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# Situationally Aware Innovative Battery Management System for Next Generation Vehicles

# InnoBMS - Deliverable report

## D1.1 - Requirements and interface definition

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| **Author(s)** | Andrey Vasilyev (PTE), Eray Altun (FMF) | 2024/06/28 |
| **Checked by** | Chandra Shekhar Tiwari (PTE) | 2024/06/28 |
| **Reviewed by** | Rich Devenport (PTE), Neeta Khare (FMF) | 2024/06/28 |
| | Dr. Sajib Chakraborty (VUB) | 2024/07/10 |
| **Coordinator** | Prof. dr. ir. Omar Hegazy (VUB) | 2024/06/28 |

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Project summary
The core objective of InnoBMS is to develop and demonstrate (TRL6) a future-ready best-in-class BMS hard- and software solution that maximizes battery utilization and performance for the user without negatively affecting battery life, even in extreme conditions, whilst continuously maintaining safety. Concretely, the InnoBMS proposal will deliver a 12% higher effective battery pack volumetric density, a 33% longer battery lifetime and a demonstrated lifetime of 15 years. The results will be demonstrated using novel testing methods that give a 36% reduction in the testing time of a BMS. The results will be demonstrated in two use cases, one light commercial vehicle (Fiat Doblo Electric) and one medium-duty van (IVECO eDaily). The key outcomes will enable a cost reduction of 12% and 9.7% for passenger cars and light-duty vehicles, respectively. The core objective will be achieved through five technical objectives. 1) advanced hybrid physical and data-driven models and algorithms to enable a flexible and modular BMS suitable for a wide range of batteries. 2) Software for a fully connected and fully wireless BMS that acts as a communication server inside the vehicle E/E-architecture, the center of connection, on-board diagnostics and decision-taking for all battery-related information. 3) A scalable, fully wireless and self-tested BMS hardware that enables using different battery sizes at different operating voltage levels, and smart sensor integration. 4) Better battery utilization and exploitation using cloud-informed strategies and procedure. 5) A heterogeneous simulation toolchain and automated test methods.

# Publishable summary

The core objective of InnoBMS project is to develop and demonstrate (TRL6) a future-ready, best-in-class BMS hardware and software solution that maximizes battery utilization and performance for the user without negatively affecting battery life, even in extreme conditions, while continuously maintaining safety.

InnoBMS leverages on seven work packages, with WP1 identifying and selecting the relevant requirements and specifications for advanced sensors, wireless cell monitoring and balancing (CMBs), BMS components (including edge, software, and hardware), and the potential use with a second-life battery. Additionally, WP1 defines base use cases and targeted test cases for InnoBMS, to validate the key outcomes for passenger car and light-duty vehicle applications. WP1 establishes relevant usage scenarios for vehicle-to-grid (V2G) applications for both vehicle types. WP1 ensures regular alignment of the subsequent WP outputs and in the final stage, impact assessment and synthesis of project results. WP1 comprises four tasks and this deliverable report D1.1 is a direct output of *Task 1.1: Requirements and interface definition*, led by FMF.

This deliverable report, D1.1, presents detailed requirements for all the features and interface definitions for this project. The process begins with defining the beyond state-of-the-art InnoBMS, discussing the Requirement engineering and management concepts, interfaces and then the details of the feature requirements followed by the conclusions and possible risks.

# Contents



# List of Figures



## List of Tables

Abbreviations & Definitions

| Abbreviation | Explanation |
|---|---|
| AC | **Alternating Current** |
| **BMS** | Battery Management System |
| **C** | Charging rate |
| **CH** | Charge (direction) |
| **CV** | Commercial Vehicle |
| **DC** | Direct Current |
| **DCH** | Discharge (direction) |
| **DOD** | Depth of Discharge |
| **EFC** | Equivalent Full Cycles |
| **EHS** | Extra High Speed segment of WLTC |
| **eLCV** | Electric Light Commercial Vehicle |
| **EOL** | End of Life |
| **EV** | Electric Vehicle |
| **HS** | High Speed segment of WLTC |
| **HW** | Hardware |
| **KPI** | Key Performance Indicator |
| **LCV** | Light Commercial Vehicle |
| **LS** | Low Speed segment of WLTC |
| **MS** | Medium Speed segment of WLTC |
| **PC** | Passenger Car |
| **SOC** | State of Charge |
| **SOH** | State of Health |
| **SW** | Software |
| **UC** | Use Case |
| **V2B** | Vehicle to Building |
| **V2G** | Vehicle to Grid |
| **V2H** | Vehicle to Home |
| **V2X** | Vehicle to everything |
| **WLTC** | Worldwide Harmonized Light Vehicles Test Cycle |

# 1 Introduction

The beyond State-of-the-art InnoBMS development for Electric vehicles will follow the V-model of the Systems Engineering and it can't happen without the requirements of this full System being understood and listed. This System engineering approach will also involve understanding of the interfaces between the sub-systems and the components. This becomes even more important if the development is being done by different stakeholders and then to be integrated. This document addresses the same and defines the high-level requirements and interfaces.

The requirements are grouped according to the features/functions of this development. The following sections will detail definitions, interface and the process of Requirement engineering and management used for this Project.

## Definition of the Beyond State-of-the-art InnoBMS

The Beyond state-of the-art InnoBMS is the product(s) which will include BMS features from Tesla and Rivian, currently available BMS other than these two plus advanced functionalities such Pressure, EIS, and gas sensing.

## Interfaces

Based on the workflow and development diagram shown in Figure 1-1.

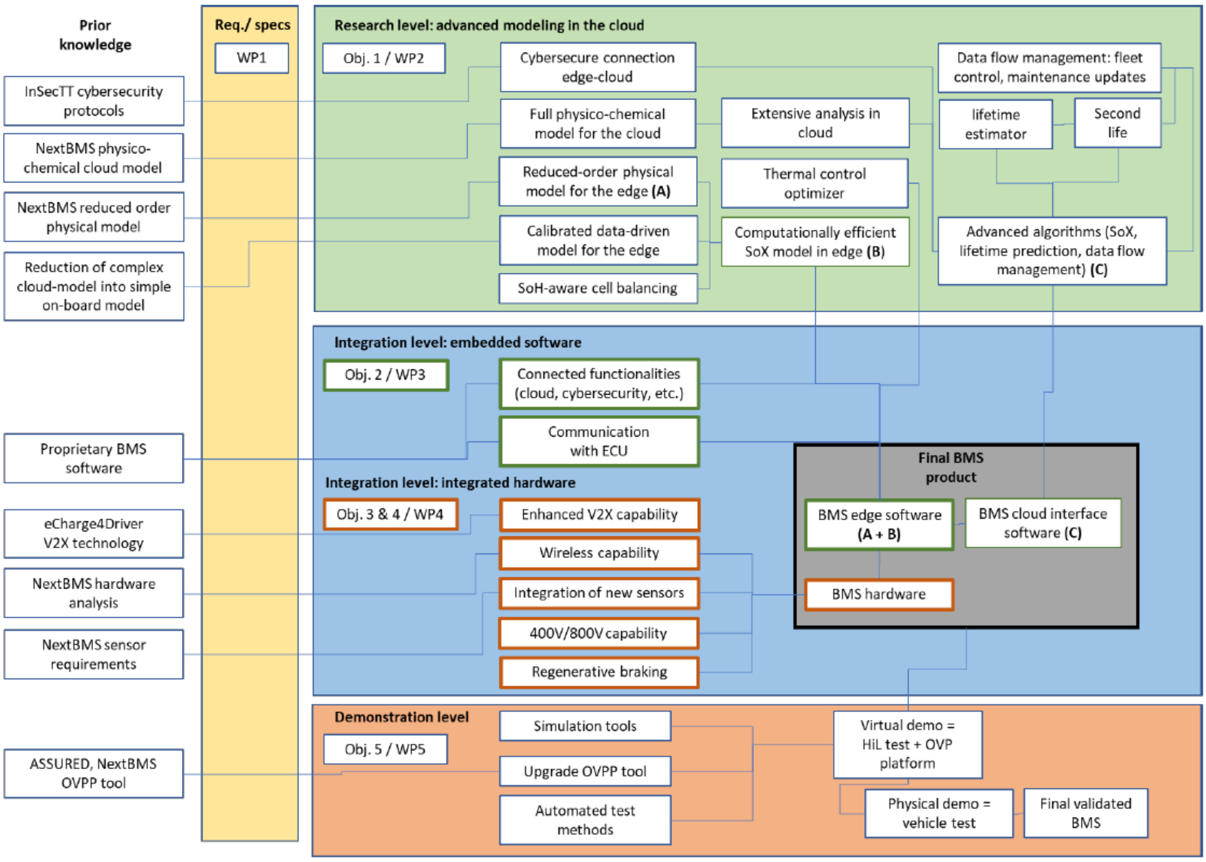


*Figure 1-1 InnoBMS workflow and development.*

We have identified the interface diagram shown in Figure 1-2.

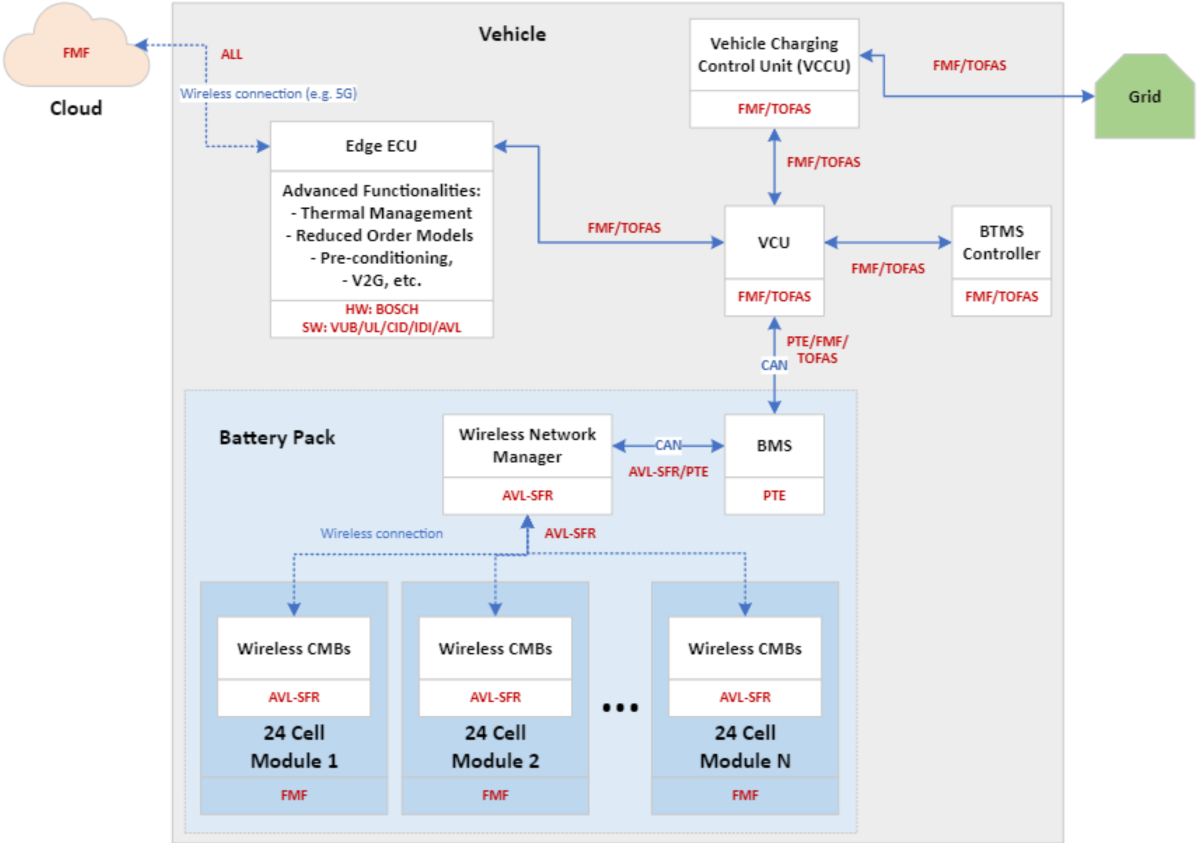


*Figure 1-2 InnoBMS interface block diagram*

# 2 Requirements Engineering and Management

## 2.1 Background

Requirements Engineering (RE) refers to the process of defining, documenting, and maintaining requirements for the sub-fields of systems engineering and software engineering. RE is the first step of a product development lifecycle process depicted in Figure 2-1 [1].

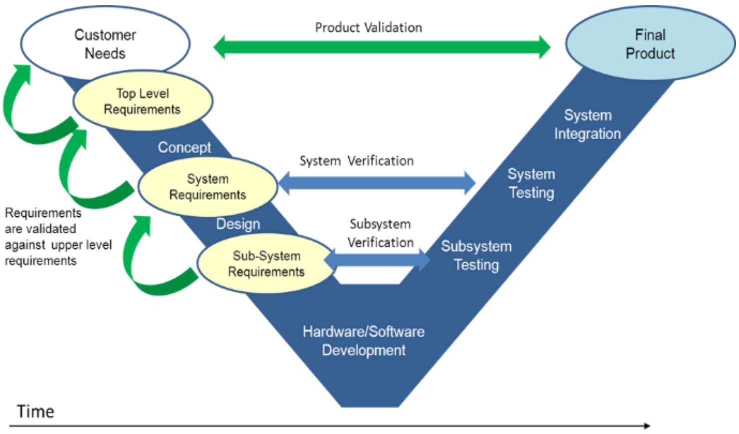


*Figure 2-1 Product Development Life-Cycle V model*

## 2.2 Procedures

The requirements development process adopts eight (8) steps shown in Figure 2-2 below:

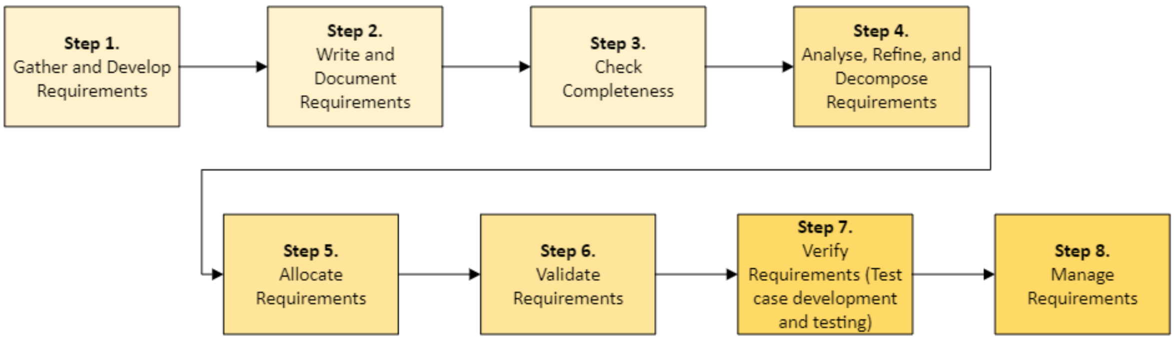


*Figure 2-2 Requirements Development Process*

In order to enable the execution of these steps, a requirement management tool is needed. There are several dedicated requirement management tools available on the market including IBM Doors NG, SpiraTest, and Polarion, however, each of these tools requires purchasing licenses by all partners and, therefore, is deemed unsuitable for this project. Instead, a spreadsheet-based approach was chosen with Excel as the tool.

## 2.3 Requirement Template

A requirements template was setup in the form of a table where each row represents individual requirements, and the columns represent their attributes. An attribute schema was selected based on the information needed to be captured for the stakeholders. The following requirement attributes were defined in this project:

- Requirement ID: unique and immutable identifier to enable requirement traceability and management.
- Status: selected from ‘In Review’, ‘Accepted’ or ‘Rejected’ to specify the stage of the requirement lifecycle.
- Type: indicates whether the requirement is ‘Functional’, ‘Non-Functional’ or ‘Safety’
- Additional Details: contains any additional details that are not needed to be included in the main body of the requirement.
- Function Name: specifies the name of the function a requirement is describing.
- Function Details: any further elaborations on the system functionality
- Author: Name and association of the requirement author
- Source: Describes the origin of the requirement or where did it come from.

Three levels of requirement decomposition were defined for the Feature Level (L1), System Level (L2) and Component Level (L3). Requirements at each level are represented in separate tables for each level of decomposition.

Such a tabular approach to data set management enables implementation of multiple views:

- Selective view by applying filtering and sorting to narrow down the dataset to a specific function or a particular status.
- Aggregate view via PivotTables to obtain an overview of the entire requirement dataset.

Various templates for writing natural language requirements have been proposed by various authors. For example, standard ISO29148 defines the following structure [2] [3] [4]:
**[<Precondition>] <Subject> <Action> <Object> [<Restriction>]**

# 3 Results & Discussion

## 3.1 Results

Tables 1, 2 and 3 provide a summary of the number of requirements at each level of decomposition. Full list of requirements is included in Appendix B.

*Table 1 - L1 (Feature Level) Requirements*

| Function Name | Count of Req ID |
|---|---|
| AC-DC Charging | 1 |
| Battery Models - Advanced Functionality & ROM | 11 |
| Battery models - Data driven models [Cloud] | 6 |
| Battery Models - SoX Edge estimator | 5 |
| BMS & VCU communication | 8 |
| Degradation-aware pre-conditioning functionality in the VCU | 6 |
| Enhanced V2G & G2V functions | 10 |
| High Voltage Compatibility | 9 |
| OTA Updates | 4 |
| Regenerative Braking | 3 |
| Secure Data transmission V2C | 22 |
| State of Safety (SOS) | 2 |
| Thermal management Vehicle & Cloud | 13 |
| V2C & C2V communication and interfaces | 4 |
| Virtual e-vehicle simulator | 4 |
| Wireless capability | 3 |
| **Grand Total** | **111** |

*Table 2 - L2 (System Level) Requirements*

| Function Name | Count of Req ID |
|---|---|
| Battery Models - Advanced Functionality & ROM | 7 |
| Battery Models - Data Driven models [Cloud] | 11 |
| Battery Models_SoX Edge estimator | 11 |
| Enhanced V2G & G2V functions | 8 |
| High Voltage Compatibility | 3 |
| State of Safety (SOS) | 8 |
| Thermal management Vehicle & Cloud | 21 |
| V2C & C2V communication and interfaces | 3 |
| Virtual e-vehicle simulator | 7 |
| Wireless Communication | 3 |
| **Grand Total** | **82** |

*Table 3 - L3 Requirements*

| Function Name | Count of Req ID |
|---|---|
| **Battery Models - Advanced Functionality & ROM** | 2 |
| **Battery Models - Data Driven models [Cloud]** | 5 |
| **Battery Models_SoX Edge estimator** | 6 |
| **Virtual e-vehicle simulator** | 1 |
| **Grand Total** | **14** |

## 3.2 Contribution to project (linked) Objectives

This deliverable contributes to all of the InnoBMS objectives as it sets up the requirement processes, list down all the features and their requirements.

## 3.3 Contribution to major project exploitable result

This deliverable is in-line with the required project targets by listing down all the requirements and interfaces for this development for the InnoBMS project

# 4 Conclusion and Recommendation

The development of a beyond state-of the art InnoBMS Battery Management System (BMS) for electric vehicles represents a significant step forward in addressing the critical challenges associated with battery performance, safety, security, and longevity.

This report has outlined the key requirements for this project, including its features, and interfaces. By leveraging advanced algorithms, additional sensors, wireless capabilities etc., this innovative product could be the product of the future Electric vehicles and a system capable of optimizing battery performance and extending the operational life of the battery pack.

# 5 Risks and interconnections

## 5. 1 Risks/problems encountered

There is no significant risk identified at this juncture of the project, but it has been observed that if the requirements, boundaries, communication between the devices and the responsibilities for the stakeholders are not clearly defined, then this could lead to the project delays and conflicts between the stakeholders during the development.

## 5.2 Interconnections with other deliverables

Based on the results of this WP, the requirements will follow through all the Work Packages.

# 6 Deviations from Annex 1

No deviations.

# 7 References

[1] INCOSE, INCOSE Systems Engineering Handbook Fifth Edition.

[2] INCOSE, *Guide to Writing Requirements,* 2023.

[3] ISO29148, *Systems and software engineering — Life cycle processes — Requirements engineering,* ISO, 2018.

[4] "Systems Engineering Body of Knowledge (SEBoK)," 06 2024. [Online]. Available: https://sebokwiki.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_(SEBoK).

# 8 Acknowledgement

## The consortium

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

**Project partners:**

| # | Partner short name | Partner Full Name |
|---|---|---|
| **1** | VUB | Vrije Universiteit Brussel |
| **2** | TOFAS | TOFAS Turk Otomobil Fabrikasi Anonim Sirketi |
| **3** | BOSCH | Robert Bosch GmbH |
| **4** | AVL | AVL List GmbH |
| **5** | AVL-SFR | AVL Software and Functions Gmbh |
| **6** | IDIADA | Idiada Automotive Technology SA |
| **7** | CID | Fundacion Cidetec |
| **8** | UL | Univerza v Ljubljani |
| **9** | THIL | Tajfun Hil Društvo sa Ograničenom Odgovornošću za Istraživanje, Proizvodnju, Rgovinu i Usluge Novi Sad |
| **10** | UNR | Uniresearch BV |
| **11** | FMF | FPT Motorenforschung AG |
| **12** | PTE | Potenza Technology Limited |

## Disclaimer/ Acknowledgment



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# 9 Appendix B – Requirement Tables

## L1 Requirements

| Function Name | Req ID | Requirement Description |
|---|---|---|
| High Voltage Compatibility | InnoBMS-L1-R001 | The Electronic and Electrical Components shall comply with road going electrical safety standards |
| High Voltage Compatibility | InnoBMS-L1-R002 | The InnoBMS shall prevent ingress of pollutants to electrical components |
| High Voltage Compatibility | InnoBMS-L1-R003 | The Electrical and Electronic Components shall operate at an altitude =<5km above sea level |
| High Voltage Compatibility | InnoBMS-L1-R004 | The InnoBMS shall have a HV working voltage of >=340V & =<850V. |
| High Voltage Compatibility | InnoBMS-L1-R005 | The Electronic and Electrical Components shall galvanically isolate High and Low Voltage circuits |
| High Voltage Compatibility | InnoBMS-L1-R006 | The InnoBMS shall raise an alarm on the BMS to Vehicle Interface, when isolation between High and Low Voltage is not maintained |
| High Voltage Compatibility | InnoBMS-L1-R007 | The InnoBMS shall transmit compatible High Voltage reporting signals over the BMS to Vehicle Interface |
| High Voltage Compatibility | InnoBMS-L1-R011 | The battery pack used for the InnoBMS project shall have high voltage isolation |
| High Voltage Compatibility | InnoBMS-L1-R012 | The demonstrator vehicle in InnoBMS shall have appropriate grounding between the battery pack and the vehicle body |
| Secure Data transmission V2C | InnoBMS-L1-R034 | All software running on a device shall be maintained by applying regular security updates |
| Secure Data transmission V2C | InnoBMS-L1-R033 | All software running on a device shall impose rate limiting |
| Secure Data transmission V2C | InnoBMS-L1-R032 | All software running on a device shall sanitize any input |
| Secure Data transmission V2C | InnoBMS-L1-R031 | All software running on a device, should apply the principle of least privilege |
| Secure Data transmission V2C | InnoBMS-L1-R030 | The system may be hardened by using a specialized, hardened kernel |
| Secure Data transmission V2C | InnoBMS-L1-R029 | The system shall be hardened by activating regular security updates, if available |
| Secure Data transmission V2C | InnoBMS-L1-R022 | The system shall be hardened by deactivating unneeded interfaces |
| Secure Data transmission V2C | InnoBMS-L1-R023 | The system shall be hardened by deactivating unneeded system accounts and changing the default credentials for needed ones |
| Secure Data transmission V2C | InnoBMS-L1-R026 | The system shall be hardened by enforcing the use of secure passwords |
| Secure Data transmission V2C | InnoBMS-L1-R024 | The system shall be hardened by issuing minimal possible privileges and file permissions for user and system accounts in general |
| Secure Data transmission V2C | InnoBMS-L1-R025 | The system shall be hardened by providing Anti-DoS and brute force measures |
| Secure Data transmission V2C | InnoBMS-L1-R028 | The system shall be hardened by using application whitelisting |
| Secure Data transmission V2C | InnoBMS-L1-R027 | The system shall be hardened by using basic network defence concepts |

| | | |
|---|---|---|
| Secure Data transmission V2C | InnoBMS-L1-R035 | The system shall use Identity Management |
| Secure Data transmission V2C | InnoBMS-L1-R019 | When sending data to external sources, the system shall provide ISO 21434 CAL4 Readiness |
| Secure Data transmission V2C | InnoBMS-L1-R018 | When sending data to external sources, the system shall use a True Random number Generator (NIST conform) |
| Secure Data transmission V2C | InnoBMS-L1-R016 | When sending data to external sources, the system shall use Key Exchange ECDHE on NIST curves (P-256, P-384, and P-512) |
| Secure Data transmission V2C | InnoBMS-L1-R017 | When sending data to external sources, the system shall use Key Management according to NIST SP 800-57 |
| Secure Data transmission V2C | InnoBMS-L1-R020 | When sending data to external sources, the system shall use Segregation measures between internal and external network interfaces (physically different adapters) |
| Secure Data transmission V2C | InnoBMS-L1-R014 | When sending data to external sources, the system shall use Symmetric Encryption/Authentication with AES-128 or AES-256 in GCM or CCM cipher modes |
| Secure Data transmission V2C | InnoBMS-L1-R015 | When sending data to external sources, the system shall use Symmetric Signatures with HMAC-SHA2-S56 |
| Secure Data transmission V2C | InnoBMS-L1-R021 | When storing data, the system shall provide cryptographic protection |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R036 | The reduced-order battery models shall use computationally efficient algorithms |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R037 | The reduced-order battery models shall be hardened against unauthorized use. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R038 | The reduced-order battery models shall communicate with sensors and cloud and BMS |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R039 | The reduced-order battery models shall be capable of simulating different battery chemistries, configurations, and operating conditions. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R041 | The reduced-order battery models shall ensure computational efficiency and scalability of battery models to handle large-scale deployment and real-time simulation. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R042 | The reduced-order battery models shall generate comprehensive outputs including cell voltage, state of charge (SoC), state of health (SoH), spatially resolved potentials, power loss, and Li/Li+ concentration profiles. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R043 | The reduced-order battery models shall Integrate battery models with cloud services for seamless deployment, monitoring, and analysis of battery performance data. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R044 | Vehicle-to-cloud communication shall employ encryption and authentication mechanisms to ensure data integrity and privacy. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R045 | The system shall have a robust data management infrastructure to store, process, and analyse incoming vehicle data and simulation results. |

| | | |
|---|---|---|
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R046 | Ensure accurate transmission and reception of battery data to prevent erroneous simulations. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L1-R047 | Implement error detection and correction mechanisms to maintain data integrity. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R048 | The cloud model must be able to communicate with the fleet control system for maintenance updates. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R049 | The vehicle usage data shall be stored and analysed in the cloud. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R050 | The cloud shall be a platform for a "digital twin" of the battery, enabling complex calculations and analysis that wouldn't be feasible in the vehicle itself. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R051 | The cloud model shall predict the remaining driving range based on real time data  and vehicle conditions. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R053 | The cloud shall generate alerts and notifications for critical failures and recommended maintenance actions. |
| Battery models - Data driven models [Cloud] | InnoBMS-L1-R054 | The cloud model should be updatable over-the-air (OTA) to integrate new algorithms |
| Battery Models - SoX Edge estimator | InnoBMS-L1-R055 | SoX edge algorithm shall provide a real time estimation of SoC, SoH and SoP |
| Battery Models - SoX Edge estimator | InnoBMS-L1-R056 | SoX edge algorithm shall be computationally suitable to run on-board in the edge BMS hardware. |
| Battery Models - SoX Edge estimator | InnoBMS-L1-R057 | SoX edge algorithm requires to compute an accurate battery model based on electrical equivalent circuits. |
| Battery Models - SoX Edge estimator | InnoBMS-L1-R058 | Algorithm shall be able to receive model parameters values as an input so they can be updated from other sources (i.e. cloud information). |
| Battery Models - SoX Edge estimator | InnoBMS-L1-R059 | The InnoBMS shall be able to integrate in the edge software a Matlab/Simulink black box with the state estimation algorithm |
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R060 | InnoBMS shall ensure the battery temperature is within the optimal range during Fast charging to maximize charging efficiency and battery lifespan |
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R061 | InnoBMS preconditioning algorithm shall optimize the pre-conditioning process to minimize energy consumption and maximize the efficiency of the charging system |
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R062 | Prior to a fast charging event, the pre-conditioning algorithm shall pre-condition the battery temperature. |
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R064 | The InnoBMS shall communicate SoX battery data to the VCU in real-time |

| | | |
|---|---|---|
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R065 | InnoBMS shall follow boundary condition towards safety measures to monitor battery temperature, voltage, and current during pre-conditioning to prevent overheating |
| Degradation-aware pre-conditioning functionality in the VCU | InnoBMS-L1-R066 | InnoBMS shall ensure that the charge level is balanced within the battery pack to prevent overcharging to ensure uniform performance |
| Enhanced V2G & G2V functions | InnoBMS-L1-R067 | The InnoBMS shall have fast and efficient bidirectional charging capabilities. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R068 | The InnoBMS charging algorithm shall optimize battery performance and life. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R069 | The InnoBMS target vehicle shall have compatibility with the V2G charging infrastructure |
| Enhanced V2G & G2V functions | InnoBMS-L1-R070 | The InnoBMS charging algorithm shall optimize financial benefits over pricing periods. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R071 | The InnoBMS ECU shall be capable of handling multiple InnoBMS functions. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R072 | The VCCU should forecast parking time |
| Enhanced V2G & G2V functions | InnoBMS-L1-R073 | The VCCU shall coordinate with the energy management system of the charging infrastructure to optimize V2G/G2V operation. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R075 | The VCCU shall have a bidirectional communication protocol. |
| Enhanced V2G & G2V functions | InnoBMS-L1-R076 | The InnoBMS charging algorithm shall have safety measures against over-discharge, over-charge |
| Enhanced V2G & G2V functions | InnoBMS-L1-R079 | The InnoBMS shall be compliant to relevant standards and protocols for vehicle-grid connection |
| Regenerative Braking | InnoBMS-L1-R082 | The target vehicle shall control the regenerative braking functionality to avoid the overcharging conditions |
| Regenerative Braking | InnoBMS-L1-R083 | The target vehicle shall have different modes for increasing the effectiveness of regenerative braking |
| Regenerative Braking | InnoBMS-L1-R085 | The target vehicle shall limit the regenerative current |
| BMS & VCU communication | InnoBMS-L1-R086 | The BMS-VCU interface shall communicate using CAN2.0 communication protocol with speed of 500kbps. |
| BMS & VCU communication | InnoBMS-L1-R088 | The InnoBMS CAN network shall have terminating resistors of 120 Ohm at the end of the CAN line. |
| BMS & VCU communication | InnoBMS-L1-R089 | The InnoBMS shall have a diagnostic interface for configuring the BMS software. |
| BMS & VCU communication | InnoBMS-L1-R090 | The InnoBMS should have scenarios for wake up and shut down. |
| BMS & VCU communication | InnoBMS-L1-R091 | The InnoBMS shall transmit the pack insulation resistance over CAN communication |
| BMS & VCU communication | InnoBMS-L1-R092 | The InnoBMS shall operate with the power supply between 9VDC-16VDC |
| BMS & VCU communication | InnoBMS-L1-R094 | The InnoBMS shall include high voltage interlock (HVIL) system. |

| | | |
|---|---|---|
| Thermal management Vehicle & Cloud | InnoBMS-L1-R095 | Thermal management Vehicle & Cloud shall limit the batteries temperature to stay within safety operating temperature range |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R096 | Thermal management Vehicle & Cloud shall run a basic thermal management control algorithm in the Edge ECU. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R097 | Thermal management Vehicle & Cloud shall run an optimized thermal management control algorithm in the cloud. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R098 | Thermal management Vehicle & Cloud shall minimize the energy consumption of the BTMS. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R099 | Thermal management Vehicle & Cloud shall maximize the lifetime of the batteries. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R100 | Thermal management Vehicle & Cloud shall have a bidirectional communication between edge and cloud. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R101 | Thermal management Vehicle & Cloud shall send the output of the optimized control algorithm from the cloud to the Edge ECU. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R102 | Thermal management Vehicle & Cloud shall send BTMS and cell temperature measurements from the Edge ECU to the cloud. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R103 | The Edge ECU shall decide which of either control algorithms (cloud or edge) to use. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R104 | When no cloud connection is available, Thermal management Vehicle & Cloud shall select the control algorithm located in the Edge ECU. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R105 | Thermal management Vehicle & Cloud initialization parameters shall be modifiable. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R106 | Advanced thermal management functionalities shall be implemented in the Edge hardware and cloud which will control the thermal management system of the vehicle in addition to existing control strategy. |
| Thermal management Vehicle & Cloud | InnoBMS-L1-R107 | Thermal management Vehicle & Cloud shall be able to precondition the battery temperature. |
| V2C & C2V communication and interfaces | InnoBMS-L1-R114 | When sending data to external sources, the InnoBMS shall be able to ensure the data protection. |
| V2C & C2V communication and interfaces | InnoBMS-L1-R116 | The communication must enable fast and reliable data transmission between the vehicle and the cloud platform. |
| V2C & C2V communication and interfaces | InnoBMS-L1-R117 | The communication from the fleet system to the cloud needs to be designed to handle a large amount of data coming from many vehicles simultaneously. |
| V2C & C2V communication and interfaces | InnoBMS-L1-R119 | The communication system shall be designed to handle variable network conditions, such as fluctuating bandwidth and latency, while maintaining a stable and reliable connection |
| Virtual e-vehicle simulator | InnoBMS-L1-R121 | The remotely accessible "real-time testbed" hosted in Novi Sad shall have the following architecture. |
| Virtual e-vehicle simulator | InnoBMS-L1-R123 | The real-time HIL Simulator and cell emulators shall operate at a response rate to the physical BMS logic board and AFEs that is indistinguishable from a physical battery system (i.e. <2 us) |

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| Virtual e-vehicle simulator | InnoBMS-L1-R124 | The "real-time testbed" shall permit fault injection for individual battery cells, including open wire fault, short circuit fault, reverse polarity, overvoltage, undervoltage, overtemperature, undertemperature, weak cell, pack current sensor fault, and pack voltage sensor fault. |
| Virtual e-vehicle simulator | InnoBMS-L1-R125 | The simulation of the full vehicle in its driving environment shall include real time interaction (co-simulation) between the Real-time HIL Simulator and VUB's cloud-based Open Vehicle Powertrain Platform (OVPP) |
| AC-DC Charging | InnoBMS-L1-R126 | The InnoBMS's vehicle shall be compatible with AC charging (1 phase and 3 phase) |
| OTA Updates | InnoBMS-L1-R131 | The BMS Edge shall provide an interface to Update the advanced BMS functions over the air (OTA) |
| OTA Updates | InnoBMS-L1-R132 | At startup the BMS Edge shall ensure the integrity of the Advanced BMS Functions |
| OTA Updates | InnoBMS-L1-R133 | At startup the BMS Edge shall authenticate the source of the Advanced BMS Functions |
| OTA Updates | InnoBMS-L1-R134 | The BMS Edge OTA function shall be available over the CAN Interface |
| State of Safety (SOS) | InnoBMS-L1-R142 | The InnoBMS shall detect a possible thermal runaway event and give a warning. |
| State of Safety (SOS) | InnoBMS-L1-R143 | The InnoBMS shall detect Lithium plating during charging |
| Wireless capability | InnoBMS-L1-R144 | Wireless BMS shall include a cell monitoring and balancing circuit board (CMB) with wireless communication |
| Wireless capability | InnoBMS-L1-R145 | The CMBs shall communicate wirelessly to a Wireless Network Manager |
| Wireless capability | InnoBMS-L1-R146 | The BMS controller shall communicate with the Wireless Network Manager over CAN interface |
| BMS & VCU communication | InnoBMS-L1-R147 | The BMS-VCU CAN interface shall implement NXP Secure CAN Transceivers |

## L2 Requirements

| Function Name | Req ID | Requirement Description |
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| High Voltage Compatibility | InnoBMS-L2-R001 | The Electronic and Electrical Components shall comply with ISO-6469-3 |
| High Voltage Compatibility | InnoBMS-L2-R002 | The Electronic and Electrical Components shall comply with ISO-60664 |
| High Voltage Compatibility | InnoBMS-L2-R003 | Electronic and Electrical Components shall be operated within a microenvironment of Pollution Degree 2 as defined by ISO-60664 |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R004 | When input data is valid, reduced-order model (ROM) shall be parametrised with the parameters obtained with the communication with the cloud model |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R005 | When input data is valid, reduced-order model (ROM) shall serve as a virtual sensor for electrode potentials |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R006 | Reduced-order model (ROM) shall be real-time capable with specified frequency |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R007 | When input data is valid, reduced-order model (ROM) shall receive data from current, voltage and temperature sensors |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R008 | The system shall be hardened by checking the validity of input data from sensors and cloud |

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| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R009 | Enable fine-grained parameterization of battery models, including electrode thickness, porosity, conductivities and diffusion coefficients. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L2-R010 | Validate incoming data for completeness, consistency, and correctness before processing. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R011 | Communication protocols shall be established between the virtual vehicle simulator and the BMS for efficient and secure data exchange to improve battery performance. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R012 | The cloud architecture shall be provided to ensure optimal battery system control, fault prognosis, and maintenance updates. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R013 | The cloud shall be able to store all historical data from the battery for warranty claims, diagnostics, and second-life battery assessment. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R014 | The cloud shall store data from the BMS, for instance cell voltage, current, temperature, pressure, gas, and EIS, for analysing and processing. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R015 | The cloud solution must be able to store and analyse the large amount of battery data collected from vehicles. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R016 | The cloud platform must be designed to continuously record all relevant battery data. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R017 | The cloud shall contain aging models and Remaining Useful Life (RUL) estimations to monitor and predict battery age and remaining life for effective predictive maintenance. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R018 | The data driven algorithms shall be deployed in the cloud platform for analysing the data and estimating the battery performance. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R019 | The cloud models must ensure the privacy and security of data transferred from the vehicle to the cloud, BMS edge to the cloud and vice versa. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R020 | The cloud platform shall run a State-of-Safety (SoS) indicator that monitors the battery's safety and provides early warnings of potential problems. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L2-R021 | The cloud-edge framework for BMS algorithms must be flexible and scalable to accommodate future updates and changes. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R022 | Estimation will be corrected in closed loop based on error minimization between the model output and the real measured value. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R023 | Different time scales can be used to estimate different states according to its change rate. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R024 | The algorithm shall take into account the cell safety limits defined by the manufacturer and the operating window from the manufacturer or from another algorithm or strategy. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R025 | Estimated SoX parameters can feed other algorithm and processes as fast charging functionality, balancing or battery operation strategy. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R026 | SoH estimation will be based on capacity and internal resistance determination. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R027 | Algorithm shall receive and compute real time measurements of current, temperature and voltage from the on-board BMS or from other available sources. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R028 | Model parameters and structure must be known to be integrated and implemented in the algorithm. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R029 | Any model parameter and especially OCV, capacity or internal resistance are expected to be updated from cloud. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R030 | Initial model parameters in the electrical equivalent circuit shall be derived from physical-chemical models. Open Circuit Voltage and capacity shall be known. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R031 | Electrical equivalent circuit model shall include Open Circuit Voltage representation. Hysteresis effect may be also included. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L2-R032 | All the parameters in the model shall be dependent on SoC and temperature. |

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| Enhanced V2G & G2V functions | InnoBMS-L2-R033 | Bidirectional charging should follow ac conductive charging standards IEC 61851-1, SAE J3068, SAE J3068/2 for level-1 and 2 charging, and the vehicle and supply equipment identification standard SAE J3068/1. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R034 | The battery pack should be operated following the performance standard IEC 61960. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R035 | The battery pack should be handled following safety standards set by IEC 62133-2, IEC 62660-3, and IEC 62281. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R036 | The bidirectional charging infrastructure should follow charging standards IEC 63110 and SAE J3068, and inverter interconnection requirements standard SAE J3072. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R037 | The intelligent algorithms and features employing data-driven artificial intelligence techniques should be implemented on secure cloud computing platforms and APIs like Amazon Web Services, Microsoft Azure, or a similar service. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R038 | The intelligent algorithms should follow energy management system application program interface standard IEC 61970, distribution interface standard IEC 61968, and framework for energy market communications standard IEC 62325-301. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R039 | Bidirectional communication should follow vehicle to grid communication interface standard ISO 15118-20. |
| Enhanced V2G & G2V functions | InnoBMS-L2-R040 | Bidirectional communication should be able to interface with a controller area network (CAN) bus. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R041 | The Edge ECU shall receive all available cell temperature measurements. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R042 | The Cloud Thermal Management shall receive all available cell temperature measurements from the VCU. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R043 | The Edge Thermal Management shall have predefined temperature thresholds for improved battery lifetime |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R044 | The Edge Thermal Management shall have predefined safety temperature thresholds defined in the datasheet of the cell |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R045 | The Cloud Thermal Management shall have predefined temperature thresholds for improved battery lifetime |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R046 | The Cloud Thermal Management shall have predefined safety temperature thresholds defined in the datasheet of the cell |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R047 | The Edge ECU shall provide the setpoint to the BTMS. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R048 | The Edge ECU shall store data needed for the algorithm in the EEPROM. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R049 | The Cloud Thermal Management shall store data needed for the algorithms in the cloud database. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R050 | The Edge ECU shall receive current inlet coolant temperature |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R051 | The Edge ECU shall receive current ambient temperature |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R052 | The Cloud Thermal Management shall minimize the energy consumption of the BTMS. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R053 | The Cloud Thermal Management shall maximize the battery lifetime. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R057 | The Cloud Thermal Management shall be based on the power profile from the pre-programmed route |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R058 | The Cloud Thermal Management shall be based on the weather forecast for the pre-programmed route |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R059 | The Cloud Thermal Management shall be based on the departure time |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R060 | The Cloud Thermal Management shall receive the current pump flow rate from the VCU. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R061 | The Cloud Thermal Management shall receive the current inlet coolant temperature from the VCU. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R062 | The Cloud Thermal Management shall receive the current room temperature from the VCU. |

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| Thermal management Vehicle & Cloud | InnoBMS-L2-R063 | Before charging, when the battery temperature is out of the charging temperature range, Thermal management Vehicle & Cloud shall precondition the battery temperature. |
| Thermal management Vehicle & Cloud | InnoBMS-L2-R064 | Before driving, when the battery temperature is out of the operation temperature range, Thermal management Vehicle & Cloud shall precondition the battery temperature |
| V2C & C2V communication and interfaces | InnoBMS-L2-R088 | An interface shall be defined between the vehicle and the cloud for data exchange and control purposes. |
| V2C & C2V communication and interfaces | InnoBMS-L2-R090 | The vehicle shall be able transmit real-time data to the cloud platform. Example: ambient temperature, trip information, the data from cameras, radars, map and other sensors on the vehicle. |
| V2C & C2V communication and interfaces | InnoBMS-L2-R091 | The vehicle shall enable remote diagnostics of the battery management system (BMS) via secure C2V communication with the cloud platform |
| Virtual e-vehicle simulator | InnoBMS-L2-R092 | Output Voltage conditions between the physical BMS Analog front end interface and the Battery emulator shall not exceed ±5 V. |
| Virtual e-vehicle simulator | InnoBMS-L2-R093 | Output Current conditions between the physical BMS Analog front end interface and the Battery emulator shall not exceed ±1 A (e.g. for active balancing). |
| Virtual e-vehicle simulator | InnoBMS-L2-R094 | Battery cell fault emulation shall occur within the cell emulators with the following architecture. |
| Virtual e-vehicle simulator | InnoBMS-L2-R095 | Battery cell validation model shall calculate behaviour in response to stimulation in real-time with a timestep of < 2 us. |
| Virtual e-vehicle simulator | InnoBMS-L2-R096 | Communication between the individual cells and the HIL device for fault emulation shall use CAN/CAN FD. |
| Virtual e-vehicle simulator | InnoBMS-L2-R097 | The cloud interface shall connect to the HIL device through a local PC over Ethernet connection. |
| Virtual e-vehicle simulator | InnoBMS-L2-R098 | The splitting of the physical e-vehicle model between the cloud instance and the physical HIL testbed shall account for communication delays during remote co-simulation (e.g. a cloud-based instance located 200 km from Novi Sad shall account for a 25 ms delay in input signals). |
| State of Safety (SOS) | InnoBMS-L2-R099 | The Thermal Runaway detection algorithm located in the edge ECU shall receive cell impedance module and phase shift from the Electrochemical Impedance Spectroscopy at a specified frequency periodically. |
| State of Safety (SOS) | InnoBMS-L2-R100 | The edge ECU shall have memory to save at least the last 3 impedance module and phase shift measurements for each cell. |
| State of Safety (SOS) | InnoBMS-L2-R101 | The edge ECU shall send a Thermal Runaway warning signal to the VCU. |
| State of Safety (SOS) | InnoBMS-L2-R102 | The Li plating detection algorithm located in the edge ECU shall receive cell impedance module and phase shift from the Electrochemical Impedance Spectroscopy measurement at a specified frequency periodically during charging. |
| State of Safety (SOS) | InnoBMS-L2-R103 | The Li plating detection algorithm located in the edge ECU shall receive cell impedance module and phase shift from the Electrochemical Impedance Spectroscopy measurement at a specified frequency periodically during relaxation after the charging for at least 2 hours. |
| State of Safety (SOS) | InnoBMS-L2-R104 | The edge ECU shall have memory to save at least the last 3 impedance module and phase shift measurements for each cell during charging. |
| State of Safety (SOS) | InnoBMS-L2-R105 | The edge ECU shall have memory to save at least the last 3 impedance module and phase shift measurements for each cell during relaxation after charging. |
| State of Safety (SOS) | InnoBMS-L2-R106 | The Li plating detection algorithm shall output a warning and send it to the VCU and cloud if Li plating is taking place |
| Wireless Communication | InnoBMS-L2-R107 | The CMB shall include the ADRF8800 for wireless communication with the Wireless Network Manager |

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| Wireless Communication | InnoBMS-L2-R108 | The Wireless Network Manager shall include the ADRF8850 for wireless communication with the CMB |
| Wireless Communication | InnoBMS-L2-R109 | The Wireless Network Manager shall include CAN transceiver for communication with the BMS |

## L3 Requirements

| Function Name | Req ID | Requirement Description |
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| Battery Models - Advanced Functionality & ROM | InnoBMS-L3-R001 | When the input signal is valid, and the predicted anode potential in ROM is below 0.0 V the system shall reduce the battery current. |
| Battery Models - Advanced Functionality & ROM | InnoBMS-L3-R002 | When the input signal is valid, and the predicted cathode potential in ROM is above 4.3 V the system shall reduce the battery current. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L3-R003 | The edge algorithm shall utilize a data-driven approach to estimate key battery parameters (SOC, SOH, RUL) based on sensor data and pre-trained models. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L3-R004 | Data driven algorithms shall be deployed in the cloud through firmware replacement workflow |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L3-R005 | Thermal Runaway (TRA) events and Lithium plating will be detected and predicted by an algorithm or by a data-driven model |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L3-R006 | The edge algorithm shall leverage data-driven models to trigger basic safety actions based on pre-defined thresholds. |
| Battery Models - Data Driven models [Cloud] | InnoBMS-L3-R007 | The edge algorithm shall be adaptable to receive and integrate updated data-driven models from the cloud for improved performance. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R008 | The standard acquisition frequency will be 10 Hz. This value can be lowered up to 1 Hz if necessary due to hardware limitations. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R009 | Real time measurements of voltage and current must be synchronized. That is, for every data point, the maximum time difference between voltage and current measurements must not exceed 100 ms. |
| Virtual e-vehicle simulator | InnoBMS-L3-R010 | The battery cell model developed by University of Ljubljana shall be capable of real-time testing, either:<br><br>-via a protected adaptation of Typhoon HIL's Battery Cell model (see diagram: link in details)<br>-via an FMI/FMU import into THCC |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R011 | Cell voltage must be kept within the maximum and minimum values defined by the cell manufacturer. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R012 | Temperature has to be kept within the maximum and minimum values defined by the cell manufacturer. These limits can vary between charge and discharge. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R013 | Current must be kept below the maximum limit. These values can change depending on SOC & temperature. |
| Battery MOdels_SoX Edge estimator | InnoBMS-L3-R014 | Another algorithm can restrict the maximum and minimum usable SOC to guarantee cell safety and lifespan. |