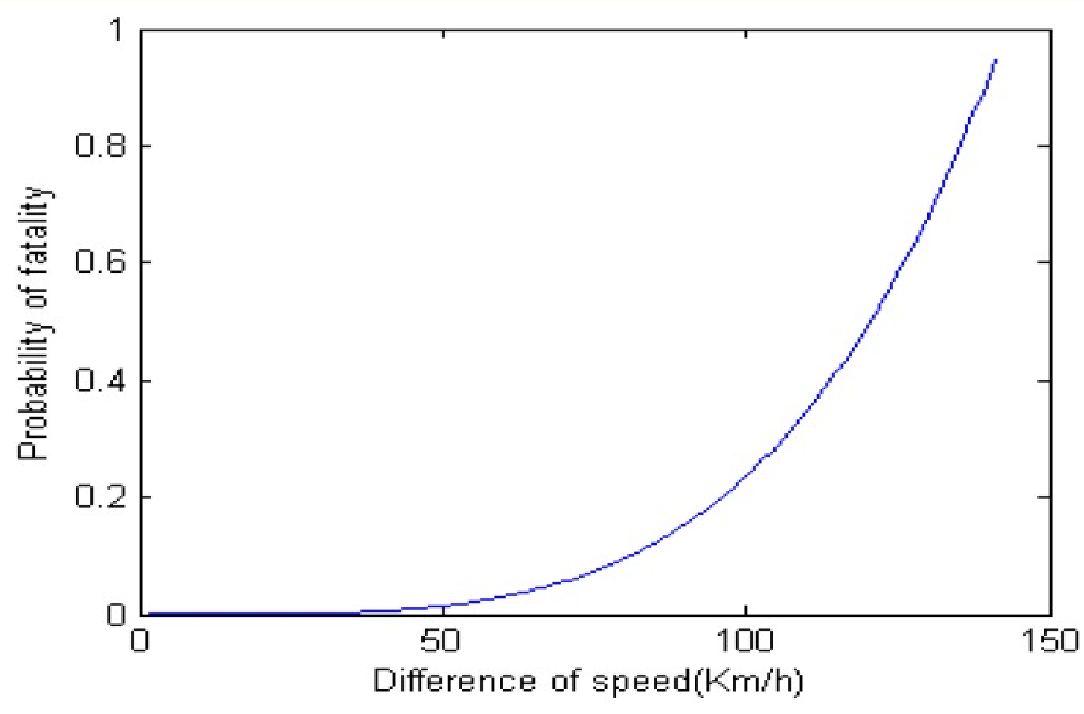

Figure 8

Relationship between the speed difference and probability of fatality.

Generally, under the assumption that the following driver immediately decelerates, the deceleration process of the following vehicle can be divided into three stages: (1) driver's reaction and brake coordination stage; (2) acceleration increase stage; and (3) uniform deceleration stage.

Driver's reaction and brake coordination stage (t_1): the following driver gets the deceleration information of the front car and then controls the vehicle. The travel distance s_1 during t_1 can be represented as Equation (6):

$$s_1 = t_1 v_{21} \tag{6}$$

Acceleration increase stage (t_2): the acceleration of the following car increases from zero to a_m. The travel distance s_2 during t_2 can be calculated by Equation (7):

$$s_2 = v_{21} t_2 + \frac{a_m}{6} {t_2}^2 \tag{7}$$

Uniform deceleration stage (t_3): the speed slows down at an accelerometer of am to v_e. The travel distance s_3 and t_3 can be calculated by Equations (8) and (9):

$$s_3 = -\frac{1}{2a_m}\left(v_{21}^2 + \frac{a_m^2}{4} t_2^2 + v_{21} a_m t_2\right) \tag{8}$$

$$t_3 = \frac{2(v_{22-} - v_{21}) - a_m t_2}{2a_m} \tag{9}$$

Therefore, we can get $s_{following}$ and $t_{following}$ using Equations (10) and (11):

$$\begin{aligned} s_{following} &= s_1 + s_2 + s_3 = v_{21}(t_1 + \frac{t_2}{2}) + \frac{v_{22}^2 - v_{21}^2}{2a_m} + \frac{a_m}{24}t_2^2 \\ &\approx v_{21}(t_1 + \frac{t_2}{2}) + \frac{v_{22}^2 - v_{21}^2}{2a_m} \end{aligned} \tag{10}$$

$$t_{following} = t_1 \ + t_2 + t_3 = t_1 \ + t_2 + \frac{2(v_{22-} - v_{21}) - a_m t_2}{2a_m} \tag{11}$$

When the driver is detected to be in danger case, we let the front car decelerate from v_{11} to v_{12} during $t_{following}$, and we can get the accelerometer of a_f from Equation (12) and s_{front} from Equation (13):

$$a_f = \frac{v_{12} - v_{11}}{t_{following}} \tag{12}$$

$$s_{front} = \frac{v_{12}^2 - v_{11}^2}{2a_f} \tag{13}$$

By combination of Equations (11) and (12), a_f is simplified as Equation (14):.

$$a_f = \frac{2a_m(v_{21} - v_{11} - 20)}{a_m(2t_1 + t_2) + 2(v_{22} - v_{21})} \tag{14}$$

By combination of Equations (13) and (14), s_{front} is simplified as Equation (15):

$$s_{front} = \frac{1}{4a_m}(v_{21} - v_{11} - 20)(a_m(2t_1 + t_2) + 2(v_{22} - v_{21})) \tag{15}$$

As shown in Figure 9, L can be calculated through Equation (16) by combining Equations (10) and (15):

$$\begin{aligned} L = D_{\min} + s_{following} - s_{front} = D_{\min} + v_{21}(t_1 + \frac{t_2}{2}) + \frac{v_{22}^2 - v_{21}^2}{2a_m} \\ - \frac{v_{12}^2 - v_{11}^2}{2a_f} \end{aligned} \tag{16}$$

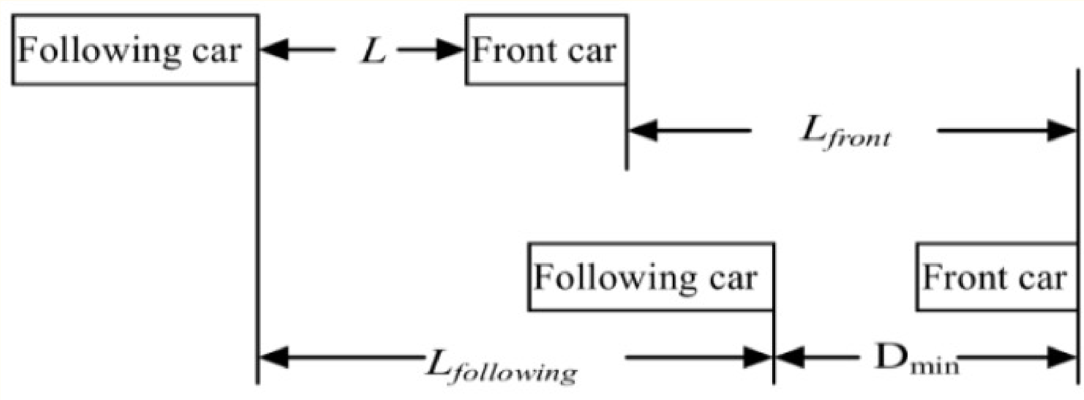

Figure 9

Car following safety model.

If the actual distance L_a of front-following vehicle is longer than the need distance L, it is safe.

Table 1 shows the range of some parameters used in this paper. Furthermore，a binocular vision system is used to obtain L_a. In the binocular vision system, the binocular-cameras is a homemade device at our lab. The binocular digital cameras have 320 × 240 resolution, and our algorithm is implemented and coded with C++ and the OpenCV library on a laptop computer equipped with an Intel i5 2.5 GHz CPU and 4 GB RAM. The parameter v_{21} can also be obtained by using the binocular vision in our experimental system. In this paper, L_1 and L_2 represent the distance of front-following car. They are measured with time internal of 0.5 s. The parameter v_{21} can be represented as Equation (17):

$$v_{21} = v_{11} + 2(L_2 - L_1) \tag{17}$$

Table 1

The range of parameters and value used in this paper.

	t_1	t_2	a_m	D_{min}
Range	0.5~1.5	0.2/0.7	0~6.0	2~5
Value	1.2	0.2	4.5	5

5.2. Vehicle Speed Control Strategy

The vehicle speed control strategy is used to determine how we should control the speed of the vehicle after driver vigilance detection. Firstly, we define three situations as follows:

- **Situation 1:** If the driver is detected to be drowsy for a constant n s, the driver is regarded as drowsy and the "deceleration" command is sent to the ECU. In this paper, the parameter n is variable according to different conditions, and we set n at 3 s in our experimental and simulation system.
- **Situation 2:** After Situation 1, if the driver is detected to be not completely alert in next $u + z$ s (z is the time after u. $u \leq k$, $z < m$, and $u + z \geq k$), the driver is regarded as very drowsy and the "braking" command is sent to the ECU in Figure 6.
- **Situation 3:** After Situation 1, if the driver is detected to be not completely alert in the next u s but alert in m s after u ($u \leq k$), the driver is regarded as awake and the "releasing maximum speed

limit” command is sent to ECU.

u and *z* are time variables for drowsy time and waking time, which are used to record the time that the driver is detected as being in the alert or drowsy state. The parameters *k* and *m* are thresholds. The variable *k* is the time used to wake up driver when the driver is drowsy, and the variable *m* is the minimum time for the driver to be woken up. If the waking up time is less than *m*, the driver has not been awoken.

As shown in Figure 10, we introduce a novel vehicle speed control strategy as follows:

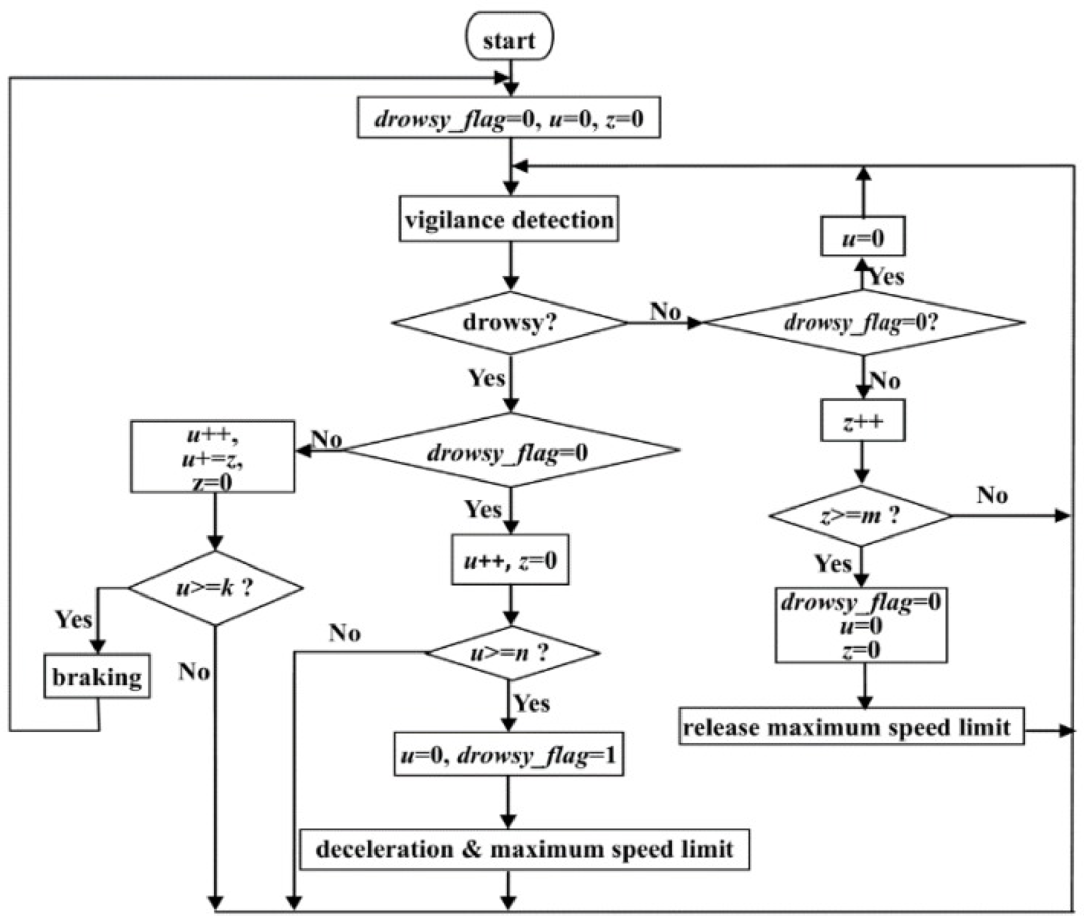

Figure 10

Flowchart of our vehicle speed control strategy.

When Situation 1 occurs, the ECU automatically operates the binocular cameras in our experimental system to acquire the v_{21} and L_a. If $L_a > L$, the ECU controls vehicle deceleration to v_{22} Km/h with the acceleration of a_f, and then keeps the maximum speed limit at v_{22} km/h. At the same time, the ECU controls the vehicle horn to wake the driver up. If Situation 2 happens, it indicates that the driver has not been woken up by the horn during time *k* or the waking up time is less than *m*. The ECU accepts the “braking” command and operates the binocular cameras to acquire the v_{21} and L_a. If $L_a > L$, the ECU controls vehicle braking slowly with the acceleration of a_f for avoiding traffic accidents because of driver deep drowsiness.

Otherwise, if Situation 3 occurs, it indicates that the driver has been woken up by the horn during time *k* and keeps awake at least for time *m*. In this condition, the ECU releases the maximum speed limit. Then, the vehicle is controlled by the driver normally. Based on the above vehicle speed control strategy, the system can control electronic throttle opening and automatic braking to reduce accident rate for avoiding drowsy driving. This makes driving safer and more reliable.

The detail of the flowchart of our vehicle speed control strategy is shown in Figure 10. The variable of *drowsy_flag* is a flag of whether Situation 1 occurs.

To further illustrate flowchart of our vehicle speed control strategy, the vehicle speed control model based on the vehicle dynamic is shown in Figure 11 and executed in our simulation and experimental system. The red box 1 in Figure 11 is the operation command input port used to receive the command, which is determined by our vehicle speed control strategy. The binocular camera detection model which was coded with C++ and OpenCV library in red box 2, is used to measure L_a and v_{21} of following car when operation commands is received. The operation selection model shown in red box 3 judges which commands is received and exports control information to vehicle dynamic model in red box 4. The vehicle dynamic model performs operation to meet the received command for safer driving.

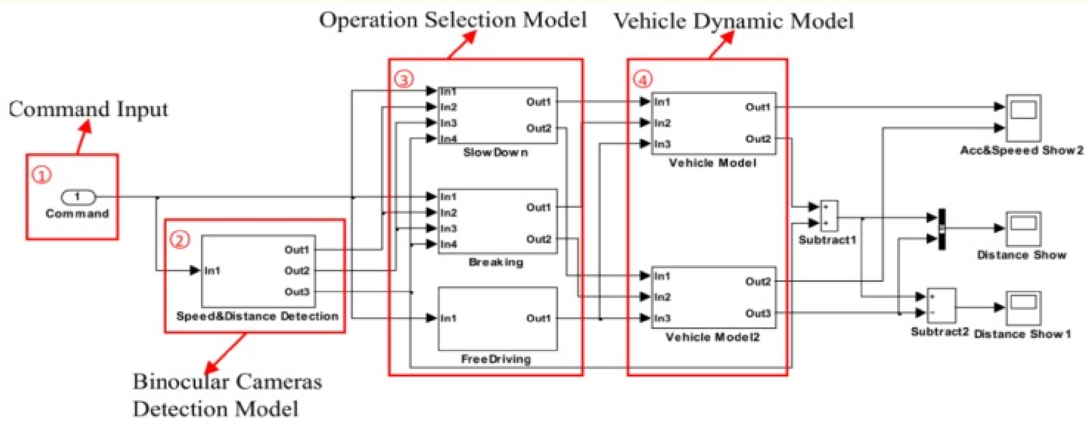

Figure 11

Vehicle speed control model based on the vehicle dynamic model.

6. System Simulation and Validation

Go to:

We have implemented an experimental environment to evaluate the proposed system's performance. The experimental environment consists of three parts as shown in Figure 12a. The first part is a homemade wearable BCI model for EEG collection. The second part is EEG signal data preprocessing and the driver vigilance detection model. The last part is the vehicle speed control module that controls the electronic throttle opening and automatic braking to reduce the accident rate.

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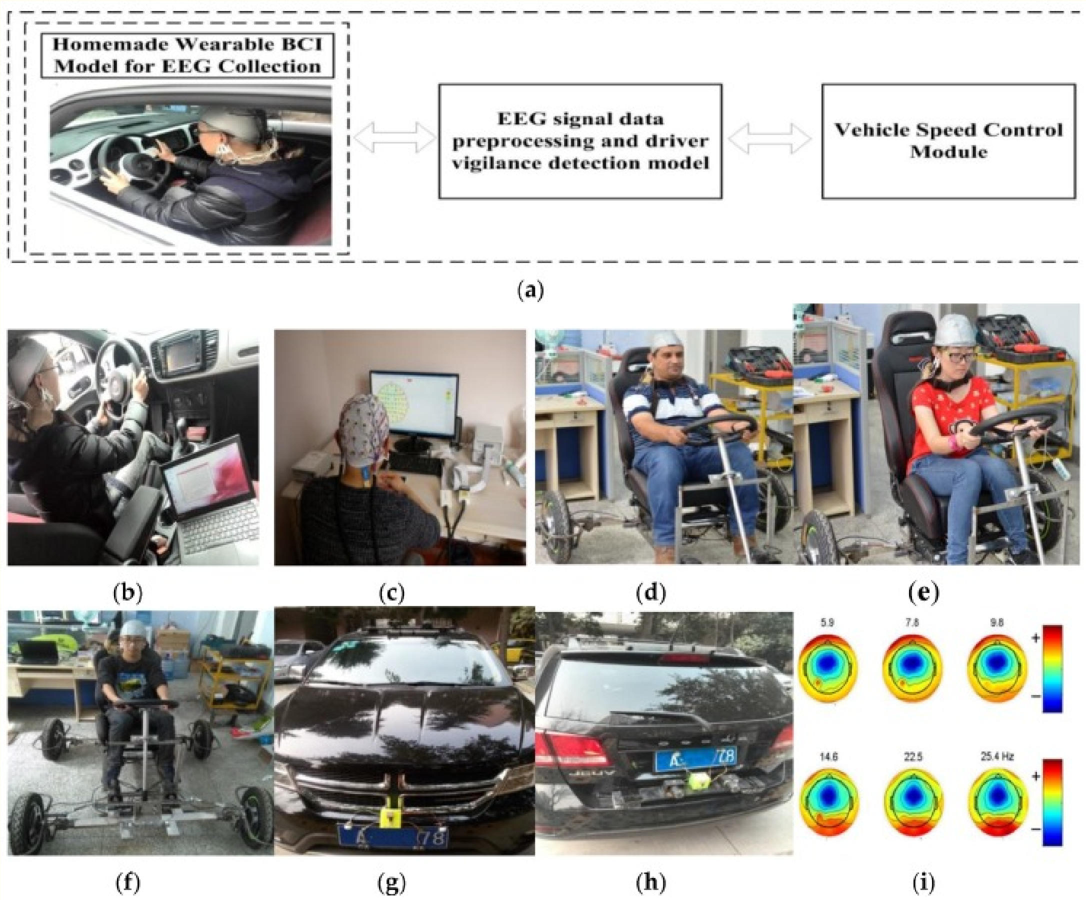

Figure 12

Experimental environment. (**a**) Experimental prototype; (**b**) EEG collection using the homemade wearable BCI system; (**c**) Complementary experiment using BP equipment; (**d**) EEG collection experiment; (**e**) EEG collection experiment; (**f**) EEG collection experiment; (**g**) The test vehicle configuration; (**h**) The test vehicle configuration; (**i**) The driver vigilance detection experiment.

6.1. Experiment of Homemade Wearable BCI Model for EEG Collection

As shown in Figure 12, we use the real driving environment and complementary simulation in the laboratory to our proposed method. Figure 12d–f illustrate the EEG collection and vigilance detection experiments of our system simulation and validation. In order to confirm the validation of our homemade wearable EEG BCI system, complementary experiment and simulation using BP equipment are shown in Figure 12c. BP is a 64-channel EEG commercial unit that the psychological research and counseling center of Southwest Jiaotong University bought from Germany. Our algorithm is implemented on a laptop computer equipped with an Intel i3 1.9 GHz CPU and 4 GB RAM. This system has been field tested on our homemade experimental vehicle in Figure 12d–f, and been done simulation on a DODGE SUV vehicle as shown in Figure 12g,h. The experimental vehicle is a DODGE SUV equipped with binocular cameras and other sensors to detect the safety distance for the vehicle deceleration algorithm and vehicle speed control. Figure 12i shows the sample image frame from the experiment for driver vigilance detection.

In our experiment, ten qualified drivers, having no neurological diseases, wore the wireless wearable BCI system in Figure 12d–f to collect the EEG signal in Table 2. The experiments of EEG collection and diver vigilance detection are the actual data and field testing. The homemade experimental vehicle is designed to test driver vigilance for avoiding traffic risk of actual fatigue driving tests. The experimental conditions are set as follows:

- **Condition 1:** (1) sleep deprivation; (2) test time is the next day between 4 a.m and 6 a.m;

- **Condition 2:** (1) having a normal night sleep; (2) test time is the next day between 9 a.m and 11 a.m.

Table 2

Ten Drivers Served in The Experiment.

Driver Sum	Subject	Number	Age
10	Male	7	26
			26
			38
			42
			23
			23
			24
	Female	3	24
			24
			25

During the whole experiment process, the investigators observe and record the subjects' physical behaviors, yawns, and the inclination of head, as a drowsiness index in the next study. Finally, each **Set**$_{ijk}$ composed of 20 min sessions is collected from both nits. **Set**$_{BP}$ contains 63 channels EEG/EOG signals with a sampling frequency of 1000 Hz. **Set**$_{HBS}$ includes two EEG channels, O1 and O2, with a sampling frequency of 512 Hz. Figure 13 shows the original EEG signal collected from a 24 year old experimental driver. Figure 13a is the alert signal, Figure 13b is the drowsy signal. The signal in the red box is alpha activity bursting in the drowsy state. Taking into account the risk of actual fatigue driving tests, simulation in the scenario is used to test driver vigilance for avoiding traffic risks of actual fatigue driving tests. This is the limitation of the presented simulation and we will construct an optimization experiment in future research.

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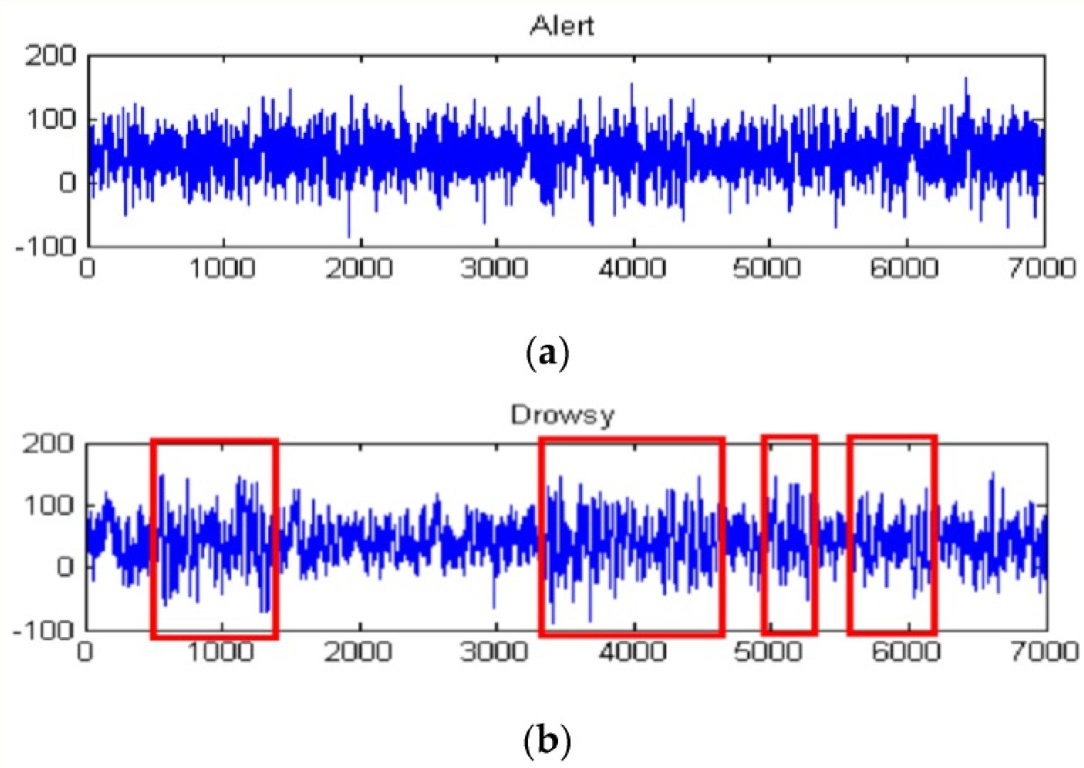

Figure 13

Original EEG signal collected from our proposed equipment. (**a**) Alert signal; (**b**) Drowsy signal.

6.2. Experimental Results for EEG Preprocessing and Driver Vigilance Detection Model

6.2.1. Preprocessing Experiment

In this subsection, the goal of preprocessing is to improve the original data quality. The original EEG signal selected from $\mathbf{Set}_{\mathrm{HBS}}$ is used in this experiment. Figure 14 shows the original signal and its decomposition signal at each level of one experimental driver. Figure 14 shows the original signal. The six level decomposition signal is uses db5. In Figure 14, the reconstructed signal a_6 is the reconstructed signal of approximate coefficients at level 6. The reconstructed signals of d_6 to d_1 are the reconstructed signals of detail coefficients at levels 6 to 1, as shown in Figure 14. The frequency range of each reconstructed signal is shown in Figure 4. Since the hardware filter of our homemade equipment is 3–100 Hz, the signal of 0–3 Hz can be regarded as noise. In addition, the frequency range of the EEG is between 0.5 and 50 Hz.

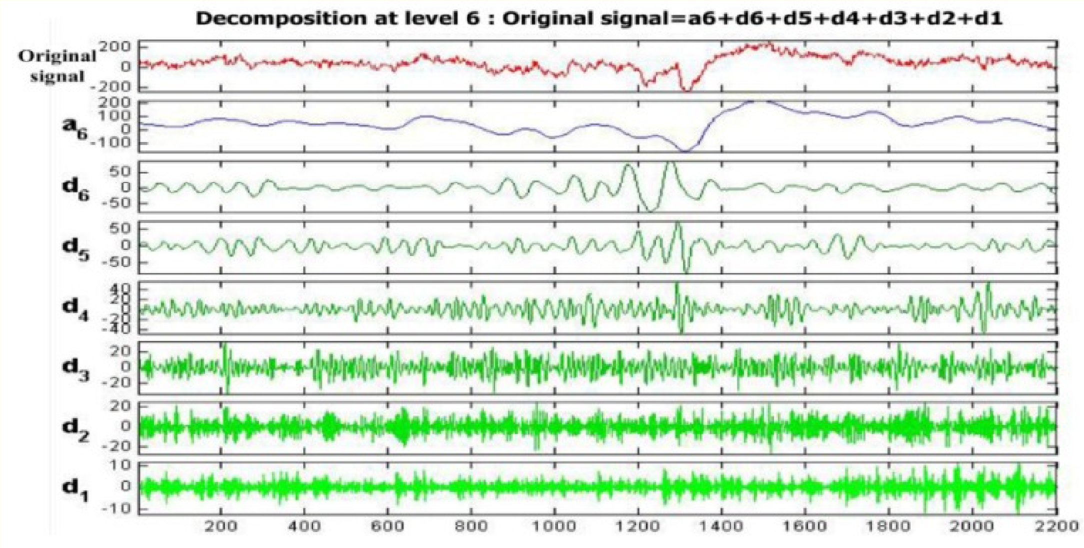

Figure 14

Original signal and its decomposition signal at each level.

The high-frequency signal (>50 Hz) can be regarded as interference. Therefore, by extracting the decomposition signal of d_3 (32–64 Hz), d_4 (16–32 Hz), d_5 (8–16 Hz), d_6 (4–8 Hz), we can get the useful EEG signal and remove some low- and high-frequency interference. Figure 15a and Figure 15b show the original signal and de-noising signal of the above experimental driver. It gives good performance of de-noising. Figure 16 shows the spectrum of them. As shown in Figure 16a, the low-frequency noise is too large to overwhelm EEG signal. In Figure 16b, the frequency of EEG is retained well and some of low frequency and high frequency noise are removed. Furthermore, we implement the de-noising algorithm in signals shown in Figure 13 to verify the de-noising performance in two states. Figure 17 shows a de-noising signal of alert and drowsy states We can see the alpha band is more obvious from other bands in the drowsy state.

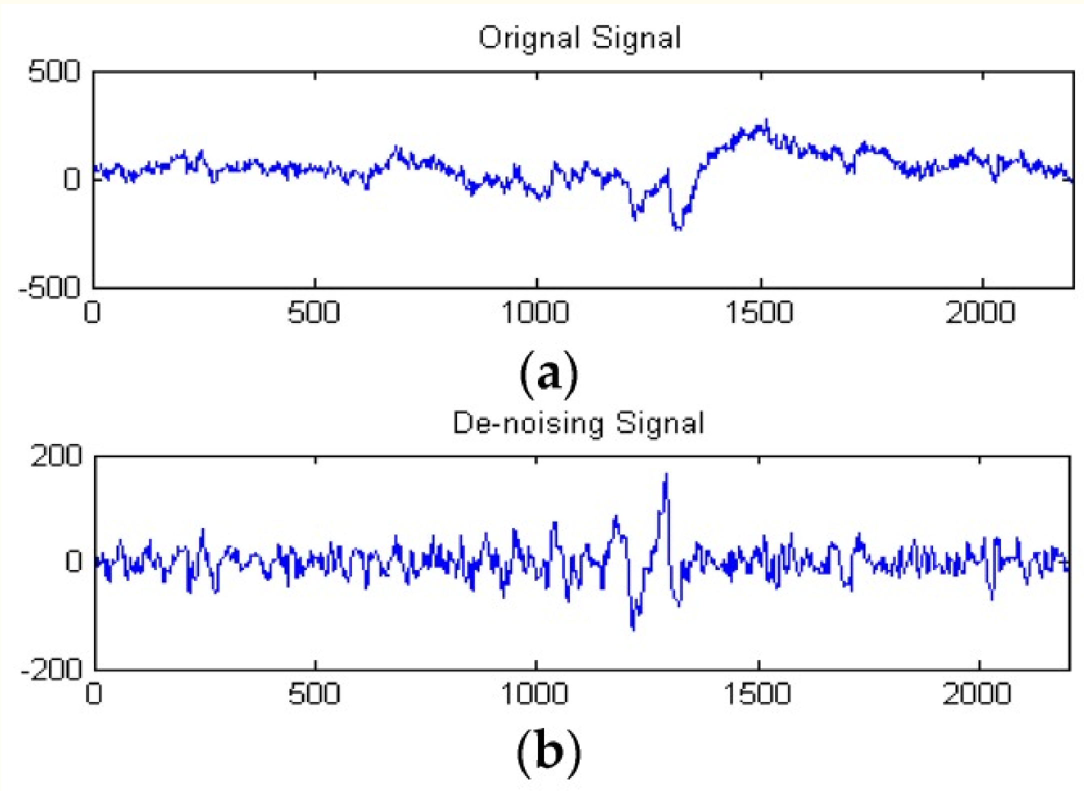

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Figure 15

(**a**) Original signal s; (**b**) De-noising signal.

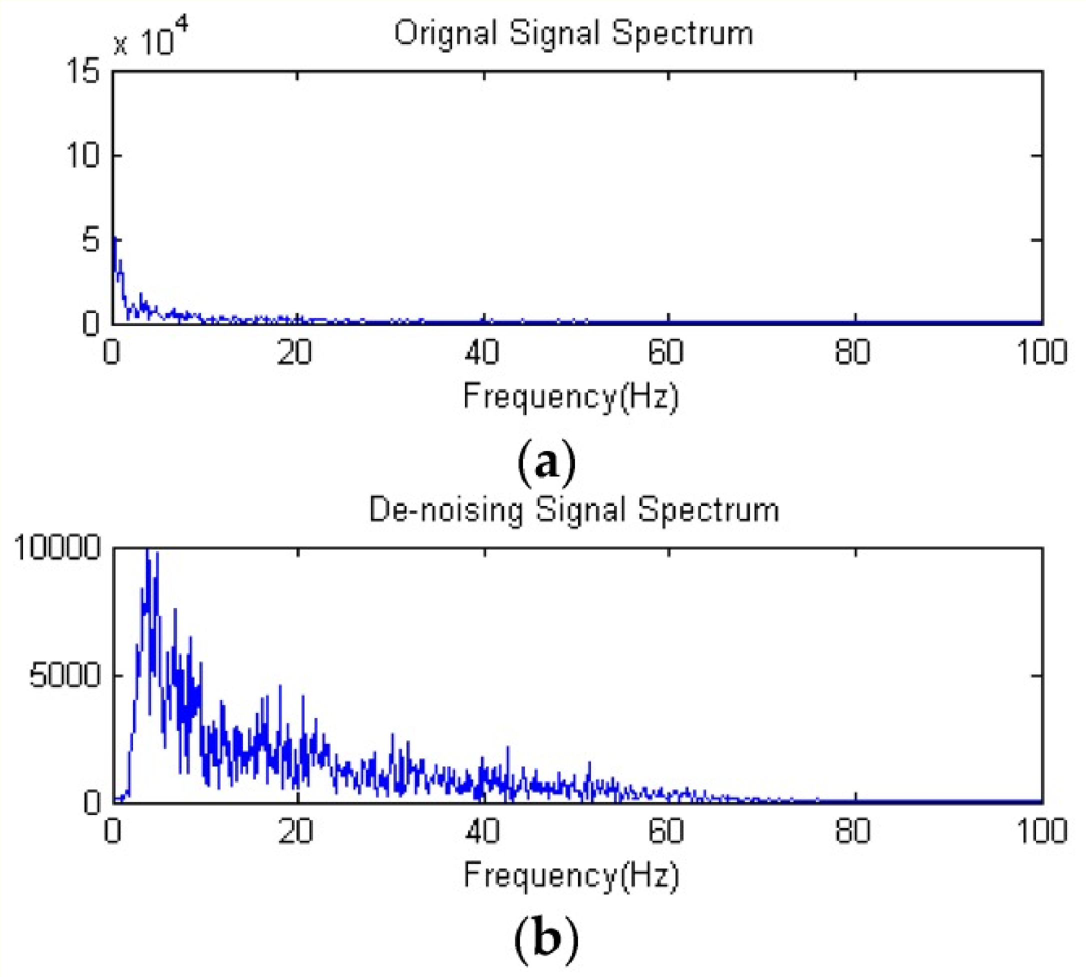

Figure 16

(**a**) Original signal spectrum; (**b**) De-noising signal spectrum.

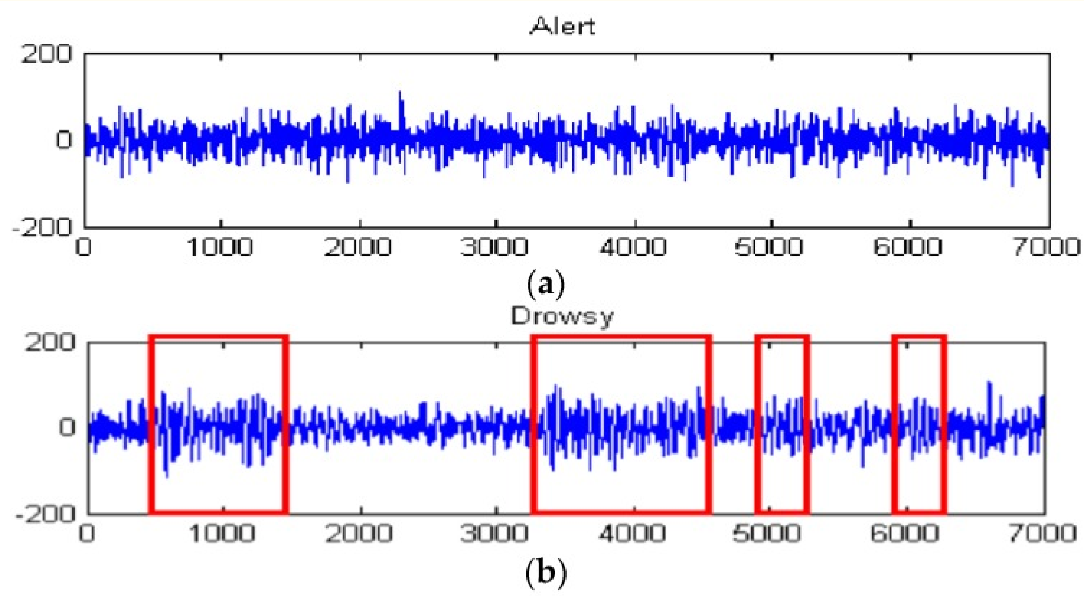

Figure 17

De-noising signal of signal shown in Figure 13. (**a**) Alert signal; (**b**) Drowsy signal.

6.2.2. Feature Extraction Experiment

Under the assumption of the driver's state at time *t* remains the same state with the previous *b* and *s*, the feature of the EEG signal at time *t* is calculated as the average PSD of previous *b* s and *t* s. The PSD is calculated using FFT. Generally, the more data is used in feature extraction, the more precise the feature . Meanwhile, this means that more time is spent. Figure 18 shows the PSD of the whole testing data. Figure 19 shows the PSD of *t*-th s under different *b* ($b = [0, 2, 4, 6, 8]$). The blue line represents the PSD of driver alert state and red line represents driver drowsy state. When $b = 0$ or $b = 2$ or $b = 4$, the discrimination of whether the driver is alert or drowsy is not distinct. When *s* increases to $b = 6$ or $b = 8$, the discrimination is much obvious. As shown in Figure 18, the power of theta and alpha rhythms in the driver drowsy state is greater than in the driver alert state. The power of the beta rhythm in the driver drowsy state is smaller than in the driver alert state. In addition, with the increase of *b*, the tendency of PSDs in Figure 19 gradually meet the PSD tendency shown in Figure 18. To estimate the running time of different *b*, the average time of 10,000 runs of the PSD algorithm is calculated, as shown in Table 3. The running time increases with the increase of *b*. That is, we should find a trade-off between the precision and time.

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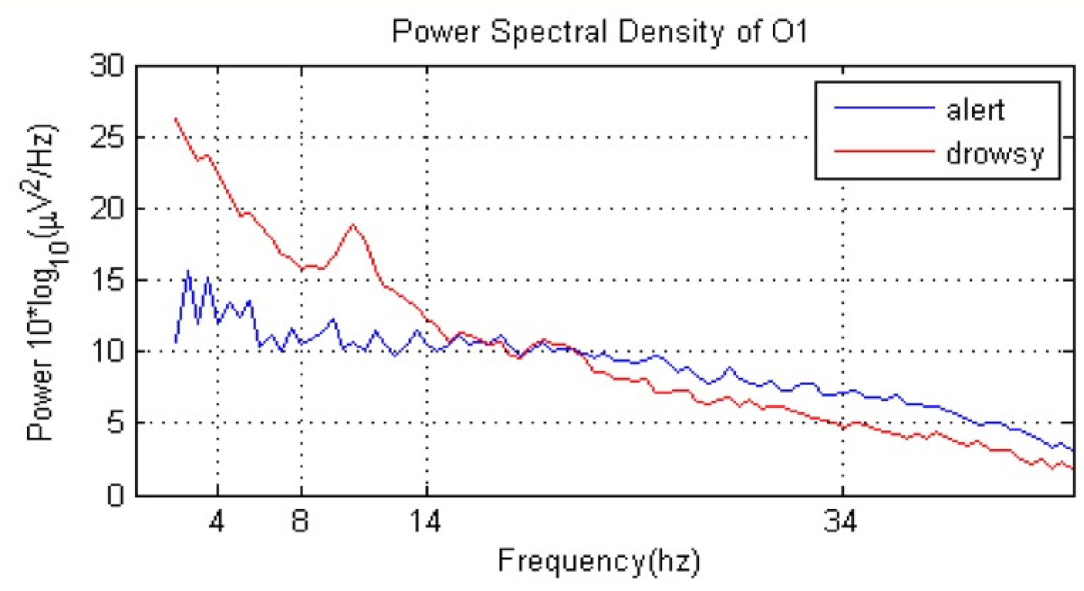

Figure 18

PSD of the whole testing data.

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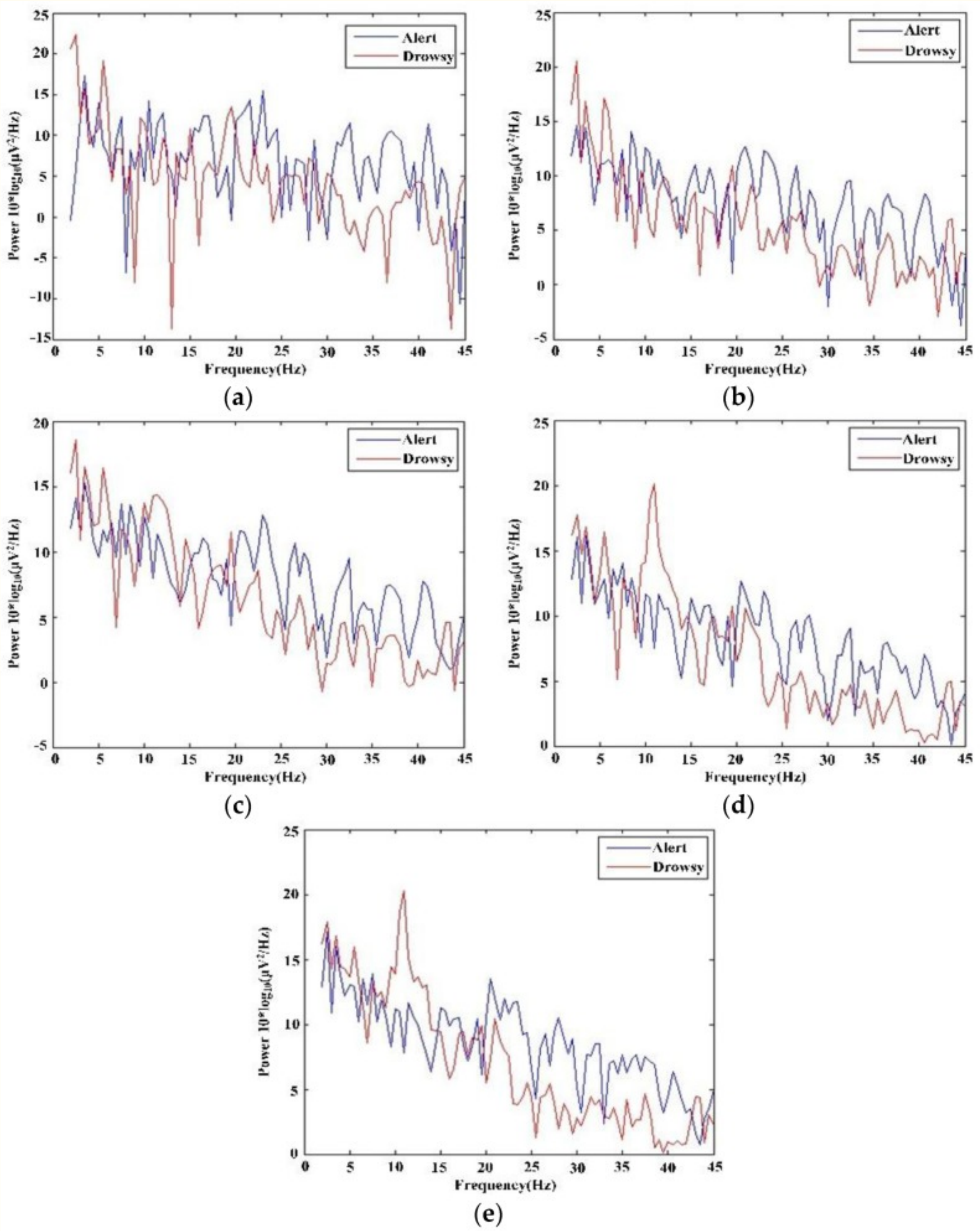

Figure 19

PSD of t-th s when s adopt (**a**) 0; (**b**) 2; (**c**) 4; (**d**) 6; and (**e**) 8.

Table 3

Running time of different b.

b(s)	0	2	4	6	8
Time(s)	0.0006	0.0015	0.0020	0.0022	0.0025

6.3.3. Classification Experiment

Orthogonal matching pursuit (OMP) is used to solve the L_0 problem. Let q represent the number of atoms in each linear combination. The greater the numbers of atoms, the easier the accuracy of the signal can be reconstructed. The class of the driver vigilance level is determined by Equation (5). The classification accuracy rate of our proposed algorithm is calculated by Equation (18):

$$accuracy\ rate = \frac{No.\ of\ correctlly\ detection}{No.\ of\ total\ detection} \tag{18}$$

Table 4 and Table 5 show the classification rate of O1 and O2 from $\mathbf{Set}_{\mathrm{HBS}}$. Driver 1, Driver 2, Driver 3, and Driver 4 are the number of different persons of ten qualified drivers. We can see that with the increase of b, the classification rate increases corresponding with the results discussed in the subsection of the feature extraction experiment. Although other algorithms have been used previously for the same task, we wanted to try to create a novel algorithm for driver vigilance detection using sparse representation classification and KSVD. In our lab, we have a strong research basis on the sparse representation classification algorithm, and we find that sparse representation classification combined with KSVD has good performance in driver vigilance classification. Thus, in this paper, we firstly introduced the proposed method to driver vigilance detection. At the same time, for our vehicle active safety model, we think the classification accuracy rate is suitable to vehicle speed control. As in the red box of Table 5, when $b \geq 7$, our equipment gives an excellent classification efficiency which is up to around 93%, and it is match the result of feature extraction experiment (the PSD are obvious difference as Figure 19d,e). These results indicate that the proposed method has good performance in driver vigilance detection. The classification rates of $\mathbf{Set}_{\mathrm{BP}}$, O1 and $\mathbf{Set}_{\mathrm{BP}}$, O2 are shown in Table 6 and Table 7. In our experiment, the experiments demonstrate the validation of the driver vigilance detection algorithm based on using EEG and sparse representation.

Table 4

Classification accuracy rate (%) of $\mathbf{Set}_{\mathrm{HBS,O1}}$.

b(s)	Driver1	Driver2	Driver3	Driver4
0	74.72	56.85	72.72	46.42
1	74.64	77.24	73.14	62.58
2	78.57	61.11	76.43	73.18
3	81.38	61.54	75.14	67.15
4	85.63	78.87	84.30	72.79
5	85.59	52.48	88.30	71.11
6	90.75	72.85	88.23	82.83
7	91.59	87.05	97.04	78.94
8	93.02	83.33	82.73	84.84

Table 5

Classification accuracy rate (%) of $\mathbf{Set}_{\mathrm{HBS,O2}}$.

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b(s)	Driver1	Driver2	Driver3	Driver4
0	74.42	47.65	59.88	72.72
1	78.92	66.14	76.13	77.77
2	81.43	69.04	78.85	79.60
3	87.97	92.80	79.31	85.43
4	91.38	62.90	76.30	85.33
5	92.22	71.54	89.53	82.55
6	94.80	97.54	87.71	82.43
7	95.65	95.04	96.47	93.87
8	95.35	96.66	98.22	94.55

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Table 6

Classification accuracy rate (%) of $\mathbf{Set}_{BP,O1}$.

b(s)	Driver5	Driver6	Driver7	Driver8
0	66.82	64.02	67.76	56.54
1	70.09	69.16	69.16	73.83
2	75.70	74.77	73.83	73.83
3	75.59	79.81	73.24	79.34
4	73.71	80.28	77.93	62.91
5	69.48	67.14	82.63	69.95
6	69.34	90.09	85.38	83.96
7	92.45	91.04	94.34	85.38
8	95.75	99.06	94.34	85.38

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Table 7

Classification accuracy rate (%) of $\mathrm{Set}_{BP,O2}$.

b(s)	Driver5	Driver6	Driver7	Driver8
0	62.15	59.81	64.95	71.03
1	66.36	65.42	69.16	68.69
2	73.36	74.77	76.17	78.50
3	75.59	76.53	80.75	80.28
4	77.46	81.22	77.93	79.81
5	69.95	82.63	80.75	82.63
6	75.00	78.77	82.08	89.15
7	82.55	88.21	91.51	90.09

b(s)	Driver5	Driver6	Driver7	Driver8
8	95.28	93.87	97.17	81.13

6.3.4. Vehicle Speed Control Experiment

To simplify the validity of our vehicle deceleration model, we assume that:

1. v_{11} = 95 km/h, v_{21} = 100 km/h, L_a = 10.5 m (The distance of L is calculated through Equation (16) and equal to 10.39 m, so condition of $L < L_a$ is satisfied);
2. When drowsiness is detected, the front car decelerates and an accelerometer of a_f is calculated by Equation (16);
3. The following car catches the information of the front car and immediately decelerates.

Figure 20 shows the vehicle following model based on the dynamics using *MATLAB*/*simulink*. The simulation results in Figure 21 shows in the course of deceleration, the speeds of two cars slow down to 80 km/h in Figure 21a, and the distance between the two cars decreases from 10.5 m to 5 m in Figure 21b,c. The deceleration model is valid for the avoidance of a rear-end collision when driver vigilance is detected.

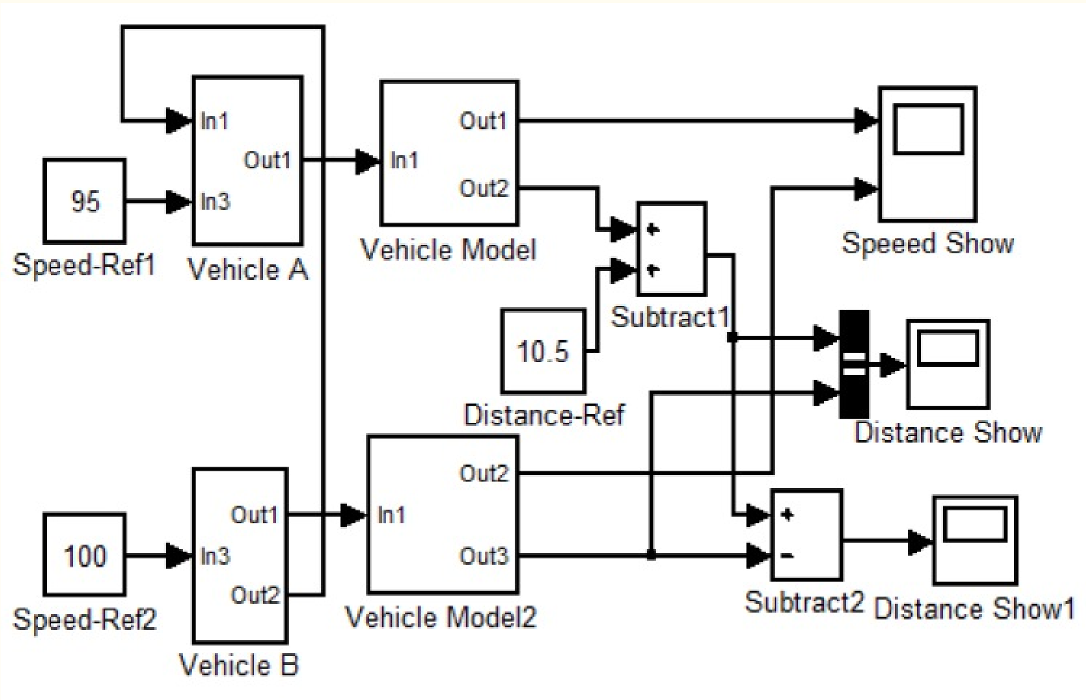

Figure 20

Vehicle following model.

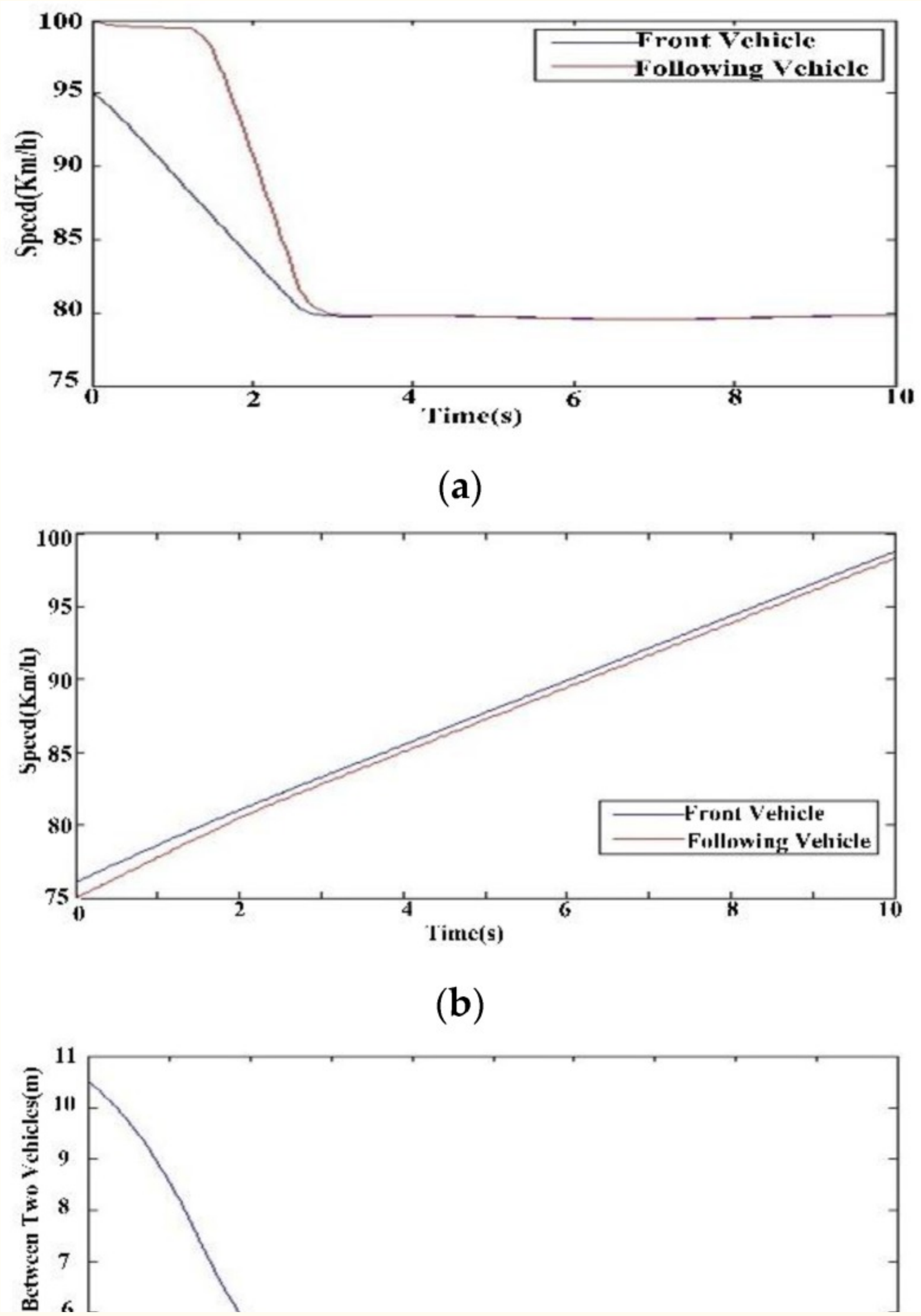

Figure 21

Changes of two cars in the course of deceleration. (**a**) Change of speed; (**b**) Change of distance; (**c**) Change of distance.

We assume that the vigilance level list is detected as Figure 22a. The "0" represents alert and the "1" represents drowsiness. To facilitate simulation, we set $n = 3$ s, $k = 10$ s, and $m = 10$ s. The command list is shown in Figure 22b. Where, "1", "2", and "3" represent deceleration, braking, and releasing the maximum speed limit, respectively. As shown in Figure 22a, the driver is detected to be drowsy for 3 s from the 7th s to the 9th s It meets the criteria for Situation 1, and the deceleration command occurs in the 9th second. Similarly, at the 21st, 28th, and 38th s, in turn, it meets the criteria for Situation 3, 1, and 2, and the commands are releasing maximum speed limit, decelerating, and braking.

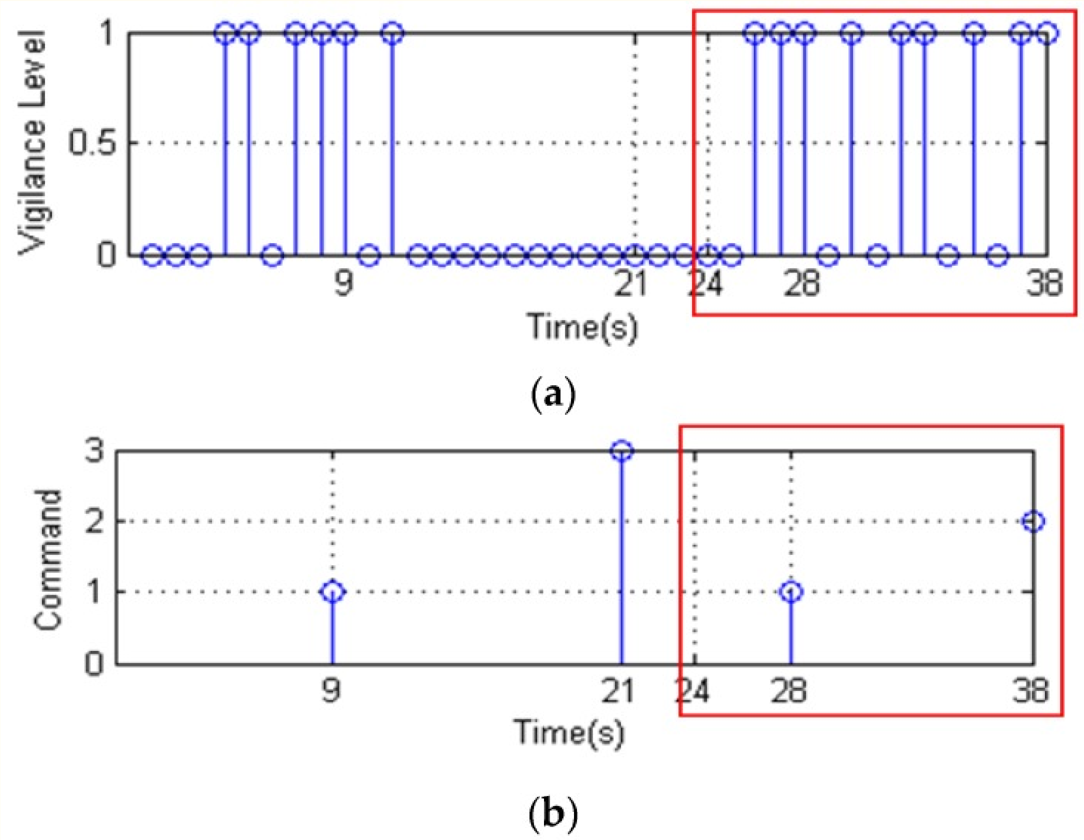

Figure 22

Result of vehicle speed control strategy. (**a**) Vigilance level list; (**b**) Command list.

Since we cannot predict the behavior of the driver after the speed limit is released, we cannot forecast the behavior of the vehicle. We only verify the commands during 24 s to 38 s in the red box of Figure 22 below the speed limit. Figure 23 shows a simplified model of vehicle speed control, which is designed for the case of red box in Figure 22b. In this model, we assume that v_{11} = 95 km/h, v_{21} = 100 km/h, $L < L_a$ at time 24 s Figure 24a,b show the change of acceleration and speed. At the 28th s, the ECU receives the deceleration command and controls the vehicle deceleration to 80 km/h. At the 38th s, the ECU receives the braking command and controls the vehicle braking slowly. The experiment and simulation show the validity of our vehicle speed control strategy when the driver is deeply drowsy.

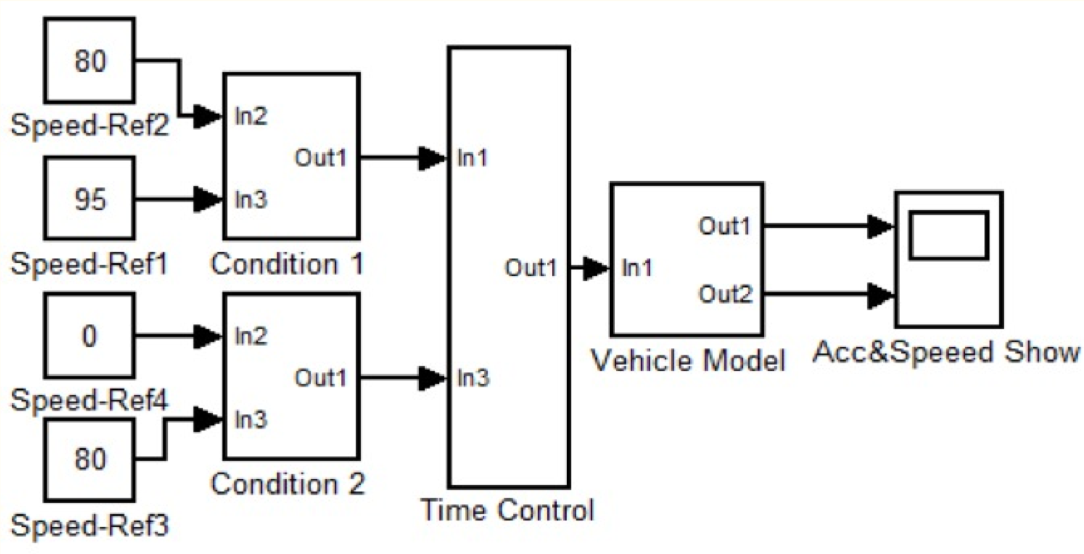

Figure 23

Simplified vehicle speed control model.

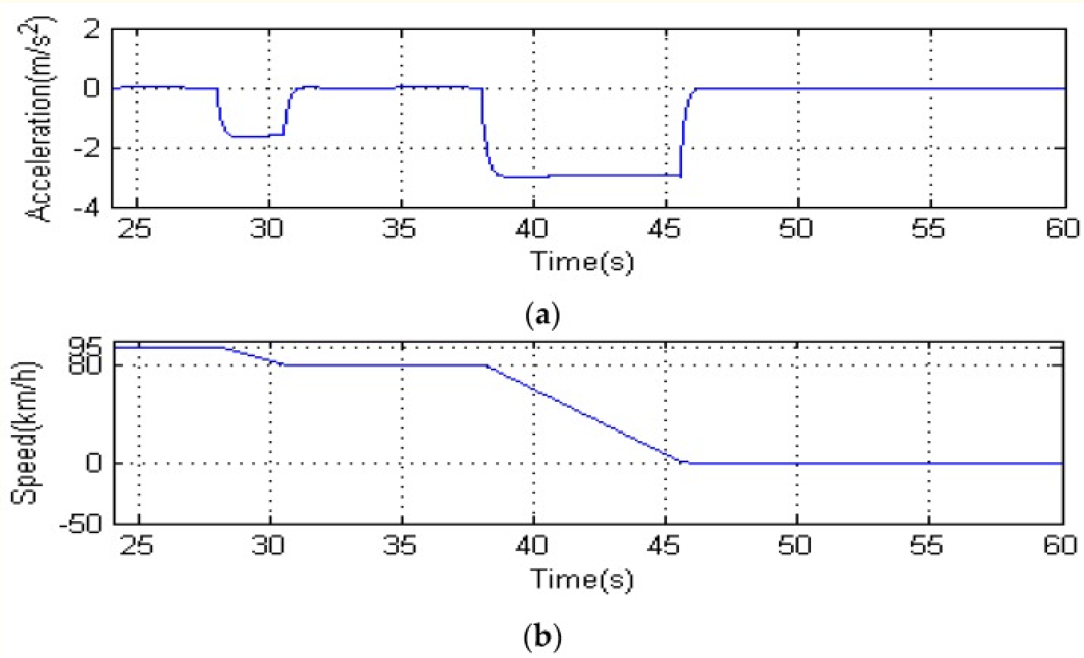

Figure 24

results of vehicle speed control. (**a**) shows the change acceleration; (**b**) shows the change of speed.

7. Conclusions

Go to:

In this paper, we have presented a vehicle active safety model for drowsy driving based on driver vigilance detection using wearable EEG and sparse representation. The methods have three steps, namely, wearable EEG collection, vigilance detection, and vehicle speed control strategy. In the first step, a homemade low-cost, comfortable, wearable BCI system with eight channels is designed for collecting the driver's EEG signal. In the vigilance detection step, wavelet analysis is used for de-nosing and FFT is introduced to calculate the PSD for extracting EEG features. Next, sparse representation classification combined with k-singular value decomposition (KSVD) is firstly introduced in PSD to estimate the driver's vigilance level. In the last step, a novel safety strategy of vehicle speed control, which controls the electronic throttle opening and automatic braking after driver fatigue detection using the above method is presented to avoid serious collisions and traffic accidents. The final experimental results show the validity of our method under the simulated and realistic conditions. From both theoretical analysis and practical experiments, it shows that the proposed system has not only good performance of EEG collection and vigilance detection, but also effective controls of vehicle speed. The result of the experiment shows that the proposed homemade wearable BCI system is accurate for EEG collection. The sparse representation is an effective method for vigilance detection. At the same time, the vehicle speed control strategy is effective when the driver is drowsy. The vehicle deceleration algorithm is effective in preventing collisions in the course of speed control.

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Acknowledgments

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Author Contributions

Go to:

Zutao Zhang and Dianyuan Luo designed the wireless wearable EEG sensors and the algorithm of driver vigilance detection. Yagubov Rasim, Yanjun Li, Guanjun Meng and Jian Xu designed the experimental system and analyzed the data. Chunbai Wang provided valuable insights in this manuscript.

Conflicts of Interest

Go to:

The authors declare no conflict of interest.

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Annex B to
Calibre Group Submission to NTC
4 Jun 18

ATSB Presentation at the RISSB Safety Conference in Sydney 2018

calibre

SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

Australian Government
Australian Transport Safety Bureau

Drones and automation—Modernising investigations

Presented by
Nat Nagy
Executive Director, Transport Safety

Australia's national transport safety investigator

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory Agency.

The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB is established by the *Transport Safety Investigation Act 2003* (TSI Act) and conducts its investigations in accordance with the provisions of the Act.

Under the TSI Act, it is not a function of the ATSB to apportion blame or provide a means for determining liability. The ATSB does not investigate for the purpose of taking administrative, regulatory or criminal action.

Purpose

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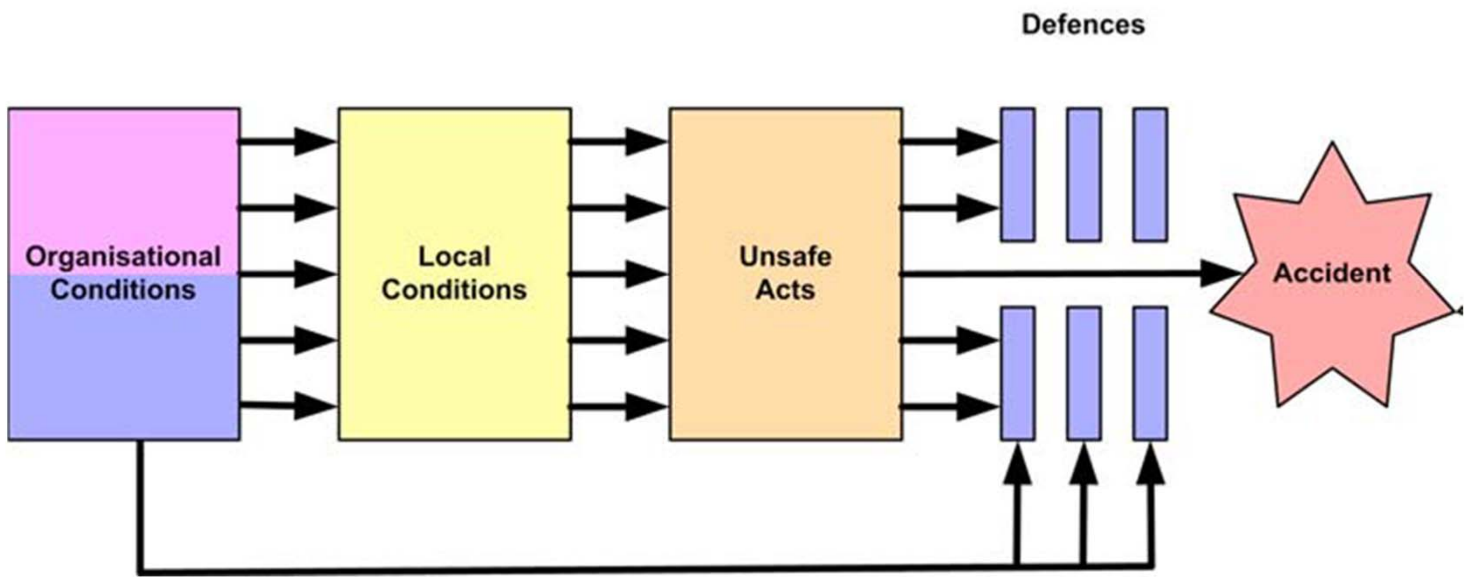
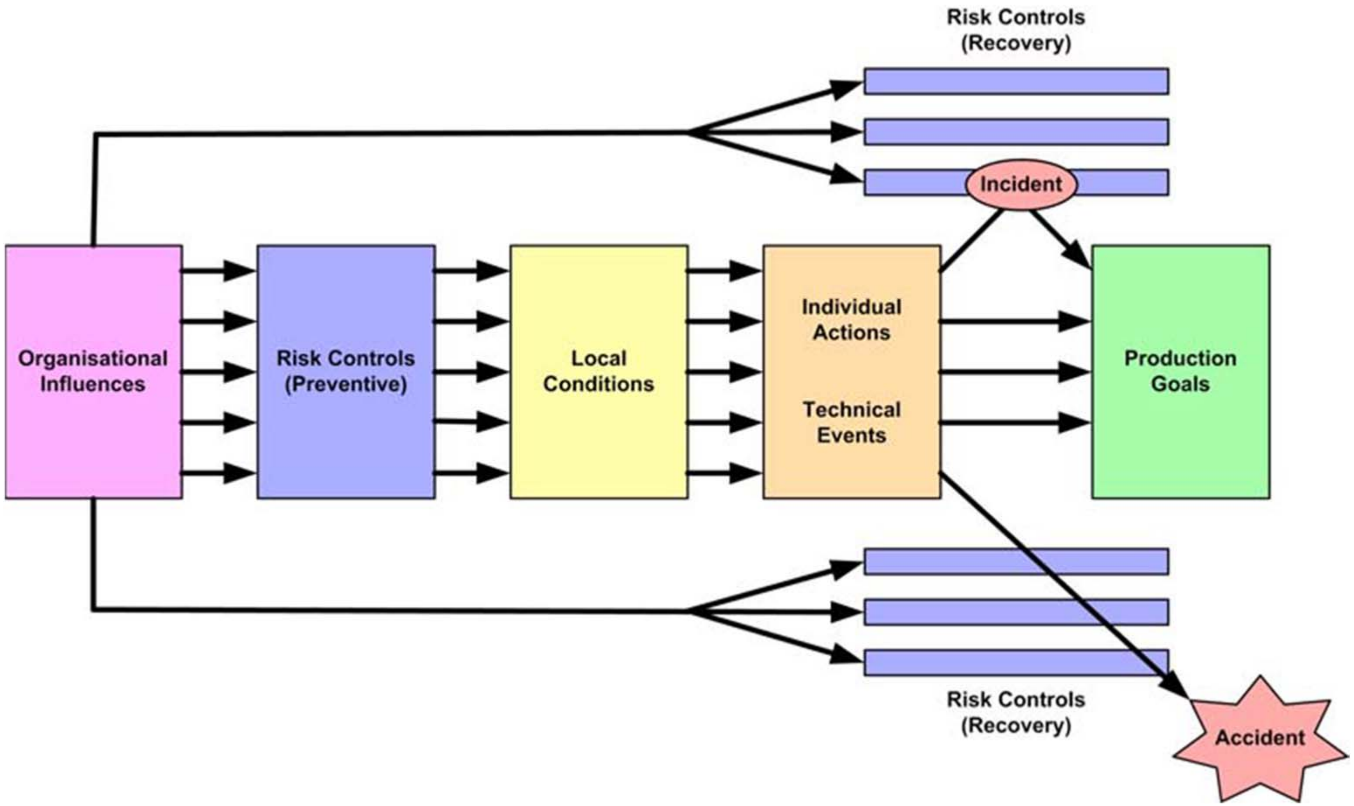
  - independent investigation of transport accidents and other safety occurrences;
  - safety data recording, analysis and research; and
  - fostering safety awareness, knowledge and action.

ATSB and rail transport safety

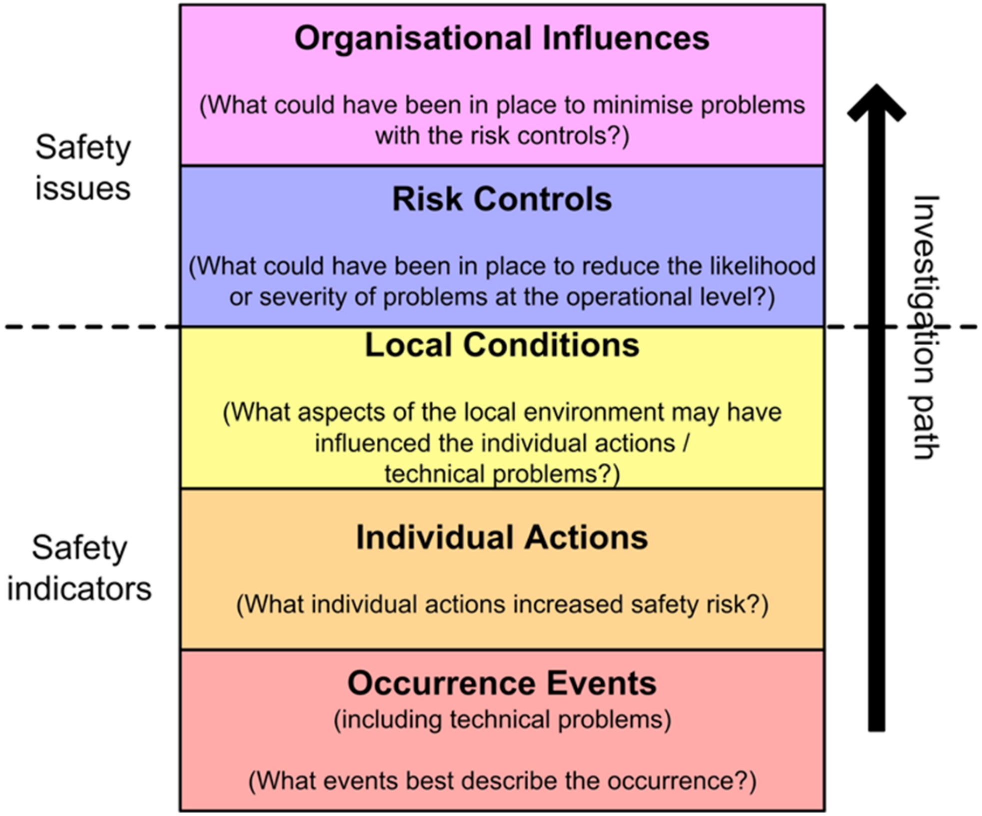
Reason model of organisational accidents



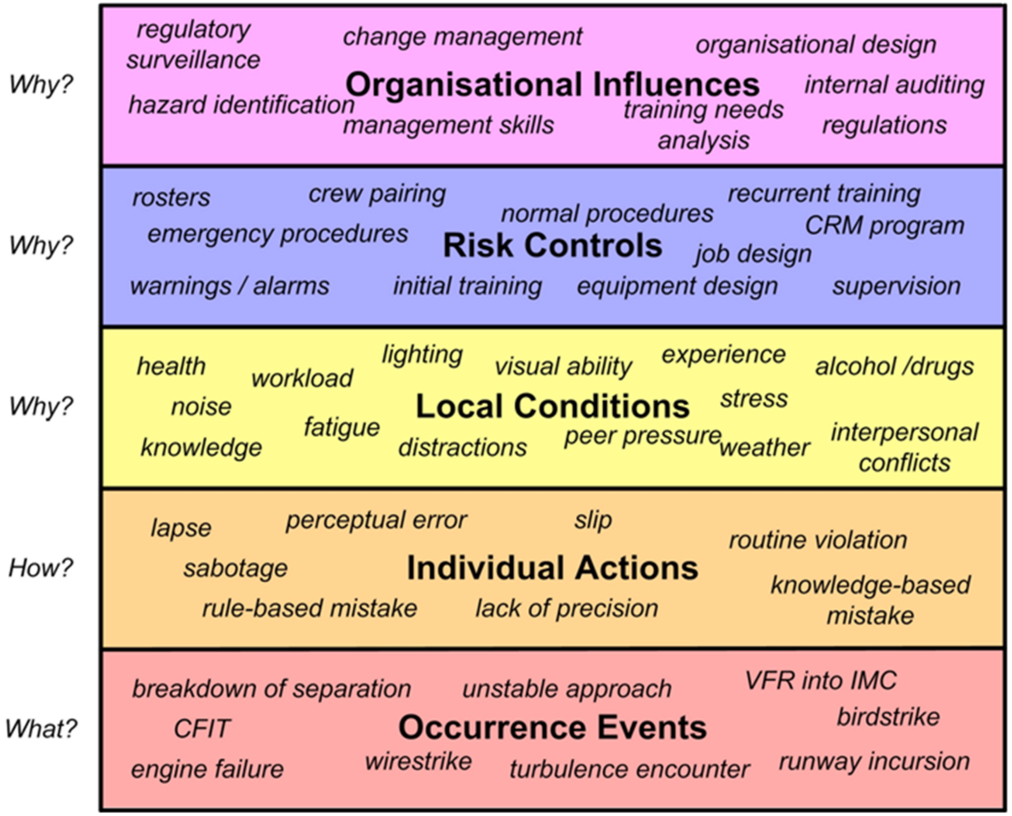
ATSB's adaption



ATSB investigation analysis model



Safety factor examples



FARO 3D site survey laser scanning

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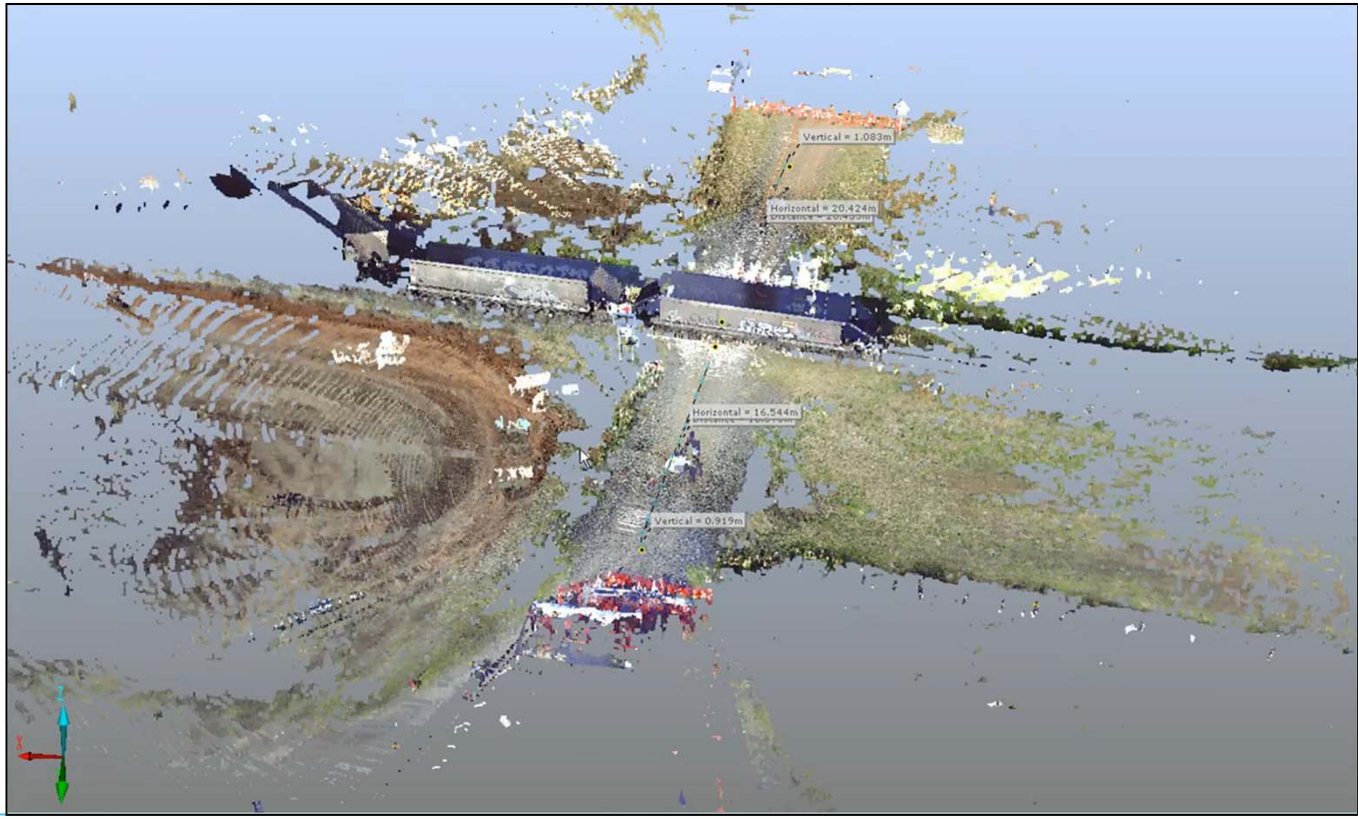

FARO laser photogrammetry

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RPAS imagery

Derailment of freight train near Julia Creek 27 December 2015

RPAS video imagery

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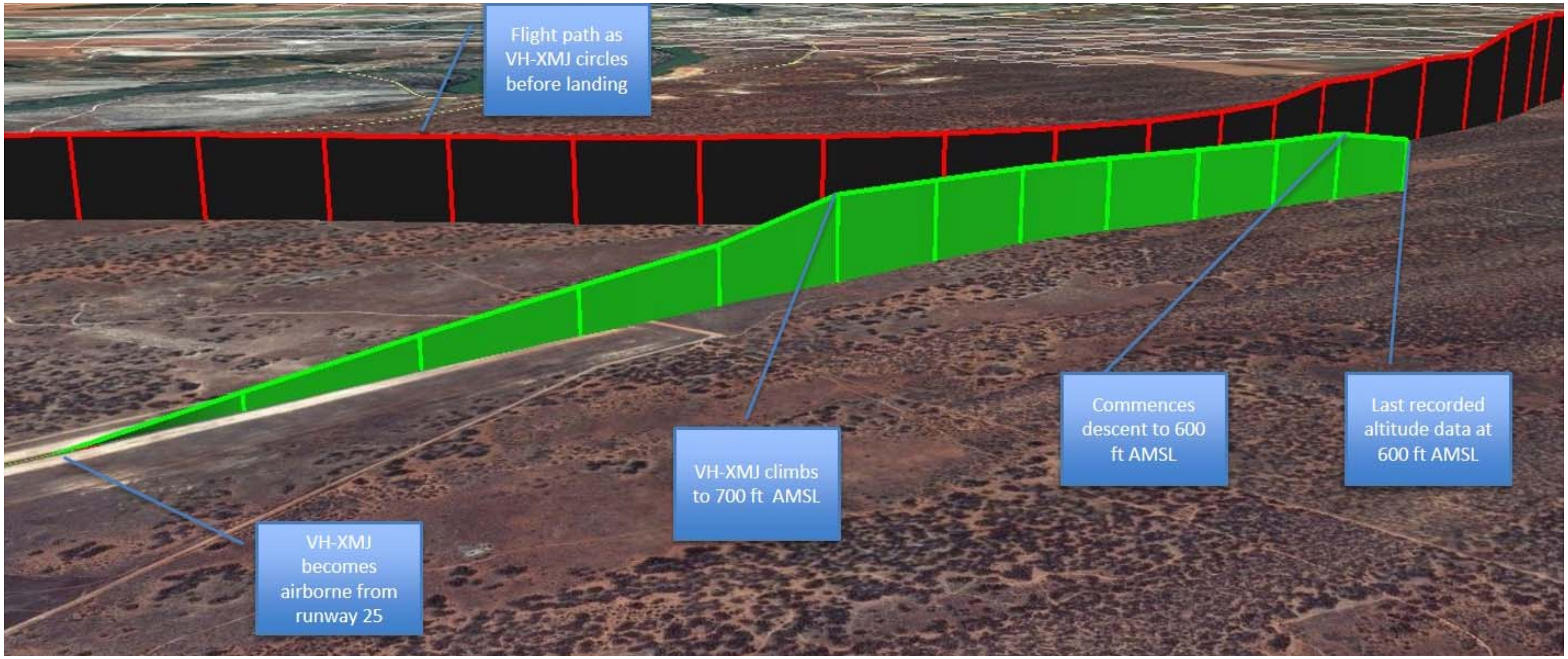
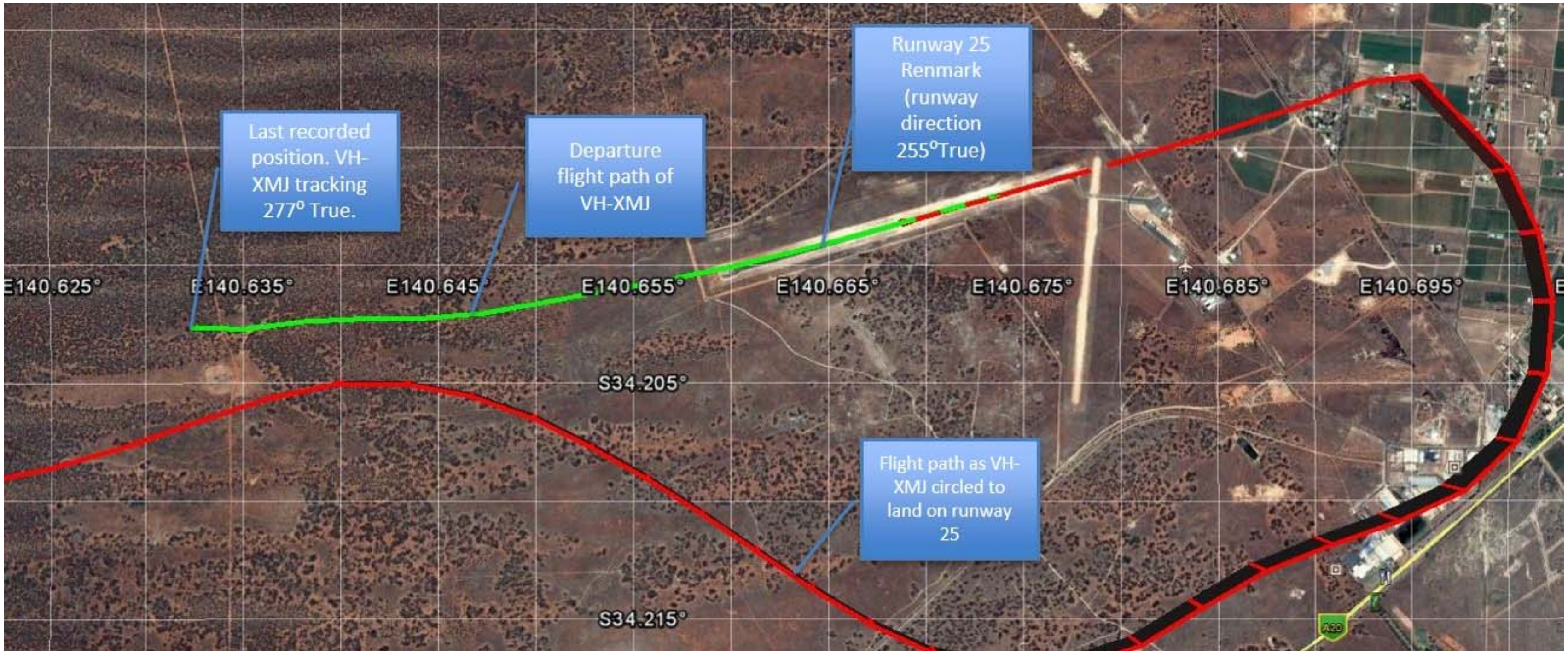
Data outputs with Google Earth



Collision with terrain involving a Cessna 441 at Renmark Airport, South Australia. Altitude information of flight paths

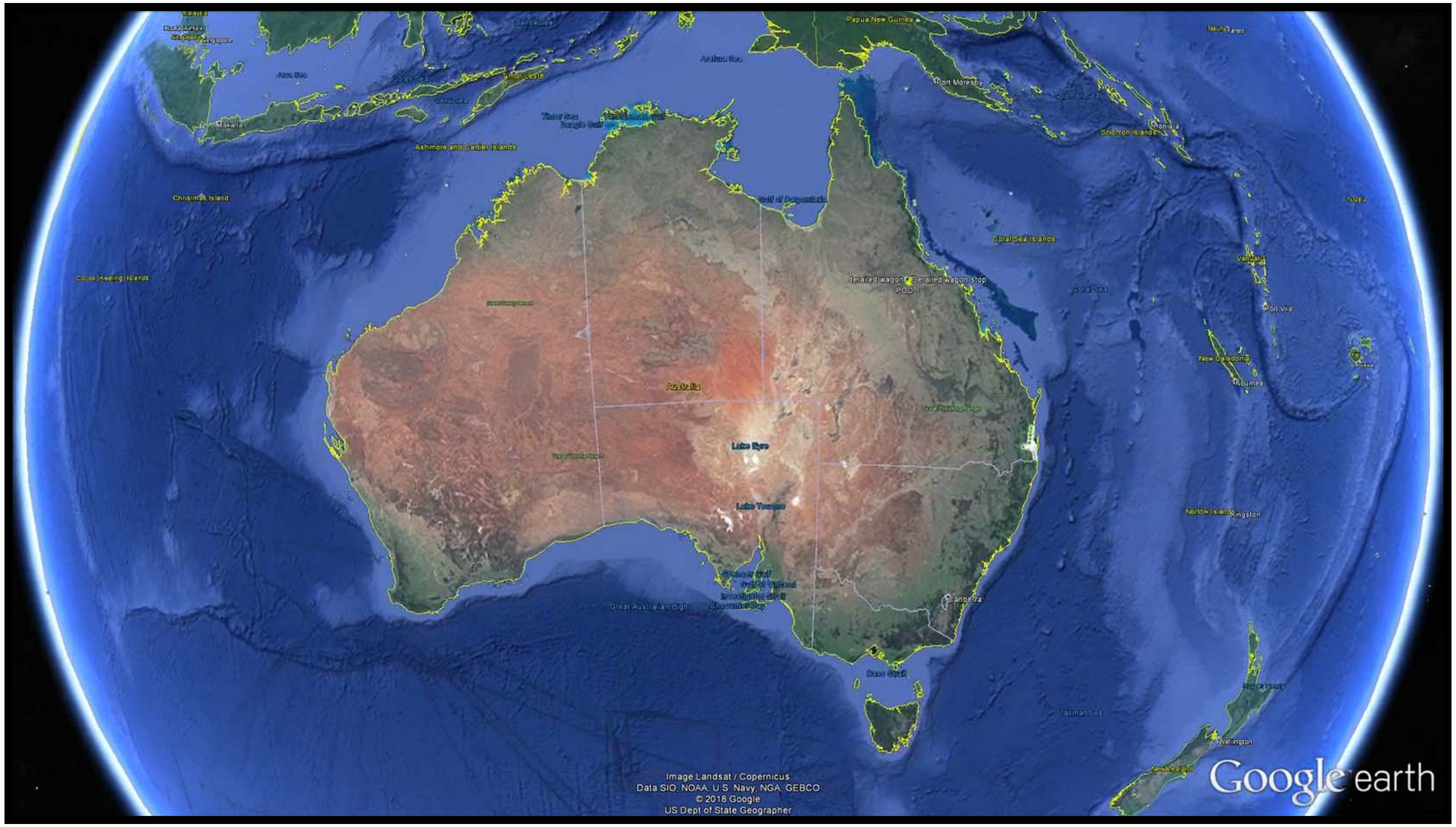
Data outputs with Google Earth



Position information of Cessna 441 as it circled Renmark Airport and landed on runway 25 (red), before backtracking and departing (green).

RPAS imagery with Google Earth

(Restricted content released under S61 of TSI Act 2003)



RPAS imagery with Google Earth

(Restricted content released under S61 of TSI Act 2003)

Mandatory accident or incident notification

- Toll-free number **1800 011 034** for advice or assistance on reporting requirements.
- If telephoning from outside Australia, please use +61 2 6230 4408 (toll free).
- Visit www.atsb.gov.au

Australian Government
Australian Transport Safety Bureau

Australia's national transport safety investigator

AVIATION | MARINE | RAIL

www.atsb.gov.au

Annex C to
Calibre Group Submission to NTC
4 Jun 18

Roy Hill Presentation at the RISSB Safety Conference in Sydney 2018

SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

RISSB RAIL SAFETY CONFERENCE 2018

Remote operations and using technology to advantage

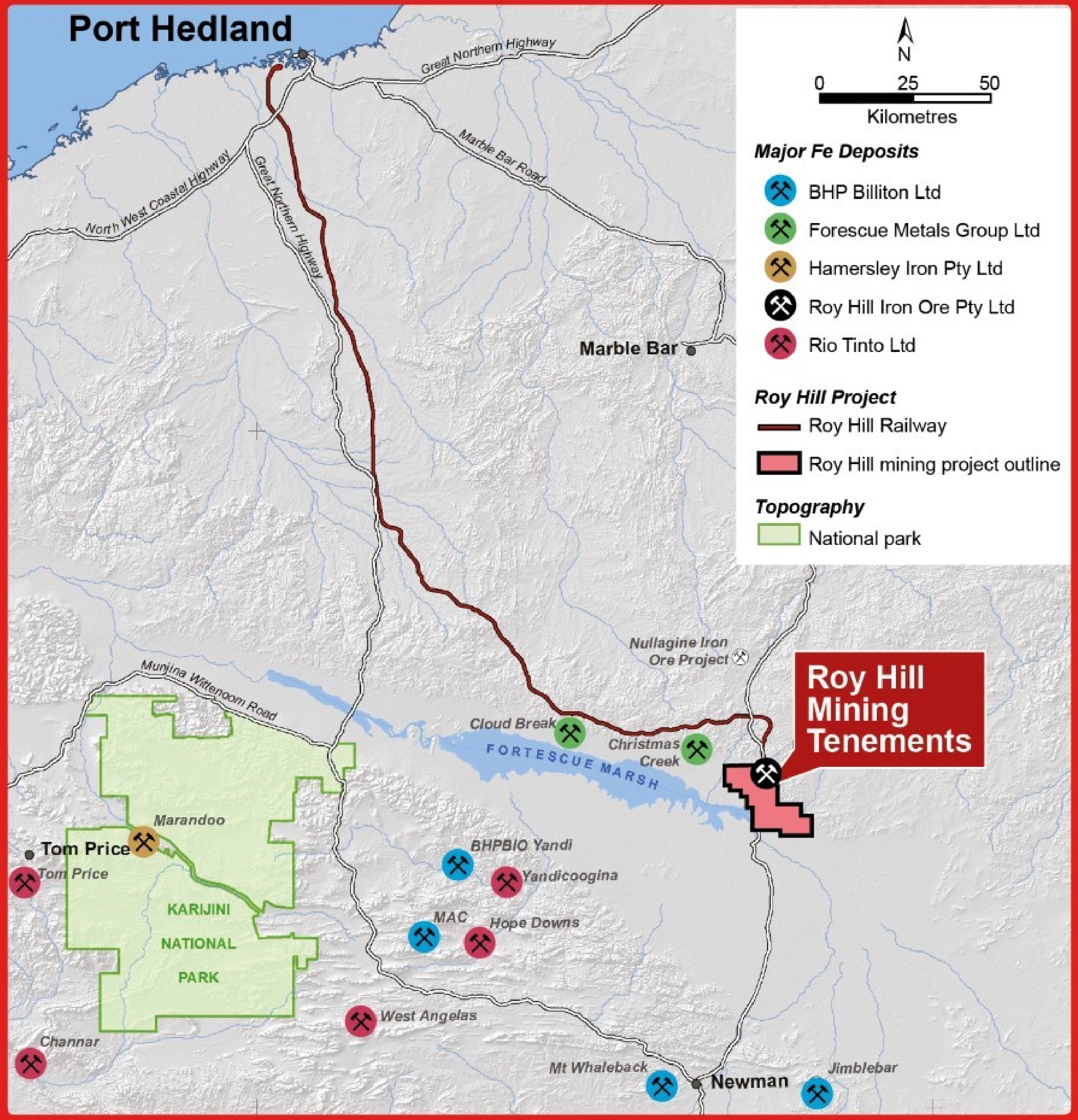
Stuart Harrison
Head of Rail Operations

LEAD • CARE • THINK • PERFORM

May 2018

Location

WEST AUSTRALIA
Wyndham
KUNUNURRA
Gibb River
Derby
Broome
Fitzroy Crossing
Halls Creek
PORT HEDLAND
KARRATHA
Whim Creek
Onslow
Exmouth
Pannawonica
Marble Bar
Tom Price
Paraburdoo
NEWMAN
Coral Bay
CARNARVON
Monkey Mia
MEEKATHARRA
WILUNA
MOUNT MAGNET
MULLEWA
GERALDTON
Laverton
MUKINBUDIN
Kalgoorlie/Boulder
Lancelin
Northam
SOUTHERN CROSS
PERTH
NORSEMAN
EUCLA
Narrogin
Bunbury
Manjimup
ESPERANCE
AUGUSTA
ALBANY



Port Hedland
Great Northern Highway
North West Coastal Highway
Marble Bar Road
Marble Bar
Munjina Wittenoom Road
Nullagine Iron Ore Project
Cloud Break
Christmas Creek
FORTESCUE MARSH
Roy Hill Mining Tenements
Marandoo
Tom Price
KARIJINI NATIONAL PARK
BHPBIO Yandi
Yandicoogina
MAC
Hope Downs
West Angelas
Channar
Mt Whaleback
Newman
Jimblebar
N
0 25 50
Kilometres
Major Fe Deposits
BHP Billiton Ltd
Forescue Metals Group Ltd
Hamersley Iron Pty Ltd
Roy Hill Iron Ore Pty Ltd
Rio Tinto Ltd
Roy Hill Project
Roy Hill Railway
Roy Hill mining project outline
Topography
National park

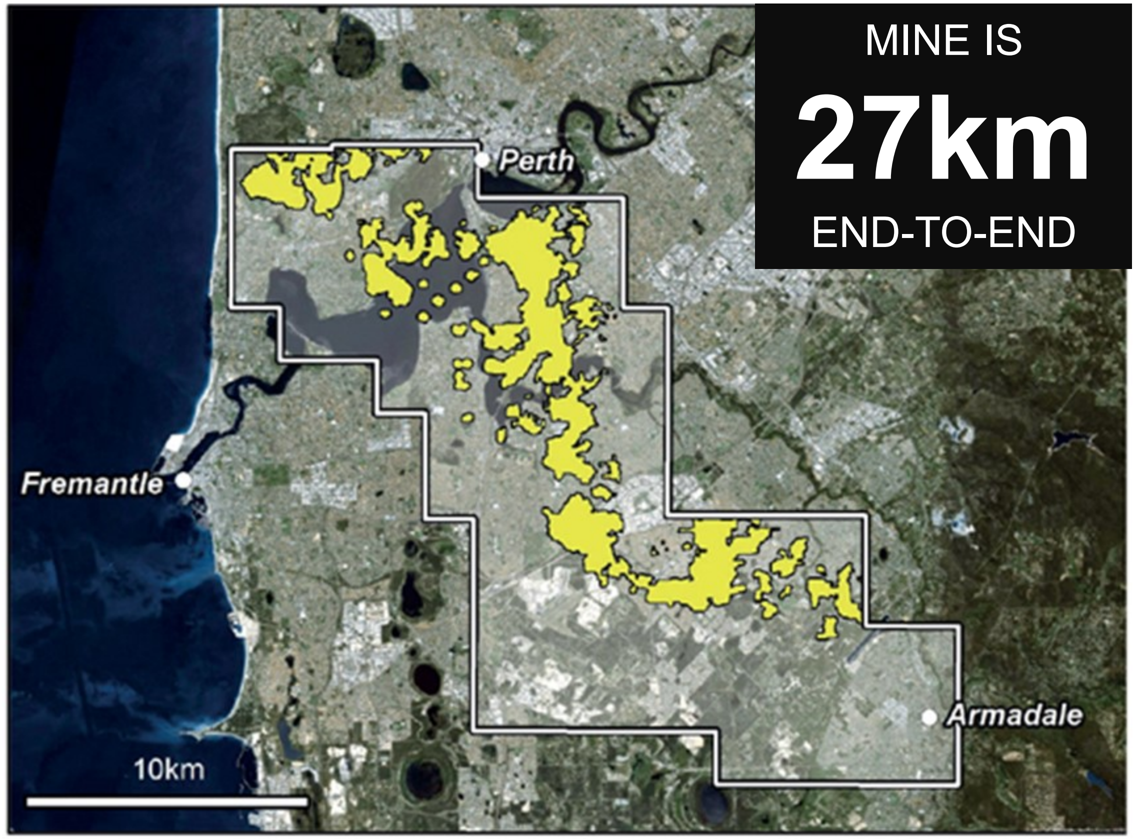
Our story

>2.3bt of +50%

FE IRON ORE COMPRISED OF **>1.2BT OF +55%** FE IRON ORE

25+ Year

MINE LIFE



OPEN CUT MINE, MULTIPLE PITS

55 Mtpa

WET PROCESSING PLANT

344km

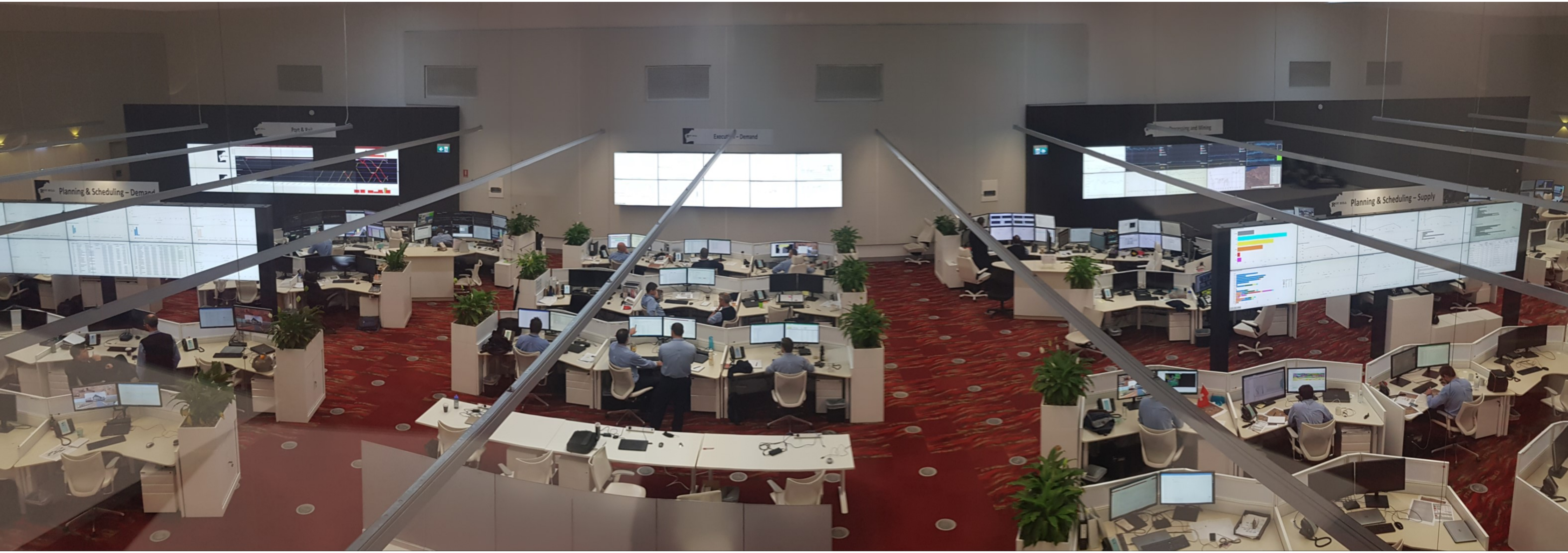
HEAVY HAUL RAILWAY

TWO BERTH WHARF, SINGLE SHIP LOADER

First shipment

EXPORTED **10 DECEMBER 2015**

Remote Operations Centre (ROC)

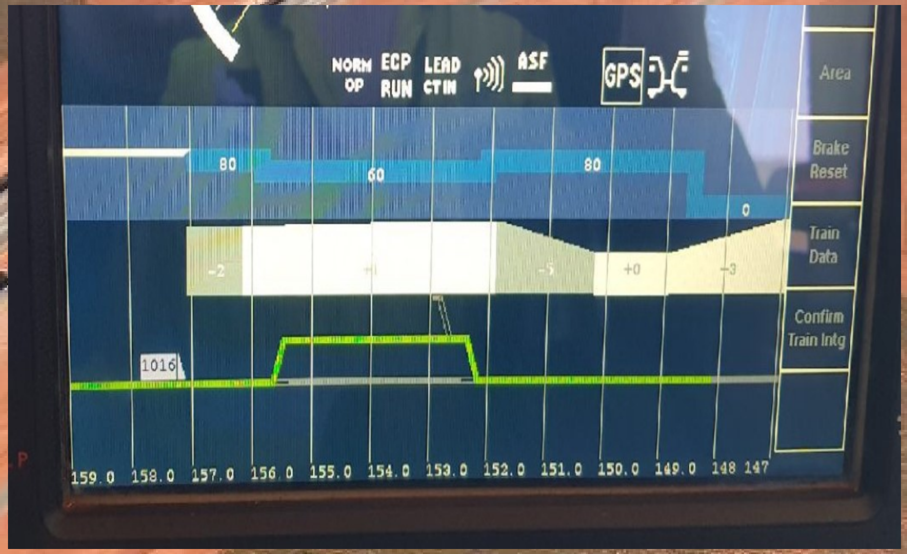


Communications Based Signalling (CBS)

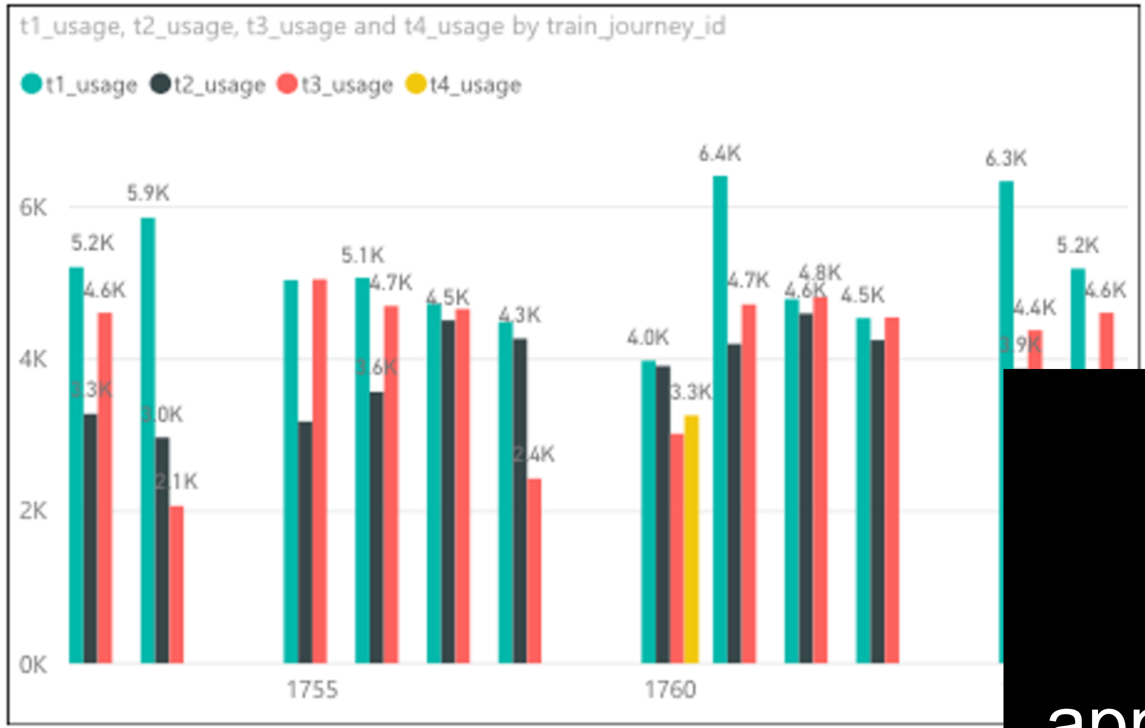
Communications Based Signalling (CBS) system which operates via a combination of:

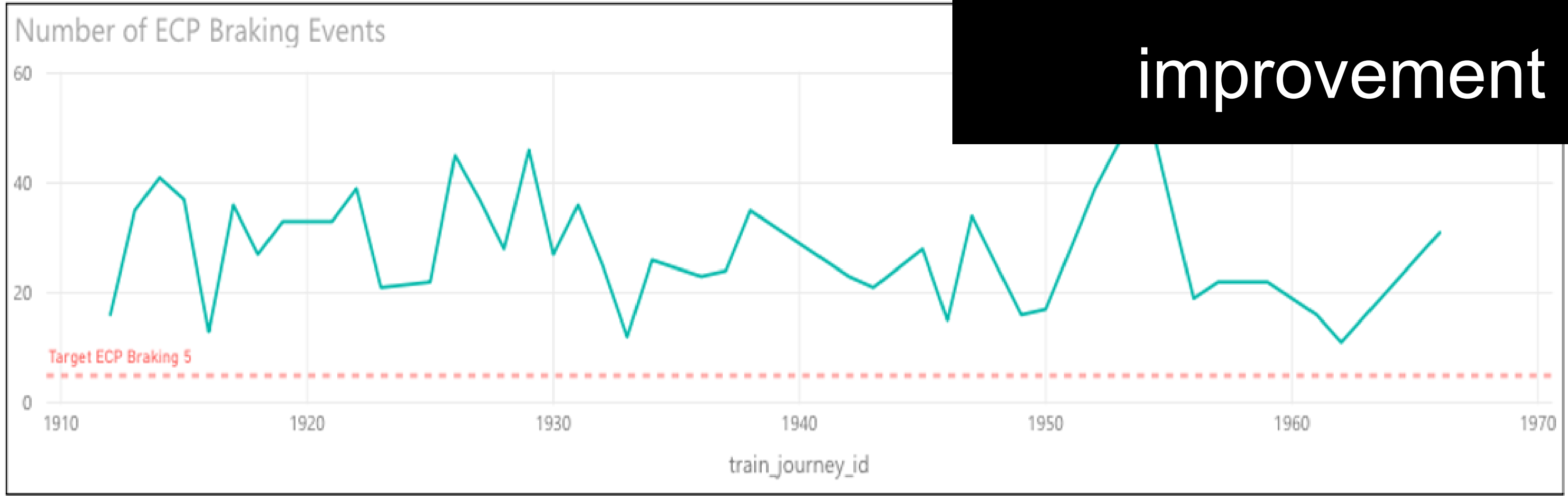
- GPS
- In Cab Signalling delivered via TETRA
- Virtual Automatic Train Protection (ATP)
- Electronic Train Authorities delivered ‘in-cab’

Enabler for future Automatic Train Operation.



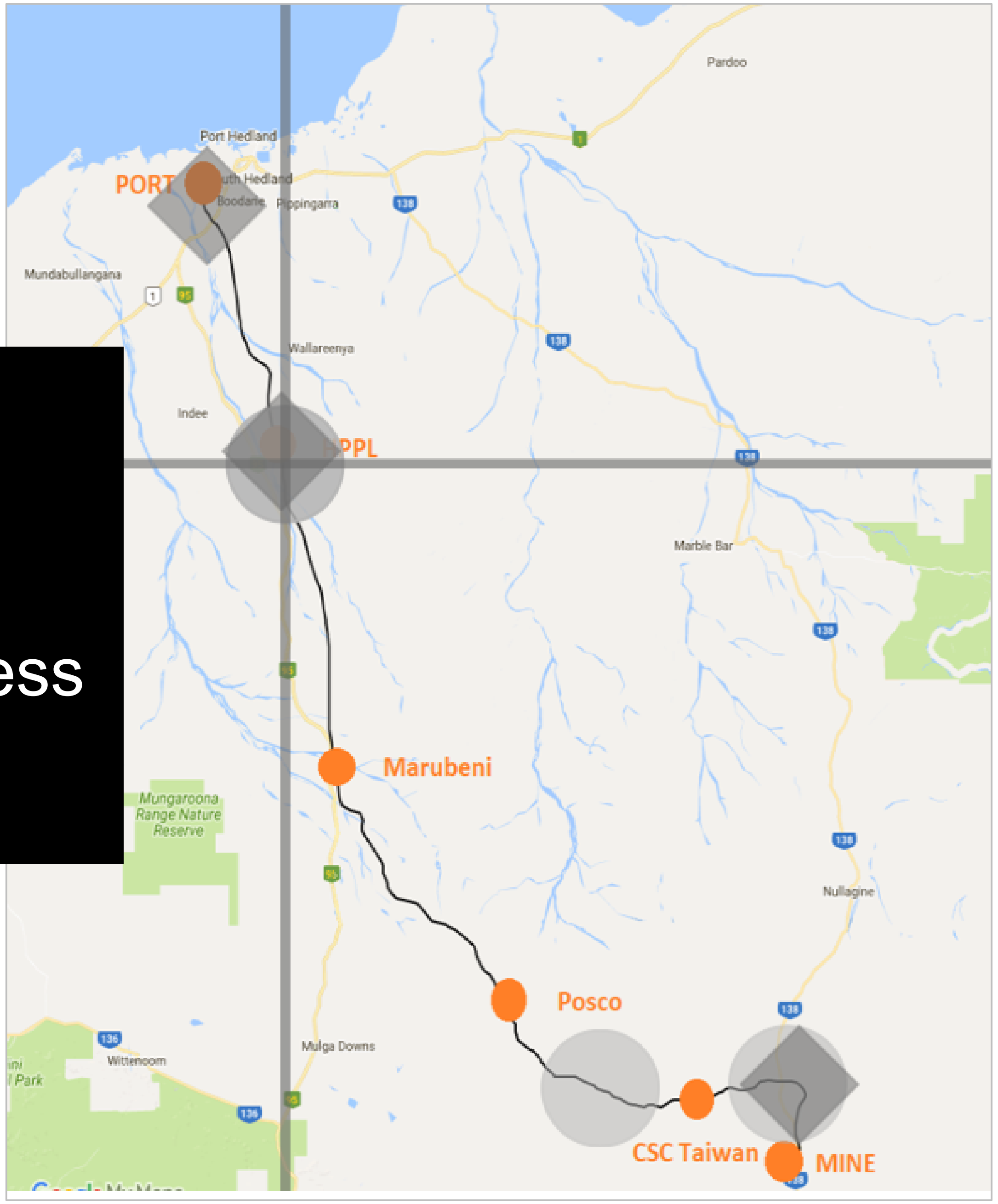
Analytical approach to business optimisation





Analytics -

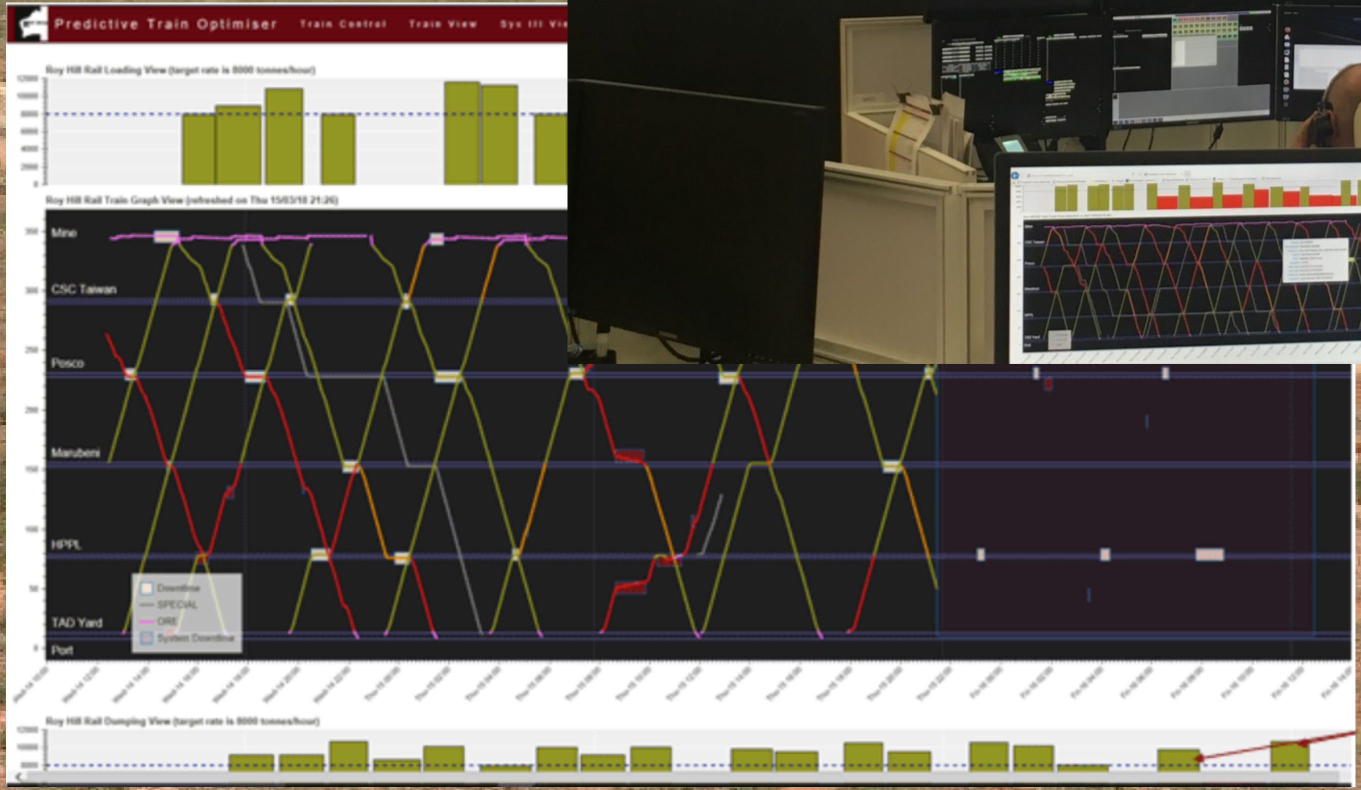
A fundamental approach for business improvement



Predictive Train Optimisation (PTO)

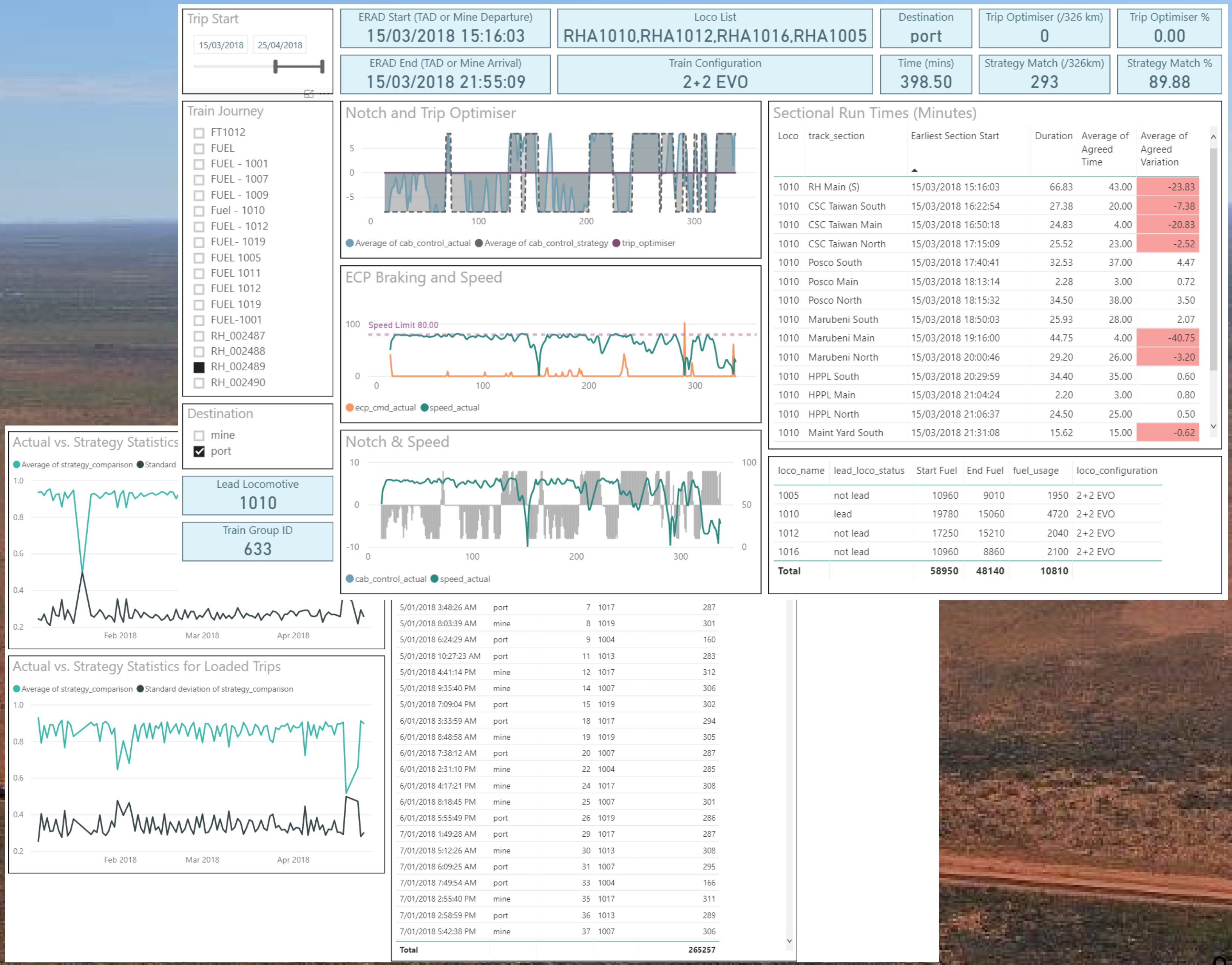
ROY HILL

Using real-time data from multiple sources to support train control planning and optimisation

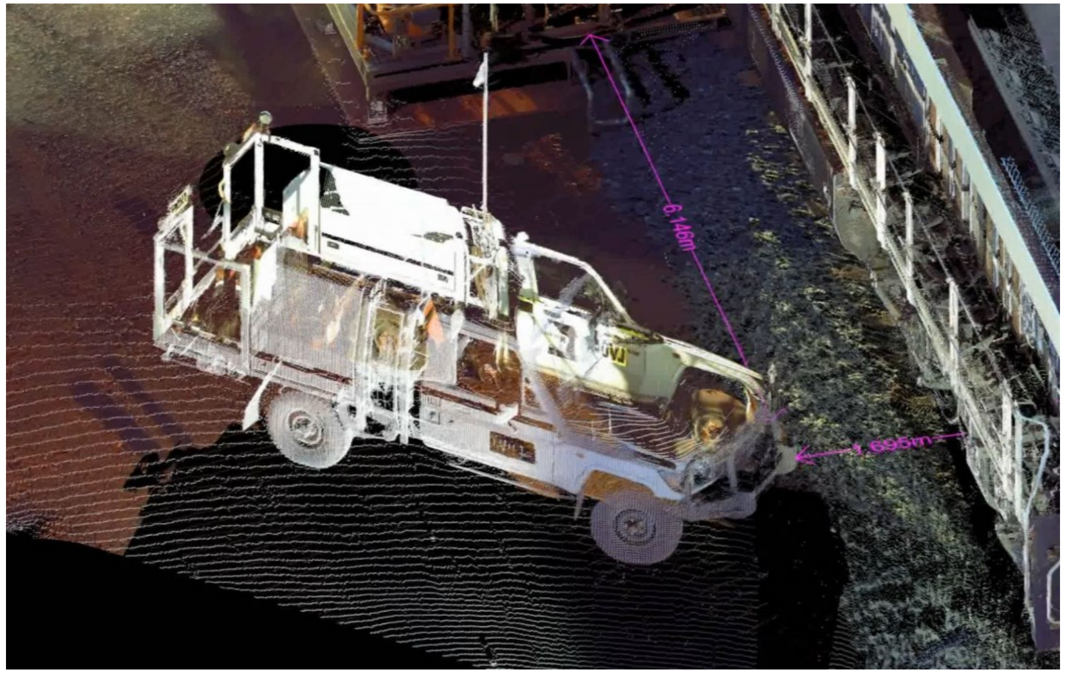


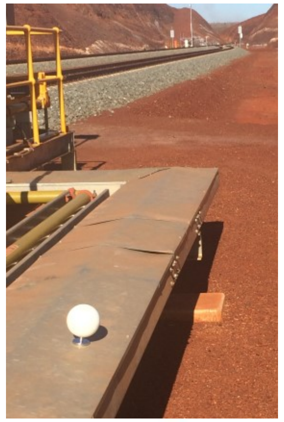
Train driving strategy

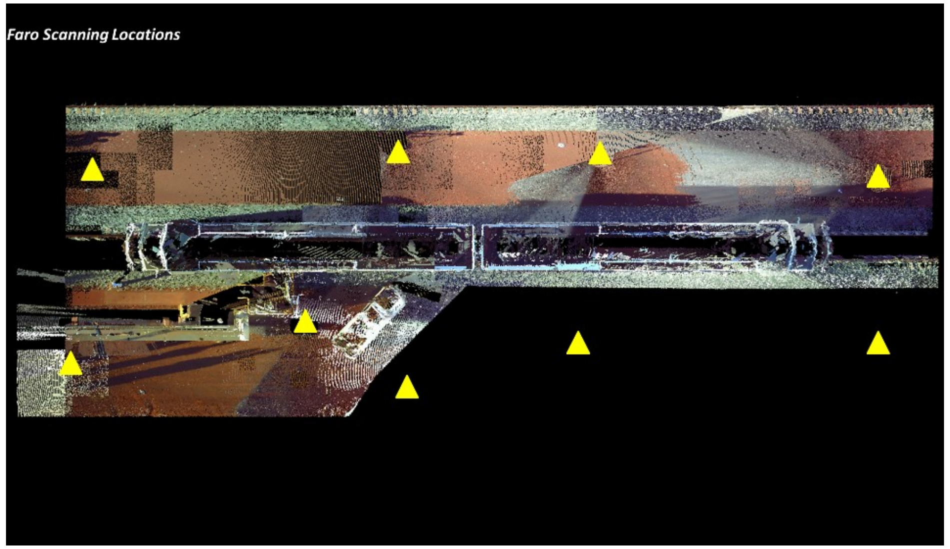
- Analytical approach to refine train driving strategy to deliver optimum train cycle performance
- Real-time review and reporting of actual train performance (TripOptimizer or Driver)

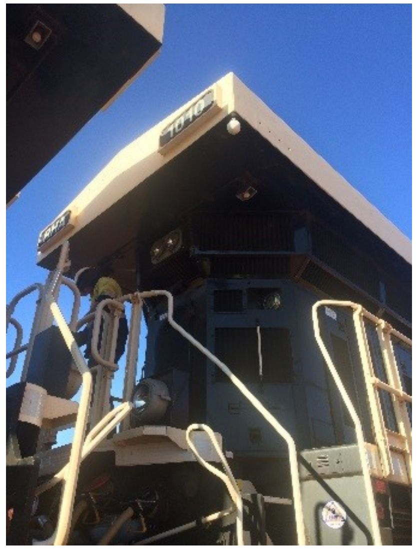


Incident scene recording using technology





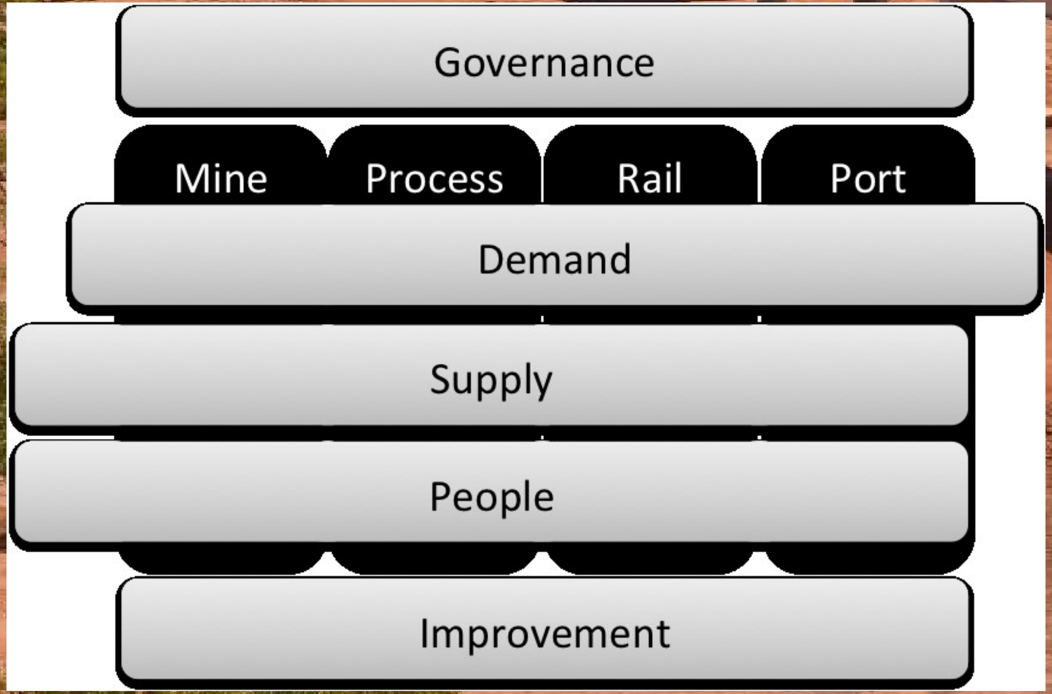





Roy Hill
Rail Incident
14/062017
RPAS (Drone) Imagery

Technology and innovation at Roy Hill

A systems approach to business improvement which demands focus on technology and innovation.



Questions

ROY HILL

THANK YOU

Annex D to
Calibre Group Submission to NTC
4 Jun 18

Generic Automotive EMC Test Standard

SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

The Automotive EMC Network
(www.AutoEMC.net)

A Generic Automotive EMC Test Standard

Project	A Generic Automotive EMC Test Standard
Customer	OPEN SOURCE SPECIFICATION
Contact	enquiries@autoemc.net
Author	Martin O'Hara
Revision	DRAFT

The Automotive EMC Network, P.O. Box 3622, Newport Pagnell, MK16 0XT

Contents

A GENERIC AUTOMOTIVE EMC TEST STANDARD

Introduction

This specification is published as a freely available "open source" specification. It is the result of an attempt by the Automotive EMC Network to produce a specification that is an approximation to a generic specification that is close to the majority of automotive vehicle manufacturers (VM) own specifications. It was produced to enable automotive electronic circuit designers and producers to develop and test products prior to obtaining specific VM approvals. The test levels and testing methods used within this specification should also be acceptable as "e-mark" testing for the European Union Automotive EMC directive (2004/104/EC) if performed by a suitable test laboratory.

There are no detailed descriptions of the test set-up or methods contained in this document, these are all in the international standard the tests refer to in this document.

Caveat

The specification was developed without the assistance or approval of any VM, therefore compliance to this test specification is not a guarantee of acceptance by any specific VM.

Test Conditions

Unless specifically stated in the referenced test document, the following basic test conditions will apply.

Test Laboratory Accreditation

All testing should be performed in an EMC test facility that has been accredited under the Automotive EMC Laboratory Recognition Program (AEMCLRP) to be compliant with the letter of this specification. The facility may be an independent test laboratory or a supplier owned test facility. Details on this program and steps for laboratory recognition may be found at check www.a2la.org.

Supply Voltage

It is assumed that the majority of tests will be conducted using a typical vehicle battery as used in the final application. Alternatively a linear power supply with very low ripple (less than 10mV at 12V output with 1A DC load) or a stabilised output power supply can be used to provide a trickle charge to a suitable car battery/accumulator. The nominal voltage will be dependant on the nominal operating voltage of the powernet of the vehicle, but for the 3 standard supply levels most commonly found these are;

Table 1: Operating Supply Voltage Limits

Nominal Battery Voltage	Minimum	Typical	Maximum	Units
12V (14V Powernet)	11	12	14	V
24V	22	24	28	V
36V (42V Powernet)	33	36	42	V

Environmental Test Conditions

The equipment under test (EUT) and measurement instrumentation should be acclimatised to the test environmental conditions for a minimum of 30 minutes and preferably 1 hour before commencing testing.

Table 2: Environmental Test Conditions

Parameter	Minimum	Typical	Maximum	Units
Temperature	18	23	28	°C
Relative Humidity	30	45	60	%

Measurement Tolerances

Where not explicitly stated, a tolerance of ±5% on any parametric value is assumed.

Table 3: Parametric Measurement Tolerances

Parametric Measurement	Minimum	Maximum	Units
Current	-5	5	%
Voltage	-5	5	%
Impedance (R, C or L)	-10	10	%
Field Strength	0	10	%

Resolution Bandwidth

The resolution bandwidth (RBW) for all emissions testing should be specified in the international (CISPR or ISO) standard that the individual test schedules specify. Where the tests use frequencies that are not covered by the specific international standard the following is applicable.

Table 4: Applicable Resolution Bandwidth

Frequency Range	RBW	Units
Below 30MHz	9	KHz
30MHz – 1GHz	120	KHz
Above 1GHz	1	MHz

Frequency Step Size

The frequency step size for all immunity testing can be as specified in the international (CISPR or ISO) standard that the individual test schedules specify. Where the tests use frequencies that are not covered by the specific international standard the following is applicable.

Table 5: Applicable Frequency Step Sizes

Frequency Range	RBW	Units
Below 10MHz	10	KHz
1MHz – 1GHz	100	KHz
Above 1GHz	1	MHz

Application Classification

Only two application classes have been adopted for this standard, in common with the majority of vehicle manufacturer standards.

Table 6: Application Classifications

Application Group	Typical In-Vehicle Applications
I	Powertrain and Safety: engine management unit (EMU), ABS, SRS, immobiliser, body control modules (BCM), exterior lighting, central locking, wiper controls
II	Comfort and Convenience: in-car entertainment (ICE), HVAC, telematics (satellite-navigation, phone-kit), instrument illumination, auto dimming mirrors

Failure Mode Severity Classification

There are two classifications within the five ISO classifications (see appendix A for full list) that have been adopted in this standard; class A for application group I products and class C for application group II products.

Table 7: Generic Test Classifications

Classification	Description
A	all functions of a device or system perform as designed during and after exposure to interference.
C	One or more functions of a device or system do not perform as designed during exposure but return automatically to normal operation after exposure is removed.

Test Methods and Levels

Where available the tests discussed as “generic” below are all based on the available international standards with no deviation from test conditions as defined in these standards. The VM specifications almost always make what initially appear as small deviations from some of the generic set-ups and conditions, maybe a slightly different harness length or pulse rise time and sometimes a different resolution bandwidth (RBW) for signal measurement. In providing a generic specification the tests noted here are all reverted to the original set-up of their base standard with no deviations in set-up or method. Some deviations for extended frequency or applied level may be made, but not for the set-up itself.

Radiated Emissions

Base Standard: CISPR-25 [1]

Only the free-field testing method of CISPR-25 (measured in an absorber-lined screened enclosure; ALSE) is used for radiated emissions measurement in this standard, at the class 3 limit levels. There are three deviations from the basic CISPR-25 standard:

1. the omitted test bands are included with limit lines derived from joining the end-of-band limits
2. the upper frequency limit is extended to 5GHz from the standard limit of 960MHz, with an increase in the limit level above 1GHz to account for the wider RBW used
3. the narrowband limits are derived from the quasi-peak limits of CISPR-25

Table 8: Radiated Emission Limits

Band	Frequency Range (MHz)	Broadband (Peak) Limit (dBuV/m)	Narrowband (Quasi-Peak) Limit (dBuV/m)
1	0.15 – 0.30	76	63
2	0.30 – 0.53	76 - 36.41 log (f / 0.3)	63 – 36.41 log (f / 0.3)
3	0.53 – 2.0	67	54
4	2.0 – 5.9	76 - 40.44 log (f / 2)	63 – 40.44 log (f / 2)
5	5.9 – 54	48	35
6	54 – 76	48 – 97.60 log (f / 54)	35 – 97.60 log (f / 54)
7	76 – 1000	37	24
8	1000 – 5000	48	35

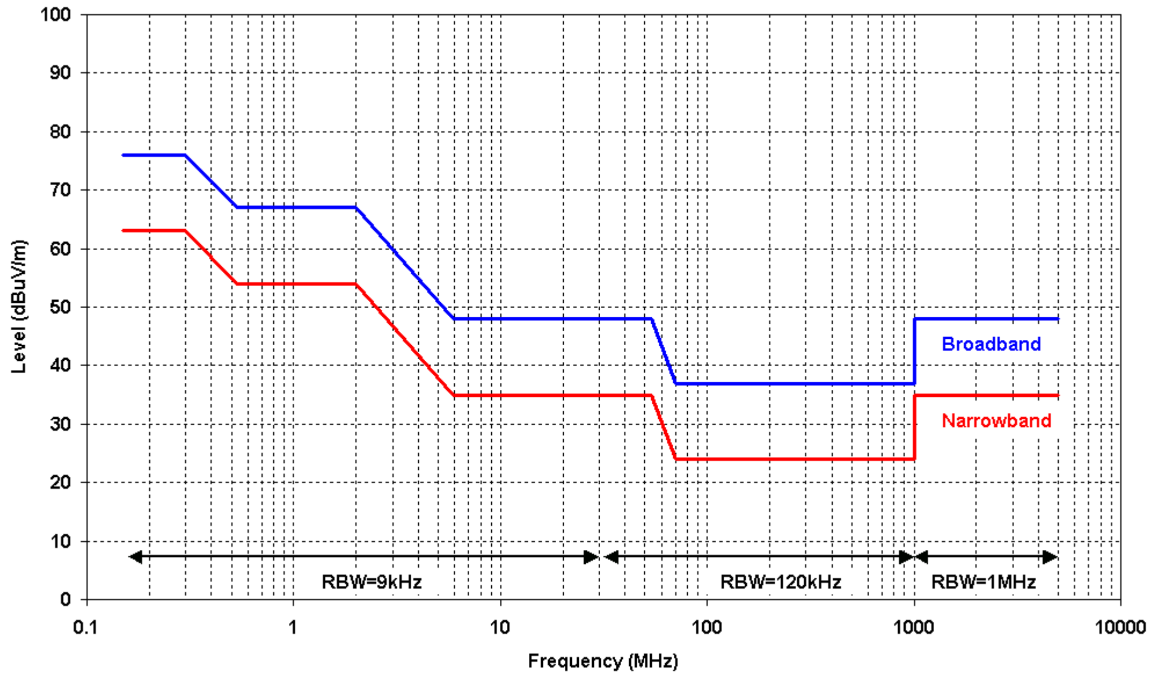


Figure 2: Generic Limits based on CISPR-25 Level 3

Radiated Immunity

Base Standards: ISO11452-2, ISO 11452-4 [3]

Testing for radiated immunity utilises just 2 test methods from ISO 11452; BCI for the lower frequency range (1MHz-400MHz) and free field (ALSE) for higher frequencies (20MHz-5GHz). There is a considerable cross-over in these ranges, but this is to enable test costs to be optimised and at the same time keep an eye to the EU automotive directive and meeting it's requirements with the same data. In practice what this means is that ALSE testing can commence at 400MHz rather than 20MHz if it is a lower cost option or there is some benefit to using BCI for the lower frequencies.

Table 9: Radiated Immunity Limits

Frequency Range (MHz)	Test Method	Modulation	Polarisation	Application Group I		Application Group II	
				Limit	Pass Criteria	Limit	Pass Criteria
1 - 400	ISO 11452-4: BCI	CM/AM	Not applicable	200mA	A	100mA	C
20 - 1000	ISO 11452-2: ALSE	CW/AM	Vertical & Horizontal	200V/m	A	100V/m	C
800 - 5000		PWM	Vertical				

Continuous Wave (CW) applied only below 1GHz.

Amplitude Modulated (AM) using 80% modulation with a 1kHz sine wave.

Pulse Width Modulated (PWM) with a pulse width of 577us and a period of 4600us.

Conducted Emissions

Base Standard: CISPR-25 [1]

Specified levels are class 3 limit levels of the CISPR-25 standard. There are three deviations from the basic CISPR-25 standard:

1. the omitted test bands are included with limit lines derived from joining the end-of-band limits
2. the upper frequency limit is extended to 200MHz from the standard limit of 108MHz
3. the narrowband limits are derived from the quasi-peak limits of CISPR-25

Table 10: Conducted Emission Limits

Band	Frequency Range (MHz)	Broadband (Peak) Limit (dBuV/m)	Narrowband (Quasi-Peak) Limit (dBuV/m)
1	0.15 – 0.30	76	63
2	0.30 – 0.53	76 - 36.41 log (f / 0.3)	63 – 36.41 log (f / 0.3)
3	0.53 – 2.0	67	54
4	2.0 – 5.9	76 - 40.44 log (f / 2)	63 – 40.44 log (f / 2)
5	5.9 – 54	48	35
6	54 – 76	48 – 97.60 log (f / 54)	35 – 97.60 log (f / 54)
7	76 – 200	37	24

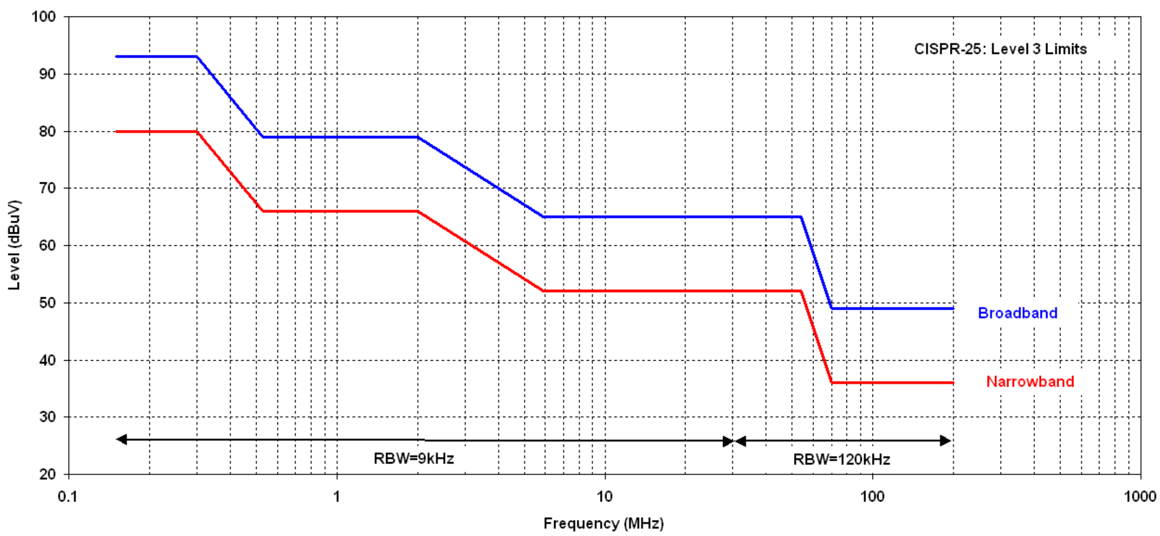


Figure 6: Generic Conducted Emissions Limits based on CISPR-25 Level 3

Conducted Transient Immunity

Power Line

Base Standard: ISO 7637-2 [2]

The chosen level adopted are from level IV of the ISO 7637-2 standard, with 2 exceptions. The first exception is the use of 100V for the pulse 2b. The ISO 7637 level IV setting for pulse 2b is 50V, this is relatively benign and even 100V is not especially onerous to meet. The other difference is the load dump (pulse 5) lower level for group II application circuits at 24V.

Table 11: 12V Power Line Transient Immunity Test Parameters

Pulse	Application Group I		Application Group II	
	Test Level (V)	Functional Class	Test Level (V)	Functional Class
1	-100	A	-100	C
2a	100		100	
2b	10		10	
3a	-150		-150	
3b	100		100	
4	7		7	
5	87		24	

Signal Line

Base Standard: ISO 7637-3 [2]

The chosen level adopted are from level IV of the ISO 7637-3 standard, with one exception;the use of 100V for the pulse 3b.

Table 12: Signal Line Transient Immunity Test Parameters

Pulse	Application Group I		Application Group II	
	Test Level	Functional Class	Test Level	Functional Class
3a	-150	A	-150	C
3b	100		100	

Electrostatic Discharge

Base Standard: ISO 10605 [4]

Table 13: ESD Test Parameters

Test	Discharge Method	Network	Test Severity Level	No. of Discharges	Functional State
Unpowered or Handling	Contact	150pF/2kΩ	±8kV	5	A (I) C (II)
	Air	330pF/2kΩ	±15kV		
Powered	Contact	150pF/2kΩ	±8kV		
	Air	330pF/2kΩ	±25kV		

Tests may gradually be raised to the values shown in the above table in steps suggested in ISO 10605.

Although only 5 discharges are required (in both positive and negative polarities), this is for any single pin or any discharge point.

A period of between 5s and 10s between discharges should be observed.

Test Report

As well as the target levels as specified here, a photograph of the test set-up for each test should be included, plus spectra for emissions measurements and finally a simple PASS or FAIL statement per test regime. As in this document it is not necessary to draw a detailed plan of the test, this is contained in the referring CISPR and ISO standard, only deviations from this may be noted (e.g. use of different harness length due to availability or pulse shape due to loading).

References

1. CISPR-25: 2002 - Limits and methods of measurement of radio disturbance characteristics for the protection of receivers used on board vehicles.

2. ISO 7637: Electrical disturbance by conduction and coupling
   Part 1: Definitions and general consideration (2002)
   Part 2: Electrical transient conduction along supply lines only (2004)
   Part 3: Vehicles with nominal 12V and 24V supply voltage – electrical transient transmission by capacitive and inductive coupling via lines other than supply lines (1995)

3. ISO 11452: Road vehicles – electrical disturbances by narrowband radiated electromagnetic energy – component test methods
   Part 1: General and definitions (2001)
   Part 2: Absorber-lined chamber (1995)
   Part 3: Transverse electromagnetic mode (TEM) cell (2001)
   Part 4: Bulk current injection (BCI) (2001)
   Part 5: Stripline (2002)
   Part 6: Parallel plate antenna (1997)
   Part 7: Direct radio frequency (RF) power injection (1995)

4. ISO 10605: Road vehicles – electrical disturbances from electrostatic discharges (2001)

5. A Generic Automotive EMC Test Specification, Martin O'Hara, Automotive EMC 2006, p81-92, NEC Birmingham, UK, 17th May 2006 (available via the Automotive EMC Network, www.autoemc.net)

Appendix A: ISO Failure Mode Severity Classification

All classifications given below are for the total device/system functional status.

Note: The word "function" as used here concerns only the function performed by the electronic system.

Class A: all functions of a device or system perform as designed during and after exposure to interference.

Class B: all functions of a device/system perform as designed during exposure; however, one or more of them may go beyond the specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain class A.

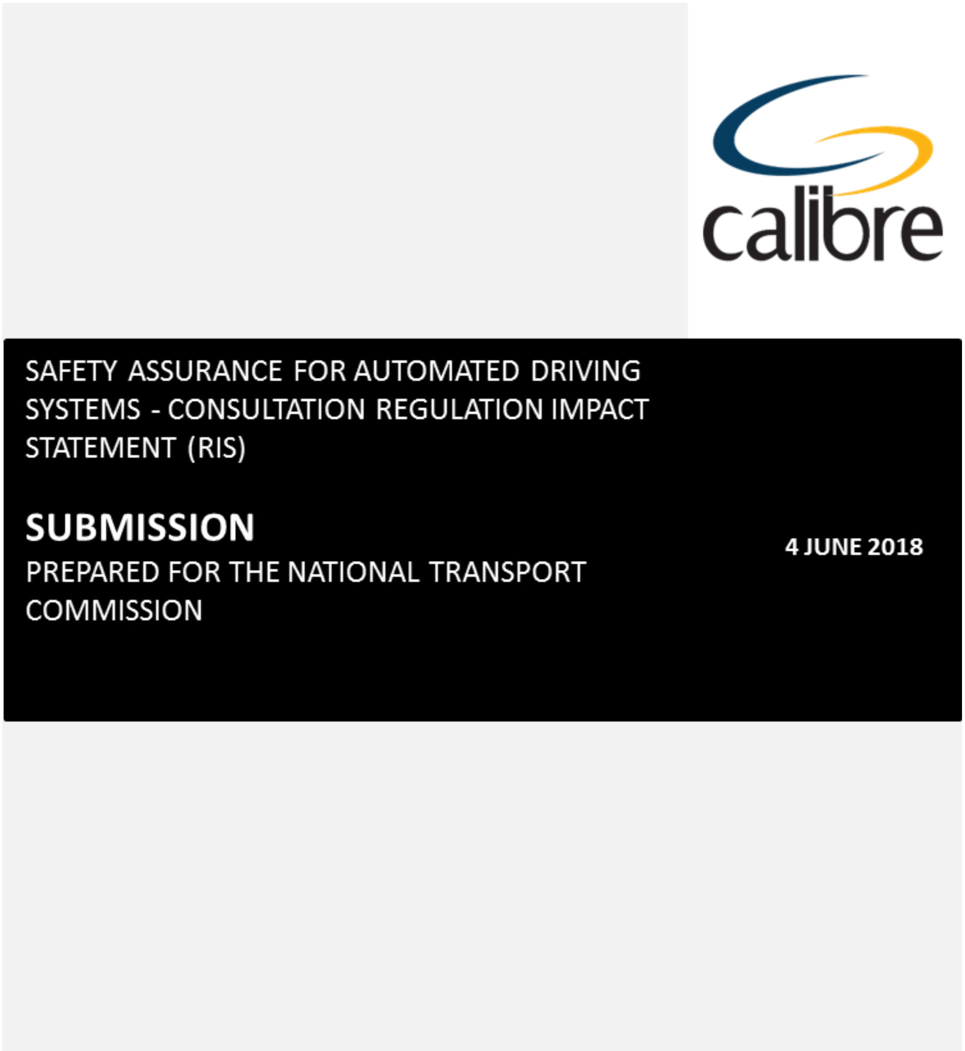
Class C: one or more functions of a device or system do not perform as designed during exposure but return automatically to normal operation after exposure is removed.

Class D: one or more functions of a device or system do not perform as designed during exposure and do not return to normal operation until exposure is removed and the device or system is reset by a simple "operator/use" action.

Class E: one or more functions of a device or system do not perform as designed during and after exposure and cannot be returned to proper operation without repairing or replacing the device or system.

Annex E to
Calibre Group Submission to NTC
4 Jun 18

EC Official Directive: Commission Directive 2006/28/EC dated 6 March 2006



SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

COMMISSION DIRECTIVE 2006/28/EC

of 6 March 2006

amending, for the purposes of their adaptation to technical progress, Council Directive 72/245/EEC of 20 June 1972 relating to the radio interference (electromagnetic compatibility) of vehicles and Council Directive 70/156/EEC on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers

(Text with EEA relevance)

THE COMMISSION OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Community,

Having regard to Council Directive 70/156/EEC of 6 February 1970 on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers [1], and in particular Article 13(2) thereof,

Having regard to Council Directive 72/245/EEC of 20 June 1972 relating to the radio interference (electromagnetic compatibility) of vehicles [2], and in particular Article 4 thereof,

Whereas:

(1) Directive 72/245/EEC is one of the separate directives under the type-approval procedure established by Directive 70/156/EEC.

(2) In order to improve safety of vehicles by encouraging development and deployment of technologies utilising automotive short-range radar equipment, the Commission has harmonised the use of two radio spectrum frequency bands by Commission Decision 2004/545/EC of 8 July 2004 on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community [3] and by Commission Decision 2005/50/EC of 17 January 2005 on the harmonisation of the 24 GHz range radio spectrum band for the time-limited use by automotive short-range radar equipment in the Community [4].

(3) In accordance with Decision 2005/50/EC, the use of 24 GHz automotive short-range radar equipment is time-limited and Member States have to set up a monitoring system aiming to quantify the number of vehicles equipped with 24 GHz short-range radar equipment registered in their territory.

(4) Directive 72/245/EEC, as amended by Commission Directive 2005/49/EC [5], provided Member States with the appropriate means to carry out this monitoring. Directive 70/156/EEC was amended accordingly by that Directive.

(5) Since then it has become obvious that the way to provide these data can be simplified for 24 GHz short-range radar equipment and that it is unnecessary for monitoring purposes to require information about the use of 79 GHz short-radar equipment in the Certificate of Conformity (CoC) in addition to the information about the 24 GHz short range radar equipment, since the 79 GHz band does not interfere with other applications and its use is not restricted. It is therefore appropriate to modify requirements related to the use of 24 GHz short-range radar equipment and delete requirements related to the use of 79 GHz short-range radar equipment in Directive 72/245/EEC. This Directive does not affect the validity of existing approvals for vehicles not fitted with 24 GHz short range radars.

(6) Only Technical Services issue attestations according to the model given in Annex III C of Directive 72/245/EEC. No further authority or administration is involved in this process. Therefore, the additional stamping of the attestation presently required is dispensable and shall be removed.

(7) Directive 72/245/EEC should therefore be amended accordingly.

(8) The amendments to Directive 72/245/EEC have an impact on Directive 70/156/EEC. It is therefore necessary to amend Directive 70/156/EEC accordingly.

---

(1) OJ L 42, 23.2.1970, p. 1. Directive as last amended by Directive 2005/64/EC of the European Parliament and of the Council (OJ L 310, 25.11.2005, p. 10).
(2) OJ L 152, 6.7.1972, p. 15. Directive as last amended by Commission Directive 2005/83/EC (OJ L 305, 24.11.2005, p. 32).
(3) OJ L 241, 13.7.2004, p. 66.
(4) OJ L 21, 25.1.2005, p. 15.
(5) OJ L 194, 26.7.2005, p. 12.

(9) The measures provided for in this Directive are in accordance with the opinion of the Committee for Adaptation to Technical Progress established by Article 13 of Directive 70/156/EEC,

HAS ADOPTED THIS DIRECTIVE:

Article 1

Amendment to Directive 72/245/EEC

Directive 72/245/EEC is amended as follows:

1. In Annex I, point 2.1.14 is deleted.

2. Annex II A is amended as follows:

   (a) Point 12.7.1 is replaced by the following:

   '12.7.1. vehicle equipped with 24 GHz short-range radar equipment: Yes/No/Optional (strike out which is not applicable)';

   (b) Point 12.7.2 is deleted.

3. The appendix to Annex III A is amended as follows:

   (a) Point 1.3.1 is replaced by the following:

   '1.3.1. vehicle equipped with 24 GHz short-range radar equipment: Yes/No/Optional (strike out which is not applicable)';

   (b) Point 1.3.2 is deleted.

4. In Annex III C, the words 'Stamp of administration' including the surrounding box are deleted.

Article 2

Amendment to Directive 70/156/EEC

Directive 70/156/EEC is amended as follows:

1. Annex I is amended as follows:

   (a) Point 12.7.1 is replaced by the following:

   '12.7.1. vehicle equipped with 24 GHz short-range radar equipment: Yes/No/Optional (strike out which is not applicable)';

   (b) Point 12.7.2 is deleted.

2. Annex III, Part I, Section A is amended as follows:

   (a) Point 12.7.1 is replaced by the following:

   '12.7.1. vehicle equipped with 24 GHz short-range radar equipment: Yes/No/Optional (strike out which is not applicable)';

   (b) Point 12.7.2 is deleted.

3. Annex IX, on side two of all models of the Certificate of Conformity (COC), is amended as follows:

   (a) Point 50 is replaced by the following and a footnote is added as follows:

   '50. Remarks [1]:

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   [1] If the vehicle is equipped with 24 GHz short-range radar equipment according to Decision 2005/50/EC, the manufacturer must indicate here: "Vehicle equipped with 24 GHz short-range radar equipment".'

   (b) Points 50.1, 50.2 and 50.3 are deleted.

Article 3

Transposition

1. Member States shall adopt and publish, by 30 June 2006 at the latest, the laws, regulations and administrative provisions necessary to comply with this Directive. They shall forthwith communicate to the Commission the text of those provisions and a correlation table between those provisions and this Directive.

They shall apply those provisions from 1 July 2006.

When Member States adopt those provisions, they shall contain a reference to this Directive or be accompanied by such reference on the occasion of their official publication. Member States shall determine how such reference is to be made.

2. Member States shall communicate to the Commission the texts of the main provisions of national law, which they adopt in the field governed by this Directive.

Article 4

Entry into force

This Directive shall enter into force on the 20th day following its publication in the *Official Journal of the European Union*.

Article 5

Addressees

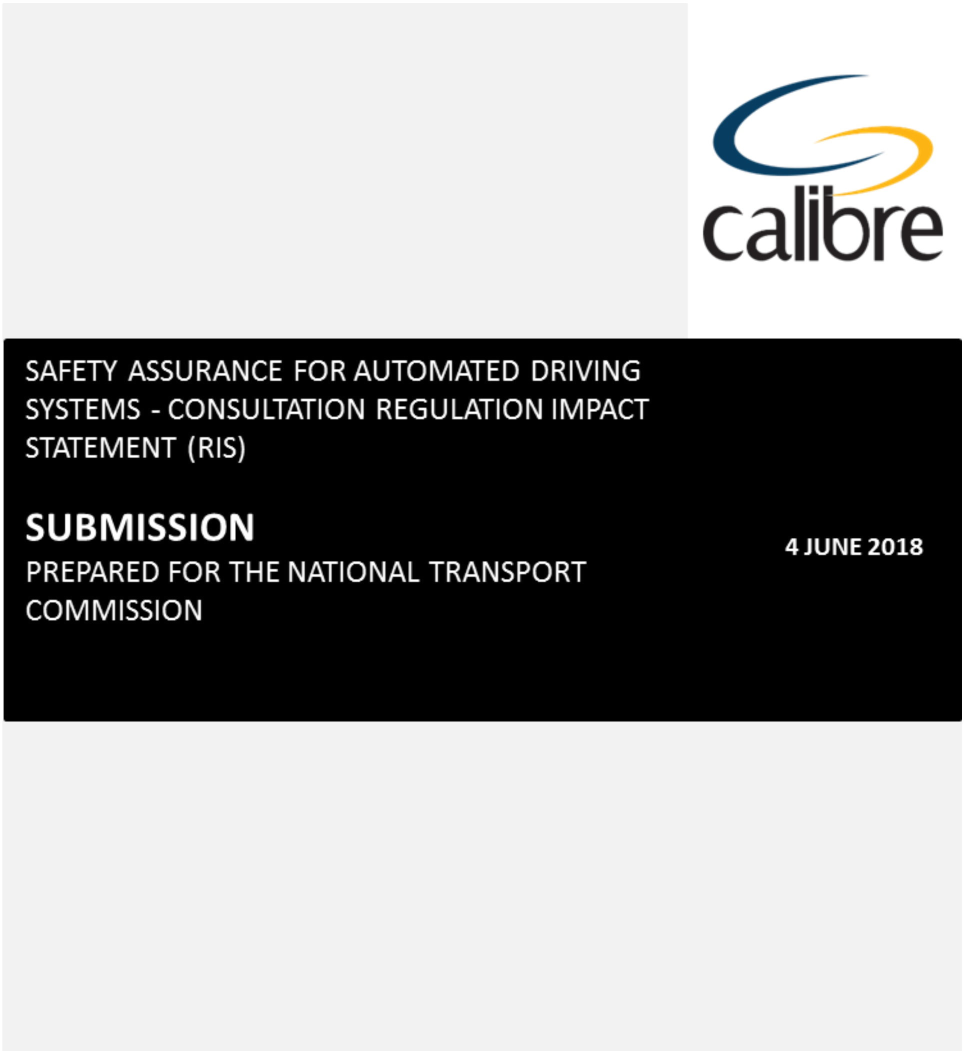
This Directive is addressed to the Member States.

Done at Brussels, 6 March 2006.

For the Commission
Günter VERHEUGEN
Vice-President

Annex F to
Calibre Group Submission to NTC
4 Jun 18

Generic Automotive (Tier 1) EMC Test Standard



calibre

SAFETY ASSURANCE FOR AUTOMATED DRIVING SYSTEMS - CONSULTATION REGULATION IMPACT STATEMENT (RIS)

SUBMISSION

PREPARED FOR THE NATIONAL TRANSPORT COMMISSION

4 JUNE 2018

A GENERIC AUTOMOTIVE (TIER1) EMC TEST STANDARD

Martin O'Hara
The Automotive EMC Network, P.O. Box 3622, Newport Pagnell, MK16 0XT

Abstract: The number of different EMC test standards available from the vehicle manufacturers (VM's) is large, disparate and often not always the most logical for the product under design or test. It can be particularly frustrating for an automotive application innovator to design a product to a suitable EMC standard that allows them to take the product around to the VM's prior to implementation on a vehicle itself. This is similarly true of aftermarket suppliers wishing to take their products directly into the VM's, but being either unsure of what tests or levels each VM will require, and being unable to justify on a speculative product the cost of testing to all the VM standards that they can obtain.

Presented here is a suggested "Generic Automotive Tier 1 Supplier EMC Test Standard", available as an open-source document, that is essentially derived from consideration of most of the larger VM EMC standards and compiled to give a "best fit" to all the data that was available to the author at the time of writing. The resulting standard is not as comprehensive as some of the VM standards, nor does it necessarily give any guarantee that meeting this standard will give a supplier easy or even easier access into a VM than any other route. What it provides is an independent perspective on what the most sensible EMC tests and test levels are, for a vehicle environment which meets the majority of VM requirements. The resulting test document gives the supplier a measure that they can present to a VM to demonstrate that their product can meet the basic VM requirements, and if not a particular full VM requirements first time, then at lower cost than a completely untested or e-mark only tested product.

The tests cover the supply of electrical products to a VM only and do not extend to whole vehicle testing, which remains exclusively the domain of the VM. The test methods employed are all based on international standards (CISPR and ISO) and the levels suggested are derived from the aggregated VM standard levels and frequency ranges.

Introduction

When I was designing satellite navigation and vehicle tracking products the management at my company would always ask if I could design the product to meet a VM standard, of course the answer was always "Yes, but to which VM standard?" The management had the belief that there was a mythical "Generic VM Standard" that would satisfy all VM's and hence make the product easier to get accepted as either a certified aftermarket product or as a line-fit item. A design to meet the Ford standard for example might meet the General Motors (GM) requirements for some test, but not others, ditto for BMW, Peugeot-Citroen (PSA), Daimler-Chrysler (DC) etc. Worse was that each VM not only have different test levels (otherwise it would have been easy to design for the worst), but they also have different frequency ranges and more problematic different methods of testing the same phenomena, for example BMW had no free field test method for radiated emissions in their standard at one point. Some VM standards also contain what might be considered as errors, such as using the IEC 61000 generic ESD test method rather than the automotive specific ISO 10605 methods.

There are significant cost implications in trying to meet multiple VM standards, both in the on-cost of additional design and circuits/components to meet all the requirements and in the test costs themselves. Some of these requirements are difficult to justify; will a radio from a Fiat car work in a BMW vehicle without problems? Of course, yet it is unlikely to have been designed or tested to anything like the same standards. There must be some middle ground where a series of sensible tests targeted at most, if not all, of the more stringent EMC specifications of the VM's can be collated. The tests must include all of the most pertinent phenomena; radiated emissions, radiated immunity, conducted emissions, conducted (transient) immunity and ESD, while avoiding the odd-ball tests that are specific to any single VM. This is what this paper set out to achieve, the output of which is an EMC Test Specification that can be adopted (or ignored) by suppliers wishing to gain VM tier 1 status but without having to over-design and over-test their product to prove its EMC capability to every individual VM's specification. Test service suppliers can also use the resulting specification as an open standard if their customers ask them the same question my management used to ask me. Essentially the result is as close as this author can get to the mythical "Generic VM EMC Standard".

Background

The background to this work was a study of the test specifications from all of the VM's that I could gain access to, this is relatively comprehensive (see references). I owe a debt of gratitude to many people who provided the necessary information for the compilation of this paper, including most VM's who gave me permission to discuss their standard even though they are not public domain documents. This impression of secrecy surrounding some VM EMC specifications is also another argument for an independent generic specification, but that in itself was not the driver for this work.

The task was divided into 5 specific test types (radiated and conducted emissions, radiated and conducted immunity plus ESD) and as already mentioned excludes any non-standard methods (i.e. non CISPR, ISO or EN referenced). While the number of test methods for each test type is not as exhaustive as some of the VM standards, the most commonly used methods are included so that there are some options available.

In-Vehicle Application Classification and Test Severity

One problem often encountered from outside a VM development is what severity level should be applied to a product? There are many levels available within most internationally recognised standards (CISPR and ISO typically having 5 severity levels) and very little information on which to apply. Most VM standards tend to have one or two severity levels only, the higher for power train and safety functions and the lower severity for comfort and convenience functions (some VM's do have as many as 4 application classifications and associated test levels). Here I have adopted the more common VM approach of using 2 of the published severity levels in the CISPR/ISO and suggest the higher severity is used in most applications.

Table 1: Application Classifications

Application Group	Typical In-Vehicle Applications
I	Powertrain and Safety: engine management unit (EMU), ABS, SRS, immobiliser, body control modules (BCM), exterior lighting, central locking, wiper controls
II	Comfort and Convenience: in-car entertainment (ICE), HVAC, telematics (satellite-navigation, phone-kit), instrument illumination, auto dimming mirrors

Failure Mode Severity Classification

There are again multiple definitions within VM specifications for the failure mode and its acceptability for specific application functions, however, I have adopted the failure classifications defined in the ISO standards (see appendix A for full listing). There are only 2 classifications within the 5 listed that will be used; class A for application group I products and class C for application group II products.

Table 2: Accepted ISO Test Classifications

Classification	Description
A	all functions of a device or system perform as designed during and after exposure to interference.
C	one or more functions of a device or system do not perform as designed during exposure but return automatically to normal operation after exposure is removed.

The distinction between classes A and B as defined in the ISO specification is very difficult to prove. It would require test equipment monitoring all the input-output parametrically to prove if a product is really passing at class A or B during the testing (i.e. in the EMC test facility). Therefore the reality is that these 2 classifications are never clearly identified and is assumed to be class A if a product continues to function throughout the test cycle without a functional deviation.

The classifications below class C are in my opinion all outright failures. In a vehicle nothing should require a user interaction to revert to normal operation, even non-critical features, hence only a selfrecovering temporary loss of function could be considered acceptable (for example losing radio reception while close to a radar installation).

Generic Test Methods and Levels

Where available the tests discussed as "generic" below are all based on the available international standards with no deviation from test conditions as defined in these standards. The VM specifications almost always make what initially appear as small deviations from some of the generic set-ups and conditions, maybe a slightly different harness length or pulse rise time and sometimes a different resolution bandwidth (RBW) for signal measurement. In providing a generic specification the tests noted here are all reverted to the original set-up of their base standard with no deviations in set-up or method. Some deviations for extended frequency or applied level may be made, but not for the set-up itself.

Radiated Emissions

The test set-up for most VM free-field radiated emissions is CISPR-25, but with most VM standards that is where the similarity ends. The most obvious deviation is the test limits, but many VM standards also deviate from the test frequency range as well. Several keep the banding of the CISPR-25 limits (i.e. have sections in the frequency range where no limit is applied) and some fill in these intervals with a variety of different methods (PSA for example adopt the limit level of the previous frequency range, but at a severity level less than the in-band level).

The situation can be further complicated by some VM specifications that do not include any free-field test, as well as making inter-VM comparisons difficult this also makes these manufacturers test results un-usable for e-mark testing (for which most CISPR-25 based tests will be suitable after the adoption of 2004/104/EC in July 2006).

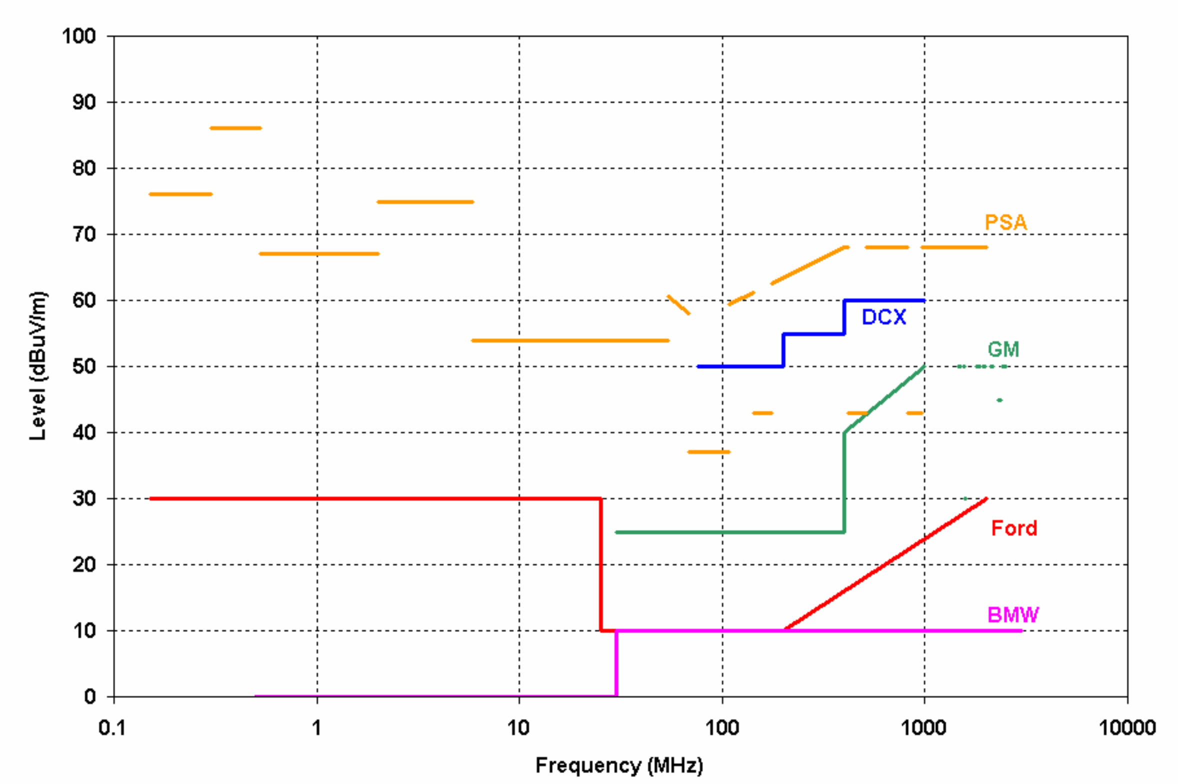


Figure 1: VM Radiated Emissions Limits

The graph (figure 1) shows the range and illustrates the significant variance in levels and frequency range, some of the differences can be explained by difference in RBW, but not all of them. The BMW test for example is significantly different from any other OEM test and is not based on the CISPR-25 test method. There are also some VM standards that simply use the CISPR-25 levels. These are not explicitly shown, except for the PSA limits that are based on level 3 of CISPR-25.

There is such a disparity between the frequency ranges and levels that it is very difficult to conceive of an easy common ground between VM tests. Even the usually common range between 30MHz and 1GHz has no common levels between any of the VM's listed. It should also be noted that the above are only the basic radiated emission and not the extended tests some of the VM's apply specifically for GPS and automotive radar applications for example.

Many of the tests extend to 2.5GHz or 3GHz, so cover the inclusion of Bluetooth and other wireless in-vehicle technologies, but undoubtedly future products will extend this to 5GHz and beyond. Even at 5GHz, only the first harmonic of Bluetooth is covered. At the low frequency end most VM's don't go below the CISPR-25 lower frequency of 150kHz.

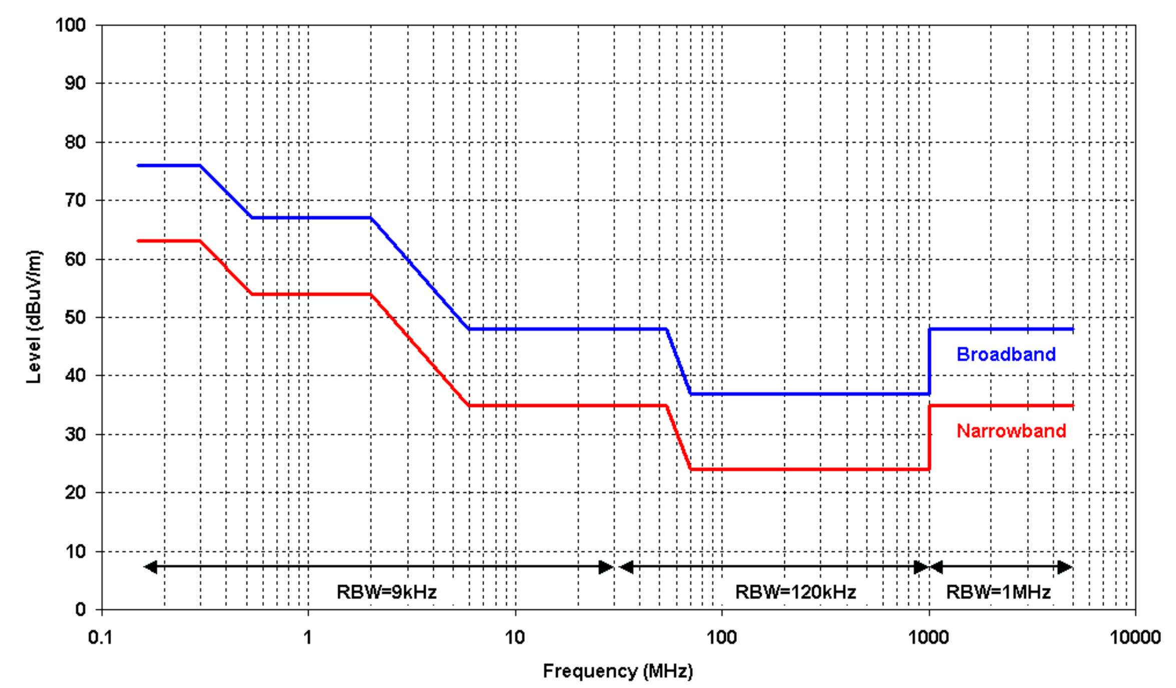


Figure 2: Generic Limits based on CISPR-25 Level 3

Since most VM's use the methods of CISPR-25, we have used the limits as well, using level 3 of CISPR-25 radiated emissions, without the omitted bands (see figure 2). This meets the PSA and DC requirements fully and covers the GM requirements above 420MHz. On first glance it would appear that the proposed generic limit does not meet the Ford specification at all, but due to the RBW used in the Ford specification (9kHz) the limits are not that dissimilar over the 5MHz-25MHz and above 70MHz (the same argument can be applied to the GM limits below 420MHz).

The above limits are also specified for testing at the CISPR-25 RBW filter sizes of 9kHz below 30MHz and 120kHz from 30MHz to 1GHz. CISPR-25 does not have a specified RBW above 1GHz but for expediency of the test over the 1GHz to 5GHz range a 1MHz RBW has been chosen with the corresponding increase in limit level of 11dB above the pre-1GHz level. It is worth noting that as in CISPR-25 we have not implemented a change in level at the 30MHz RBW change, this gives the limit just above 30MHz a significantly more stringent requirement that immediately below 30MHz, but this is done for consistency of method and application with CISPR-25 rather than any genuine test case reason.

Radiated Immunity

This is the test requirement that has the most numerous number of method employed in its application, not only in VM specifications but also within the international standards (ISO11452 has 7 parts, 1 general then 6 for different test methods). Many VM's do utilise the ISO 11452 test methods for some of the set-up and calibration, but most have significant deviations in many of the harness placement, lengths and placement of equipment under test and support equipment (as well as the usual frequency and level differences, see figures 3 and 4).

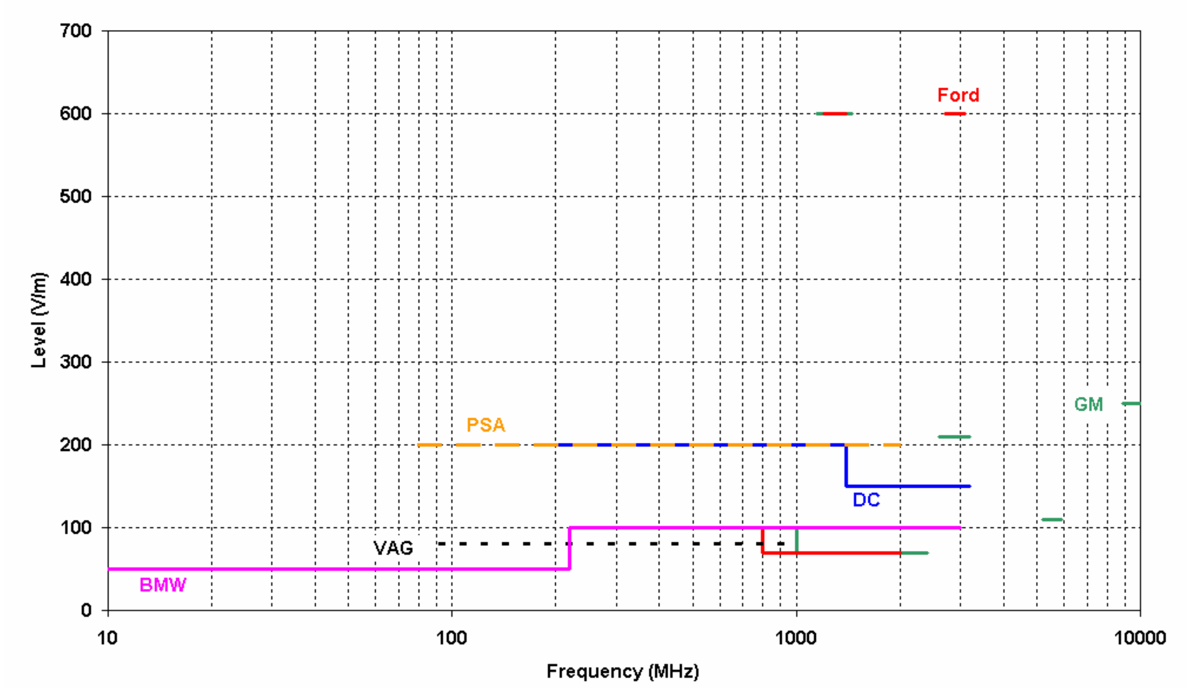


Figure 3: VM Free-Field Radiated Immunity Levels

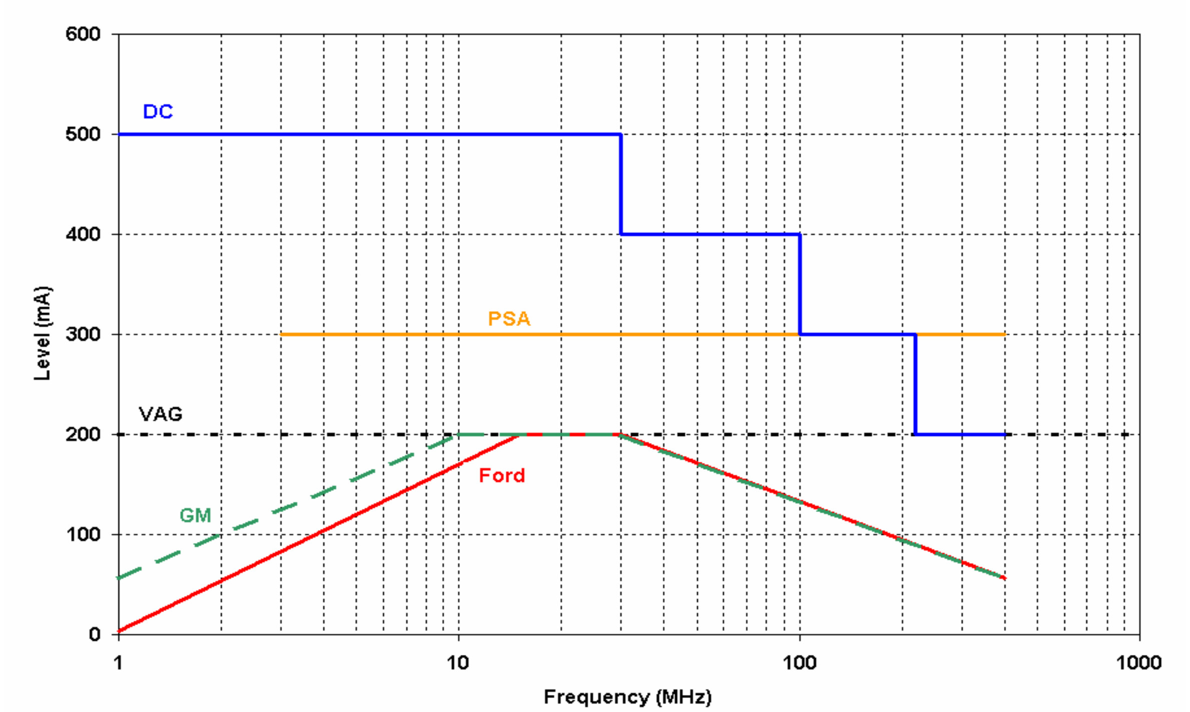


Figure 4: VM BCI Immunity Levels

Here we are only going to use 2 test methods; BCI for the lower frequency range (1MHz-400MHz) and free field (measured in an absorber-lined screened enclosure; ALSE) for higher frequencies (20MHz-5GHz). There is a considerable cross-over in these ranges, but this is to enable test costs to be optimised and at the same time keep an eye to the EU automotive directive and meeting its requirements with the same data. In practice what this means is that ALSE testing can commence at 200MHz rather than 20MHz if it is a lower cost option or there is some benefit to using BCI for the lower frequencies, but if ALSE testing can be performed down to 20MHz BCI testing may be omitted entirely.

Table 3: Generic Radiated Immunity Parameter Summary

Frequency Range (MHz)	Test Method	Modulation	Polarisation	Application Group I		Application Group II	
				Limit	Pass Criteria	Limit	Pass Criteria
1 - 400	ISO 11452-4: BCI	CM/AM	Not applicable	200mA	A	100mA	C
20 - 1000	ISO 11452-2: ALSE	CW/AM	Vertical & Horizontal	200V/m	A	100V/m	C
800 - 5000		PWM	Vertical				

The majority of VM requirements are met with these limits for ALSE, with the exception of the few higher limits of Ford and GM. The free-field limits also exceed the frequency range used by most, but this is to cover WiFi hotspots and some short-range roadside communications systems. The BCI limits likewise cover most VM requirements with the one exception of the higher DC limits at low frequency (DC are out of alignment with the other VM's here).

It should also be noted that the limits in figures 3 and 4 are the maximum limits used by the VM's and many have lower limits depending on the application or physical location in-vehicle. Some VM's have 4 separate application categories for radiated immunity and this can make determining the correct limits to apply difficult. Here we have used the 2 previous defined application groups and functional classifications of passes.

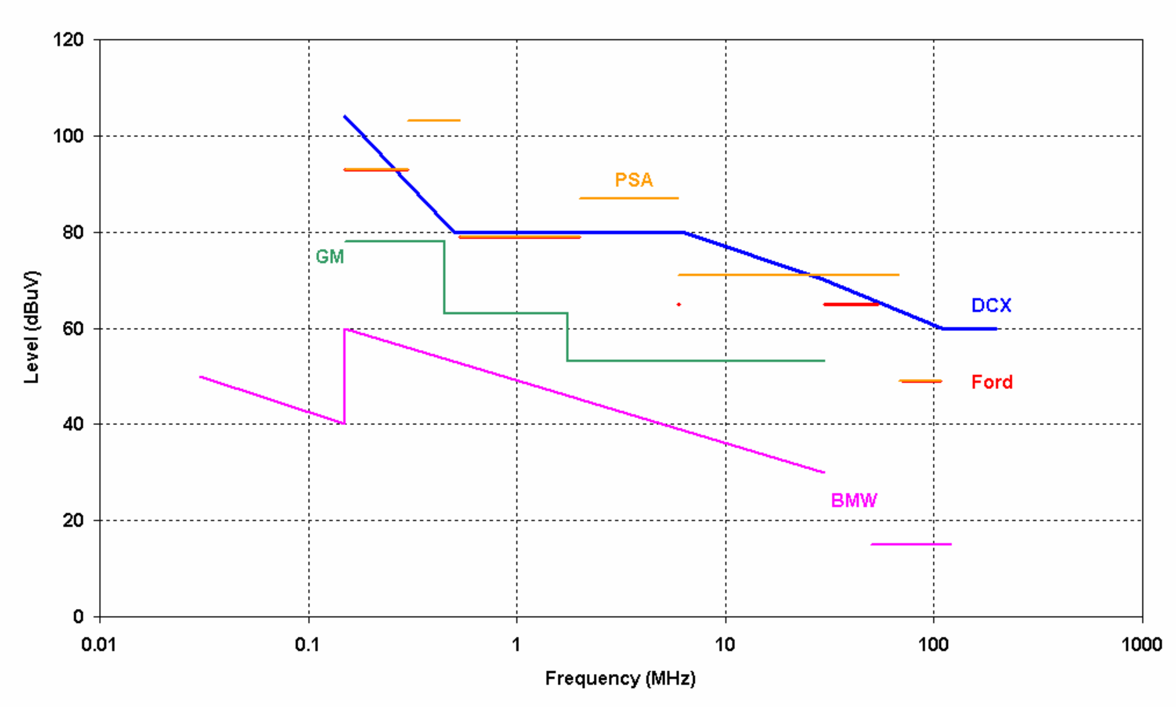


Figure 5: VM Conducted Emissions Limits

Conducted Emissions

The CISPR-25 test method for conducted emissions is almost universally adopted by VM's within their test specifications. The frequency range of 150kHz to 108MHz is generally maintained, with a few exceptions; DC go up to 200MHz and BMW start at 30kHz. Beyond this, however, nothing else appears a common commodity (see figure 5).

Both Ford and PSA use the limit levels from CISPR-25, but most other VM's apply different levels. It is possible that some of the other applied limits are similar, but is obscured by the use of different resolution bandwidth (RBW) filters applied across different frequency ranges. Even with the Ford and PSA standards, which both apply the level 3 limits of CISPR-25 for power line conducted emissions, PSA apply level 2 in the out-of-band ranges whereas Ford omit limits in the out-of-band regions. The lack of limits out-of-band in CISPR-25 is a strange omission for a VM specification and Ford are one of the few VM's that do not apply limits within these missing bands, although there is no consistency with the VM's on how these out-of-band regions are regulated.

The level 3 of CISPR-25 will also meet the DC levels and as well as PSA and Ford if simply linked directly across the out-of-band levels. The main problem with using this level is in failure to meet the GM specification, however the narrowband of level 3 is still lower than the GM limits. The GM limits are termed for spark generated and non-spark generated sources (not shown) hence not as clear-cut as the CISPR-25 limits or other VM definitions. The RBW of 10kHz for GM is similar to the CISPR-25, Ford, DC and PSA value of 9kHz for frequencies below 30MHz. A low RBW of 200Hz helps explain the lower limits below 150kHz for BMW and above 50MHz where BMW maintain a 9kHz filter, but the reason for such low values across the 150kHz to 30MHz range is difficult to explain. Having examined the powernet of these vehicles myself I can state that it is not possible to claim they are any quieter than other vehicle powernets.

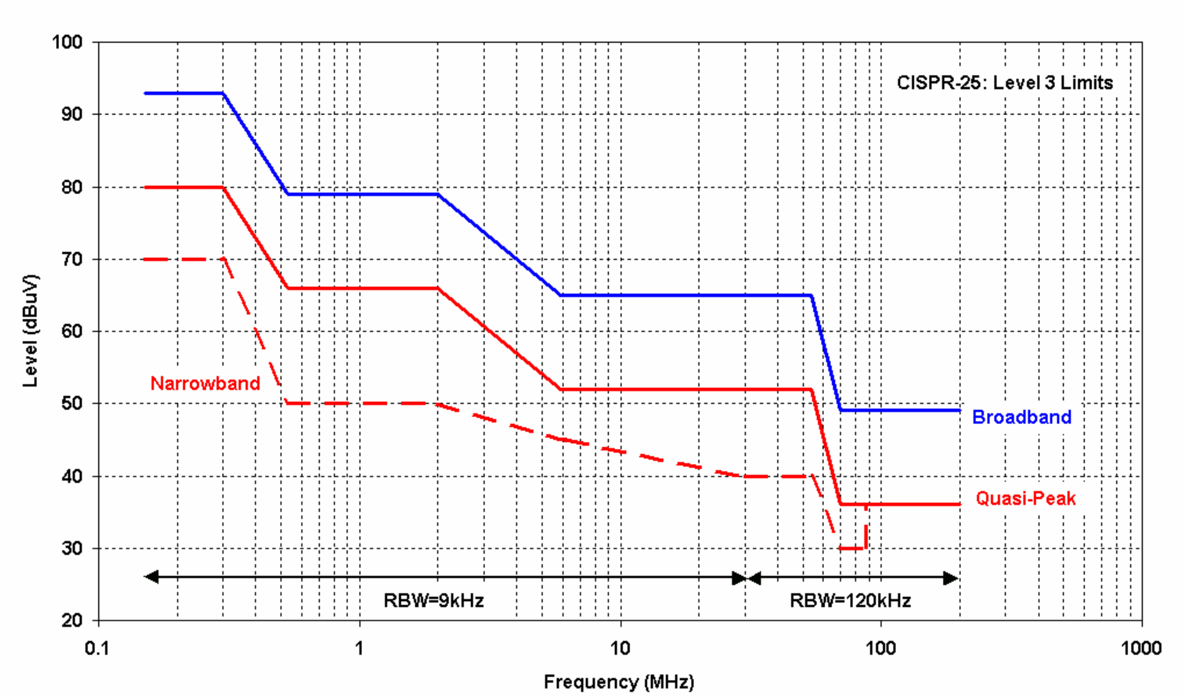


Figure 6: Generic Conducted Emissions Limits based on CISPR-25 Level 3

The pragmatic approach is therefore to adopt CISPR-25 level 3 without omitted bands (figure 6) and with the broadband and narrowband levels as they appear in the CISPR-25 document, while extending the upper test frequency limit to 200MHz to complete the DC requirement. The extension for DC may appear slightly at odds with the desire to minimise test costs, but including here adds only a few more minutes to a test sweep for the complete DC specification range and is a significantly lower cost than repeating the full test for this 108MHz to 200MHz extension.

The narrowband limits applied are in fact the quasi-peak limits from the appropriate table in CISPR-25 (table 6 of CISPR-25:2002) and not the quoted narrowband limits (table 7 of CISPR-25:2002), which are another 13dB lower and inconsistent with the definition of narrowband at the front of the CISPR-25 document (shown as dashed line in figure 6).

Conducted Transient Immunity

Conducted transient tests are one area it is easy to gain a consensus, the methods in the ISO 7637-2 standard have been around for over 15 years and were used before this by many VM's. These are basic good engineering tests for compatibility to the automotive electrical environment (powernet) as much as EMC specific tests. The biggest surprise is the relatively common set of pulse levels used, typically severity level 4 of ISO 7637-2 for pulses 1 to 4 (table 4).

Load dump, pulse 5, is the only signal that shows significant differences across the VM's and could be argued to be genuinely VM dependant. Some VM's will use some form of load dump suppression on their alternator (e.g. PSA, GM) whereas others clearly do not (e.g. Ford, BMW). It is probably also true that not all circuits within the vehicle need independent load dump handling capability, possibly the application group I products (Powertrain and Safety), but the group II (comfort and convenience) products could have a lower level applied (I think if you had a genuine load dump occurrence you wouldn't be too concerned that the radio stopped working).

Table 4: VM and Generic Transient Immunity Pulse Levels for ISO 7637-2 Pulses (values in Volts)

Pulse	GM	VAG	Ford	DC	PSA	BMW	Porsche	Generic
1	-100	-100	-100	-100	-100		-100	-100
2a	50	50	150	100	100		100	100
2b	10						100	10
3a	-150	-150		-150	-150	-112	-150	-150
3b	100	100		100	100	75	100	100
4	7	7			4.9	7.5	8	7
5	34		60		21.5	66.5	24	87 (I) 24 (II)

The chosen level adopted are from level IV of the ISO 7637-2 standard, with 2 exceptions. The first exception is the use of 100V for the pulse 2b to meet all but the Ford requirements. The ISO 7637 level IV setting for pulse 2b is 50V (as specified in the VAG and GM standards), this is relatively benign and even 100V is not especially onerous to meet. The other difference is the load dump (pulse 5) lower level for group II application circuits at 24V, in line with PSA and Porsche and close to the GM level.

Another difference is that the VM's usually change the majority of the pulse test parameters; rise times, pulse duration, etc. These deviations create the impression of a greater difference than really exist in these VM specifications and these are one test type that is often accepted by other VM's. The tests here use the mean of most of these additional test parameters and will be fully listed in the test specification document.

Electrostatic Discharge

ESD is considered the easiest EMC test method to get a reasonable consensus on across automotive VM's, however, there is still some significant discrepancies with some of the VM specifications. Notably DC and BMW use the standard derived for systems primarily connected to a domestic power supply (commercial EMC standard IEC 61000-4-2) rather than the ISO 10605 ESD standard that was derived specifically for the automotive environment.

There are many similarities in the 2 standards; they use the same type of ESD generator, the same voltage waveform and the same discharge tips. The differences are in the human body model (HBM) where the commercial standard uses a resistance of 330Ω compared to 2000Ω for the automotive standard. The HBM capacitance values are the same in each standard at 150pF and 330pF for air and contact discharge respectively, although some of the VM specify the same capacitance for both discharge methods. The resistance value is quite a significant difference and it should be remembered that the commercial standard is for a system that has an earth reference conductive discharge path (i.e. a path to the reference against which the static is measured), whereas in the automotive environment the discharge is really a charge transfer between two systems essentially isolated from the earth reference (body-to-vehicle). Not only do I feel the ISO 10605 standard is better for the automotive environment as a representative test, but for non-powered handling tests I would even encourage commercial testing to adopt ISO 10605 where the discharge is again charge transfer between isolated systems.

Table 5: VM Standards ESD Parameters

Vehicle Manufacturer	Handling (kV)		In-Vehicle (kV)		Human Body Model	Standard Referenced
	Contact	Air	Contact	Air		
BMW			±8	±15	150pF/330Ω	IEC 61000-4-2
DCX	±4	±8	±8	±25	150pF/330Ω	IEC 61000-4-2
Ford	±6	±8	±8	±25	330pF/2000Ω	ISO 10605
GM	±6	±8	±8	±25	150pF/2000Ω	ISO 10605
Porsche	±8	±25	±15	±25	150pF/2000Ω	ISO 10605
PSA	±4	±30	±8	±15	150/330Ω & 330pF/2000Ω	IEC 61000-4-2 & ISO 10605
Renault			±8	±15	330pF/2000Ω	ISO 10605
VAG	±8	±15		±25	150pF/330Ω	IEC 61000-4-2

The main differences therefore between VM standards are the levels at which tests are applied, and sometimes the number of pulses (between 3 and 10) and tests types (e.g. air, contact, powered and unpowered/handling). Here I have used both test scenarios and discharge methods and set the limits at a relatively high level to satisfy the majority of VM test requirements. The 2 application categories are treated the same since the powertrain and safety critical products are not directly accessible by the vehicle occupants. Consequently, although they tend to have a higher test requirement, the powertrain and safety critical products are unlikely to see any direct ESD during functional operation. Conversely the comfort and convenience functions are usually in the cabin and have directly accessible controls and as such are more likely to suffer a direct discharge during operation.

Table 6: Generic ESD Test Parameters

Test	Discharge	Network	Test Severity Level	No. of Discharges	Functional State
Unpowered or Handling	Contact	150pF/2kΩ	±8kV	5	A (I) C (II)
	Air	330pF/2kΩ	±15kV		
Powered	Contact	150pF/2kΩ	±8kV		
	Air	330pF/2kΩ	±25kV		

Tests may gradually be raised to the values shown in the above table in steps suggested in ISO 10605.

Although only 5 discharges are required (in both positive and negative polarities), this is for any single pin or any discharge point. The higher requirement of 10 used by some VM's can result in an excessively long tests where there are multiple pins to discharge to (30 pins is not uncommon) and retest after each discharge or even series of discharges will add to the overall test costs. A period of between 1s and 10s between discharges, as per ISO 10605, should be observed.

Other Test Possibilities

The tests presented here are the most common ones used throughout the automotive industry, however, they do not include some of the common test methods such as TEM cell and stripline testing. These may be introduced at a later stage should the cost prove prohibitive for radiated immunity in particular, however, part of the purpose of this work was to reduce the number of test methods to a manageable common set, in that respect adding more tests is counter productive.

The most likely new addition would be the use of reverberation chamber testing for high frequency radiated immunity (and even emission) to cover the 5GHz-18GHz range. Free-field testing in this region would be extremely expensive at high field. Similarly pulsed mode testing at specific frequencies (e.g. 24GHz and 77GHz for adaptive cruise control and collision avoidance radar) could also be a future additional test method, should a near consensus be achievable between VM's.

Further Test Information

The resulting test regime suggested here needs more information to fully be used as a test specification, there are numerous parameters such as step size for radiated emissions testing and all the pulse parameters for transient immunity that need defining, however that is beyond this papers scope, but will be included in the test document once that is completed. The tests generally meet the majority of the VM test requirements, although not all. The tests included here also meet (exceed) the requirements of the new EU automotive EMC directive (2004/104/EC), hence results can be used to submit for e-mark certification.

Summary

The "big 3" US VM's (Ford, GM and DCX) have already recognised the potential benefits of a common standard for EMC tests and have been working to align their methods over the last 3 or so years. However, there are vested interests and a speed of response that does not always meet with market demand for change. Although some progress has been made, many independent commentators, particularly from test service providers, still note significant differences between what these VM's require. On the same note Ford is still the only VM that publicly make their EMC standard freely available (www.fordemc.com). The apparent "secrecy" surrounding other VM EMC requirements continues to suggest a lack of commonality. Some EMC specifications, the Japanese VM's in particular, are difficult to obtain information from even if you are a Tier 1 supplier, hence it can be almost impossible to gain an insight into what might be required.

It was suggested by some of the reviewers of this paper that it would mainly be useful as a comparison of VM standards, but this has been done several times before and to what aim? Simply to highlight the disparities in the VM marketplace? What I wanted to provide here is a possible solution to some of these disparities, a "middle way" through the minefield of VM standards that gives the reader something other than a simple and long list of VM tests and levels. At the same time I recognise that there is no authority in this work to adopt any of the recommendations made here. It is therefore left open to the industry to determine even if such a "middle way" is required, or if the existing methods of struggling along with a plethora of different, and often difficult to obtain, test standards is adequate. Maybe my example of being asked for the mythical "Generic VM EMC Standard" was an isolated case, but I believe not and hope someone will find the output of this work useful.

Conclusion

The results presented here and the suggested test levels will not guarantee any supplier access to every VM or even any particular VM. They are presented as a best "middle way" that gives a very good indication of likelihood of VM compliance while minimising the number and cost of EMC testing required. While obviously I commend them to the Tier 1 and test service suppliers, in particular as a solution for speculative developments and/or aftermarket designs hoping to eventually obtain line-fit acceptance.

Caveat

I should stress that there has been no direct VM input to this work and that the VM's themselves do not have any vested interest in any other than their own EMC standards.

Appendix A: ISO Failure Mode Severity Classification

All classifications given below are for the total device/system functional status.

Note: The word "function" as used here concerns only the function performed by the electronic system.

Class A: all functions of a device or system perform as designed during and after exposure to interference.

Class B: all functions of a device/system perform as designed during exposure; however, one or more of them may go beyond the specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain class A.

Class C: one or more functions of a device or system do not perform as designed during exposure but return automatically to normal operation after exposure is removed.

Class D: one or more functions of a device or system do not perform as designed during exposure and do not return to normal operation until exposure is removed and the device or system is reset by a simple "operator/use" action.

Class E: one or more functions of a device or system do not perform as designed during and after exposure and cannot be returned to proper operation without repairing or replacing the device or system.

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Biographical Notes

Martin O'Hara is the founder of the Automotive EMC Network and the Automotive EMC Conference organiser. Author of "EMC at the Component and PCB Level" and numerous papers on EMC and circuit design. Martin has previously designed satellite navigation systems, vehicle tracking products and traffic information devices for Trafficmaster PLC and prior to that was Electronic Technologist at Motorolas' Automotive division in their European Design Centre. Now Technical Director for Danfoss Randall Ltd.