UNIVERSIDAD
DE ANTIOQUIA

Development of Functional Architecture and Systems Integration in the Engineering Design Process for the Implementation of New Functions in E-TECH Hybrid Powertrains.

Luis Felipe Burbano Mosquera

Degree work to obtain the title of Aerospace Engineer

Internal Advisor
Juan Francisco, Puerta Ibarra, MSc.

External Advisor
Jhoan Sebastián Giraldo, PhD.

Universidad de Antioquia
Faculty of Engineering
Aerospace Engineering
Carmen de Viboral, Antioquia, Colombia
2024

Cita	Burbano Mosquera, 2024 [1]
Reference IEEE (2020)	[1] Burbano Mosquera, L. “Development of Functional Architecture and Systems Integration in the Engineering Design Process for the Implementation of New Functions in E-TECH Hybrid Powertrains.”, Bachelor’s degree project, Aerospace Engineering, Universidad de Antioquia, Carmen de Viboral,Antioquia,Colombia,2024.

Astra Research Group

Dedicatoria

A mis padres, Reinerio Burbano y Diana Mosquera, que nunca han dejado de estar a mi lado y me han apoyado en todas las etapas de mi vida. Siempre les estaré agradecido por el cariño incondicional que me han brindado. Su memoria acompañará permanentemente mis triunfos.

Agradecimientos

Al concluir este trabajo de grado, quiero expresar mi profundo agradecimiento a todas aquellas personas e instituciones que, de una u otra forma, han sido partícipes en mi proceso de formación y en la realización de este proyecto. En primer lugar, deseo agradecer a la universidad y a mis asesores, cuya orientación, conocimiento y valiosa retroalimentación fueron fundamentales para el desarrollo de mi trabajo.

Extiendo mi gratitud a los Semilleros Delta V, Voyager y Vulcano; en los cuales encontré un espacio para profundizar mis conocimientos, crear fuertes vínculos con mis compañeros y desarrollar actividades que amplificaron mi pasión por la carrera.

Deseo reconocer a la empresa FEV Iberia y a mi equipo de trabajo, quienes me acogieron durante mis prácticas y me brindaron los conocimientos necesarios para enriquecer los resultados del presente trabajo.

Agradezco a mi familia, por su apoyo constante e incondicional, por ser una fuente inagotable de motivación. Su fe en mis capacidades y talentos ha sido un pilar fundamental a lo largo de mi desarrollo profesional.

Finalmente, a todos mis compañeros de estudio y buenos amigos que pude hacer durante mi estancia en la universidad, quienes, con sus palabras de aliento, compañía y gratos momentos, hicieron muy satisfactorio este largo camino. A todos ustedes, muchas gracias.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acronyms and Abbreviations

AMS	Architecte Métier Système (System Architect)
CR	Change Request
DLS	Driveline State
EAD	Environment And Driver
ECU	Electronic Control Unit
EM	Electric Motor
EV	Electric Vehicle
GBA	Gear Box Actuator
HECM	Hybrid Engine Control Module
HEV	Hybrid Electric Vehicle
HEVC	Hybrid and Electrical Vehicle Controller
HM	Hybrid Management
HPEO	Hybrid Power-train Energy Optimization
HSG	High Speed Generator
ICE	Internal Combustion Engine
NF	New Function
PFS	Pilote Fonctions Systême (Pilot System functions)
PGSP	Powertrain Gear Set Point
PHEV	Plug-in Hybrid Electric Vehicle
PKM	Perform Kinematic Mode
PSTC	Powertrain State and Target Coordinator
PTM	Powertrain Torque Management
PTSP	Powertrain Torque Set Point
SCDR	System Control Design Review
SDR	System Design Review
SI	Software Incident
THEO	Trip Hybrid Energetic Optimization
WTSP	Wheel Torque Set Point

ABSTRACT

This report presents the development of the author's internship that took place at FEV Iberia SL, a Spanish company of German origin that specializes in the provision of engineering services to a number of leading manufacturers of propulsion systems worldwide. The project is primarily concerned with the implementation of services and technical assistance, including PFS (Pilote Fonctions Système), in the design and development of internal combustion engines, hybrid and electric vehicle propulsion systems. The project specifically focuses on the study of the functional architecture and integration of the S34 (Powertrain Torque Management) and S42 (Hybrid Management) systems in the powertrain of the E-TECH vehicles of the RENAULT-HORSE group. Additionally, it analyzes the impact of these systems in relation to other engine systems and functions established in the vehicle software. The main objective of these developments is to ensure compliance with international standards in the automotive industry. They are organized around a federative process led by HORSE, which forms the basis of the company's Design System framework. This, in turn, contributes to the efforts to reduce emissions in the market, as well as to the optimization of the systems implemented in the vehicle's power plant, with the goal of ensuring competitiveness and customer satisfaction in the supply of hybrid vehicles that meet the standards proposed by the brand in the coming years.

Keywords — **Powertrain Torque Management System, Hybrid Engines, Functional Architecture, Hybrid Management System, Requirements engineering.**

RESUMEN

En este informe se presenta el desarrollo de las prácticas académicas realizadas por el autor en FEV Iberia SL, una empresa española de origen alemán que se centra en ofrecer servicios de ingeniería a algunos de los grandes fabricantes de sistemas de propulsión en el mundo. El proyecto se basa principalmente en la implementación de servicios y asistencia técnica, como PFS (*Pilote Fonctions Système*), en el diseño y desarrollo de motores de combustión interna, sistemas de propulsión de vehículos híbridos y eléctricos. En concreto, se centra en el estudio de la arquitectura funcional e integración de los sistemas S34 (*Powertrain Torque Management*) y S42 (*Hybrid Management*) en la planta motriz de los vehículos *E-TECH* del grupo *RENAULT-HORSE*, así como en el análisis del impacto de estos en relación con otros sistemas del motor y funciones establecidas en el software del vehículo. El objetivo de estos desarrollos busca cumplir de manera efectiva la normativa internacional en la industria automotriz y sigue un esquema organizativo de procesos federativos dirigidos por *HORSE*, en torno a los cuales se articula el marco del Sistema de Diseño de la compañía. Este contribuye, a su vez, con los esfuerzos para la reducción de emisiones dentro del mercado, así como con la optimización de los sistemas implementados en la planta motriz, con el fin de asegurar la competitividad y satisfacción de los clientes en la oferta de vehículos híbridos para cumplir con los estándares propuestos por la marca en los próximos años.

Palabras clave **— Sistemas de Gestión de Torque, Planta Motriz, Motores Híbridos, Arquitectura Funcional, Sistema de Gestión Híbrida, Ingeniería de Requisitos**

I. INTRODUCTION

The progression of the internship is situated within the context of a continuously evolving automotive industry, where technological advancement and ecological responsibility are inextricably linked, collectively influencing the futuristic trajectory of mobility [5]. In light of the necessity to diminish polluting emissions and enhance energy efficiency in its engines, the Renault group is dedicated to investigating solutions that not only satisfy the most rigorous environmental criteria but also present viable and competitive alternatives in the market. Consequently, the company has set the objective of attaining carbon neutrality by 2040 in Europe, establishing electric and hybrid mobility technology as the foundation for the majority of its forthcoming models [6].

The company is pursuing this objective through the implementation of a strategy that involves the introduction of vehicles equipped with E-Tech engines. These developments are presented in different variants and are founded upon pioneering technologies, including: The three E-Tech line variants; the fully electric (EV) vehicle, the full hybrid (HEV), and the plug-in hybrid (PHEV)[6]. The continuous improvement and rapid growth in demand for these vehicles present the organization with the need to establish effective processes that can adapt to continuous change, facilitating innovation and research developments in the engine and powertrain area through a solid foundation.

The dynamic evolution of the product within the context of compressed and complex timelines presents an opportunity to encourage multidisciplinary collaboration between the various branches of engineering. The analysis and incorporation of the systems engineering approach is becoming an increasingly vital aspect of highly complex processes. As it plays a foundational role in the advancement of the aerospace industry[7], it similarly offers a compelling option for automotive organizations facing increasingly intricate and demanding processes. This approach enables the conceptualization, development, and production of a vehicle that aligns with all proposed objectives and performance standards, while adhering to budgetary and project scheduling constraints.

This work presents the evolution of the initial plan for the intern's participation in the company's powertrain research and development, with a particular focus on the S34 PTM & S42 HM Systems. It is organized as follows: First, Section I presents a brief introduction to the internship's context, which includes a general description of the corporation's goals and the project objectives; Section III provides an overview of the fundamental concepts and techniques utilized in the implementation of the projects covered during the internship period; Section IV contains a more detailed description of internship's methodology; Section V outlines the evolution of the plan throughout the internship, delineating which objectives were achieved, which were not, and the rationale behind these outcomes; This section also presents an overview of the design requirements, implementation, and validation related to the projects involved in this phase, which constituted the majority of the author's work. In closing, Section VI presents the findings and conclusions derived from the internship project.

A. PFS: System Function Pilot Overview

In the course of the internship presented in this work, the author assumed the role of PFS in the engine development process for the Renault group. The principal duties and responsibilities associated with this role will be delineated in greater detail below.

The System Function Pilot holds several key responsibilities that are crucial for the successful management of system designs and architectures. They participate in vehicle project functional reviews, system design reviews, and project arbitrations, ensuring alignment with the System Architect's delegation [8]. The role of a PFS involves overseeing the design, validation, and integration of various system variants within a larger engineering framework. A PFS is primarily responsible for ensuring that system designs are aligned with the specific requirements of different stakeholders, such as product development teams, customer performance experts, regulatory bodies, and manufacturing units. This requires close collaboration to define the system's functional and constructional architecture while addressing the unique needs and use cases of each stakeholder group. The main goal of this job is to ensure that the system meets the desired performance, safety, and regulatory standards.

In addition to these collaborative efforts, the PFS plays a crucial role in establishing the validation strategy for the systems under their responsibility in this case, S34 Powertrain Torque Management (PTM) and S42 Hybrid Management (HM) systems. This involves working with validation teams (LIS) to create comprehensive validation plans that guarantee the system performs reliably under various conditions [9]. They also ensures that system configurations, including the technical documentation, are properly managed and updated. This documentation encompasses system models, technical requirements, design documents, and safety plans. All of these must comply with established processes and standards (Fig.1). The information contained in the SCDR documents will be explained in detail in other sections.

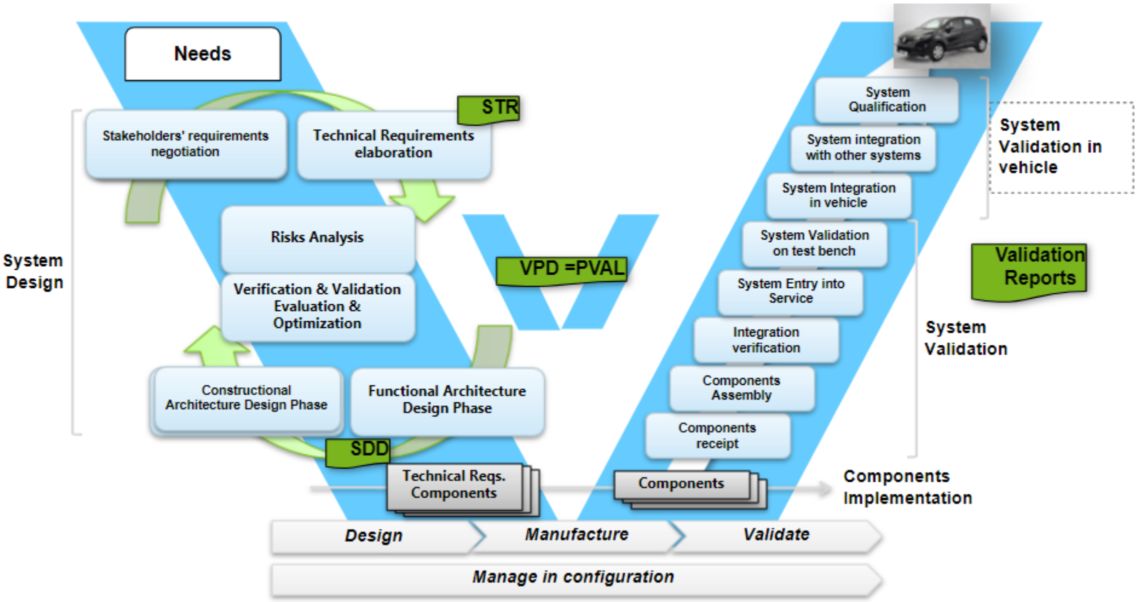


Fig. 1. Organization and Process [1].

During different project phases (Design process), from the early design stages to the pre-contract vehicle phase, the PFS ensures that selected system variants are integrated into projects in accordance with system roadmaps. This involves not only meeting technical requirements but also ensuring that all system components, such as hardware, software, and electrical elements, are correctly interfaced and aligned with the project's goals. Throughout the process, the PFS actively participates in system design reviews, project functional reviews, and, when necessary, project arbitration meetings. Furthermore, It contributes to the continuous improvement of the system by enhancing the standard rules, processes, and tools used across projects. This effort often includes knowledge-sharing activities and intellectual property management, such as co-innovation and patent filing [10]. In conclusion, the role encompasses a broad scope, encompassing a multitude of system families or innovative systems, including those related to vehicles, powertrains, or other services. It necessitates coordination across disparate geographical areas and project timelines, from the nascent stages of development through to serial production. It must moreover ensure that the project is aligned with the Alliance SE process, thereby guaranteeing coherence and integration across projects.

It is important to mention that the development of the functional architecture is limited to the integration of the S34 (Powertrain Torque Management) Sub-Module PGSP and S42 (Hybrid Management) Sub-Module PKM systems, which are related to the handling of the main engine control unit, as well as the management of all power requirements, efficiency analysis, design conditions, and limitations to effectively coordinate specific capabilities in the engine's operating modes. This aims to enable the implementation of new functions without compromising the performance or safety of the vehicles.

II. OBJECTIVES

The objectives outlined by the author for his participation in this project are as follows:

A. General Objective

Establish the design requirements for the functional architecture related to the S34 Power-train Torque Management (PTM) and S42 Hybrid Management (HM) systems in the power-train of Renault Group's Etech vehicle line, necessary for the implementation of new functions (HNF) or modifications to existing ones (CR) in the projects undertaken during the internship period.

B. Specific Objectives

- Identify the needs of the various stakeholders involved in the projects development.
- Examine the architecture of the existing systems in the engines within the brand's ecosystem.
- Analyze the necessary modifications to the functional architecture for the implementation of changes in the system and related subsystems.
- Identify the main risks associated with the introduction of NF and CR in the ETECH environment for engine development.
- Develop a proposal for modifying the functional architecture of the specified systems to ensure the proper integration of the expected changes in the power-train.

III. THEORETICAL FRAMEWORK

The project's theoretical foundations are based on the underlying concepts of the aforementioned systems and their interactions with other subsystems within the engine to achieve the established objectives. Each of these will be detailed below.

A. Requirements Engineering and Systems Modeling

Requirements engineering is an essential discipline within systems development, focusing on the process of gathering, documenting, validating, and maintaining system requirements throughout the life cycle of a project. This plays a vital role in the fundamental tasks of the PFS role, being a recurring concept throughout the internship progression in the company. This structured approach ensures that systems meet the needs of stakeholders while adhering to technical and operational constraints, due to its importance in the development of this project, it is crucial to understand each of the fundamental phases in its process and its applicability in the industry. The requirements engineering process begins with requirements elicitation, where information is gathered from key stakeholders such as end users, clients, and system architects . This phase identifies both the functional requirements, which define what the system must do, and the non-functional requirements, such as performance, security, and reliability constraints. Techniques like interviews, workshops, and use-case analysis are commonly used to capture these diverse perspectives [11].

Following elicitation, the next step is requirements specification, where the gathered requirements are formally documented. This specification must be clear and structured to ensure that all stakeholders share a common understanding of the system's objectives [12]. It typically includes functional requirements—detailing specific behaviors or operations of the system—and non-functional requirements, which impose constraints on the system's performance and compliance. The output from this phase serves as a blueprint for both the software and validation teams [13].

In addition, the next critical phase, is the requirements validation where the documented requirements are rigorously reviewed to ensure they accurately represent stakeholder needs, in the context of the internship, this is achieved through numerous meetings with the different systems involved, as well as the AMS responsible for the evaluated system and their respective PFS in the creation of documents such as the SCDR0, which will be explained in later sections. Validation is crucial to prevent misinterpretation and errors that could lead to costly revisions later in the project. Methods such as peer reviews, inspections, and prototype testing help to ensure the requirements are both feasible and necessary, highlighting any potential ambiguities or misalignments early in the process [13], This is evidenced in the documents that follow the creation of the proposal in SCDR0, such as SCDR1 and SCDR2, which focus on the meticulous review of the solution presented by the software team.

The basis of the requirements engineering process can be more clearly evidenced in the diagram presented in Figure 2, shown below.

Fig. 2. Requirements Engineering Process [2].

Subsequently, one of the most powerful tools in the requirements engineering process is systems modeling. It serves as a bridge between abstract requirements and concrete system design by providing a visual representation of how the system's components will interact. Modeling languages like SysML (Systems Modeling Language), In our case, the **MagicDraw** software is used by the company to carry out this part of the process, this enable the structured depiction of system architectures, behavior, and interfaces [11]. In other words, these tools help stakeholders and developers (software team) visualize how the system will function in diverse scenarios. This component is instrumental in maintaining the traceability between requirements and design, enabling better alignment between what the system must do and how it will achieve those functions. It also aids in identifying potential design flaws or mismatches before full-scale development begins. For instance, a use-case diagram may depict different operational scenarios, showing how system components should respond to specific inputs, thereby validating the system's design against the initial requirements.

Finally, the phase of requirements management, ensures that requirements are carefully tracked and updated throughout the development process. Tools such as *IBM DOORS* are used by the company to maintain traceability, linking requirements to design elements, test cases, and verification results. As projects evolve, changes to requirements are often necessary due to new information or external factors. Proper management ensures that these changes are integrated without jeopardizing the system's design or operational goals. This phase also ensures that the requirements remain aligned with the system design, linking them through every phase of the system's development [13].

Applicability to the Role of the PFS (System Function Pilot) :

This focus is intricately linked to the principles of requirements engineering, particularly in the areas of requirements gathering, validation, and management. The PFS is responsible for ensuring that system variants meet the functional and operational needs of the project, aligning with the broader goals of quality, cost, and delivery (QCD) targets [8]. During the requirements elicitation phase, the PFS collaborates closely with various stakeholders—including product development, regulatory bodies, customer performance teams, and manufacturing units to identify the specific needs for the system under development. This mirrors the elicitation phase in requirements engineering, where the PFS ensures that the system's functional scope and variant designs meet stakeholder expectations and comply with external constraints [12].

A critical aspect of the PFS's role is overseeing the creation of key documents such as the *System Design Document (SDD)* and the *System Control Design Review (SCDR)*, both of which are central to the requirements specification phase. These documents detail the architecture and requirements of the system, ensuring that all functional and constructional requirements are clearly defined. The PFS must also ensure that these documents align with the project's structured framework for the rest of the development process to follow.

In the validation phase, the PFS plays a key role in defining the system validation strategy and coordinating with validation teams to develop comprehensive validation plans. These plans ensure that the system behaves as expected under various conditions and that any discrepancies are identified and addressed early in the development process [13]. The PFS also ensures that the system configurations are accurately managed, reflecting any changes in the requirements or system architecture.

Throughout the software development cycle, the PFS is deeply involved in requirements management, ensuring that all system documentation is kept up to date and that any changes in requirements are properly tracked and implemented using tools like *IBM DOORS* [8]. This ongoing management ensures that the system remains aligned with its intended goals and that any quality issues identified during development or serial production are addressed promptly.

*B. System S*34 *- Powertrain Torque Management*

The purpose of the Powertrain Torque Management (PTM) system is focused on the optimal integration and coordination of engine torque, electric motor power, and transmissions that direct torque to the vehicle's wheels to meet operational needs [14]. This system is evaluated with the goal of controlling and optimizing the vehicle's dynamic responses, such as acceleration, deceleration, and steering, in alignment with the driver's demands—whether real or simulated via virtual controllers in bench tests. It also takes into account the physical limitations of the powertrain and the energy optimization provided by other systems for each scenario.

The research focuses on the design and modeling of algorithms and control strategies that enable precise synchronization between the components of the drive-train. It considers the interaction with the vehicle's operational environment and driver control inputs to continuously and adaptively adjust the vehicle's handling characteristics, as well as the impact of powertrain changes with the adaptation of new functions and how they affect each of these aspects.

This also includes evaluating the impact on the vehicle's energy efficiency and the quality of the driving experience. This involves a detailed analysis of how variations in torque management affect energy consumption and emissions, as well as the safety and comfort of the driver and passengers [14]. Below is a breakdown of the system's main components, with particular emphasis on the PGSP (Powertrain Gear Setpoint) subsystem, as it is one of the components for which the author is directly responsible during their internship period:

WTSP - Wheel Torque Set Point :
This subsystem converts the driver's request, whether through a physical action like the accelerator pedal or a virtual command, into a Set Point for the expected wheel torque. It includes an arbitration mechanism between various torque requests and takes into account the powertrain's limitations to deliver a filtered and optimized value for the required torque.

PTSP - Powertrain Torque Setpoint :
This component of the system converts the wheel torque preliminary condition provided by the WTSP into specific set-points for the different powertrain components, such as the internal combustion engine (ICE), the high speed generator (HSG) and electric motors (EM). To achieve this, torque limitations for all power sources in any powertrain configuration are taken into account, and requests are issued to accessories under specific conditions.

In essence, the most crucial elements to be taken into account when making a torque selector decision are as follows:

- The distribution of torque between the machines should be based on an energetic optimization proposal.
- It is necessary to establish compensation if the driver's request is to be respected at any given time.

Figure 3, shown below, provides a simplified description of how the torque split is determined by the system, outlining its main inputs and outputs while considering information and constraints from other systems. The terms CB and PTM_Plim present in the diagram refer to the combustion engine and the physical limitations of its components, respectively.

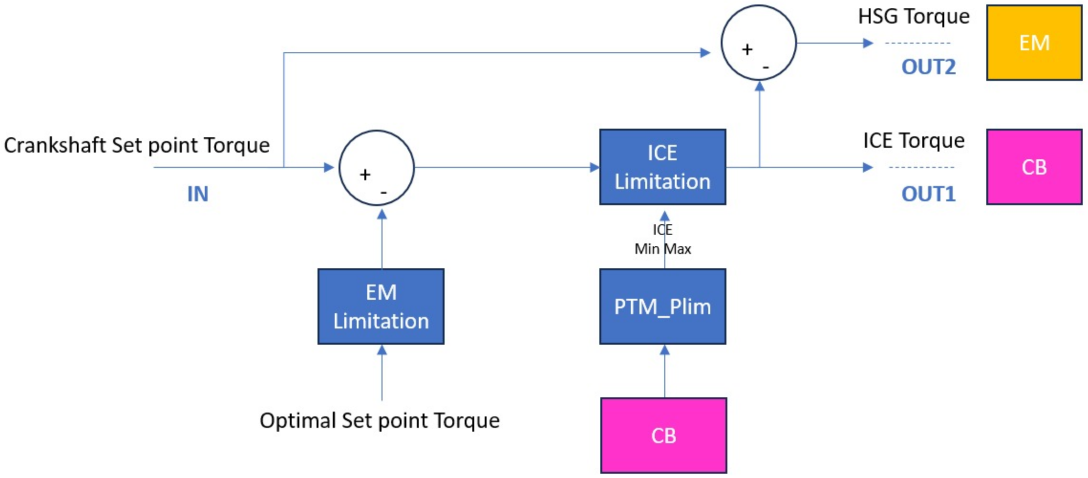


Fig. 3. Basic Torque Split Conception.

In later sections of this report, the possibility of considering the additional component of available power delivery based on the type of fuel the vehicle is using will also be evaluated. This applies to some developments in engines with dual-fuel capabilities, such as the *HR18 Gasoline-LPG engine*.

PGSP - Powertrain Gear Set Point :

The Powertrain Gear Set Point (PGSP) subsystem is a crucial element within the S34 PTM, It is primarily responsible for selecting and adjusting gear ratios to optimize the torque distribution between the internal combustion engine (ICE) and electric motors [15]. This optimization ensures that the powertrain operates efficiently across different driving conditions, balancing vehicle performance, energy efficiency, and emissions reduction. A core concept central to the functioning of the PGSP is the Driveline State (DLS). The DLS represents the various operational states of the powertrain, describing how power is distributed between the ICE and the electric motors in a hybrid powertrain setup. In a hybrid system, the DLS can vary depending on whether the vehicle is running on electric power only (Zero Emission Vehicle mode), hybrid power (combining electric and combustion power), or purely on combustion power. In fact, this also incorporates various configurations, such as charging modes where the ICE is used to recharge the battery while driving, or performance modes that prioritize acceleration and torque.

The Driveline State (DLS) structure involves multiple operational modes, including:

1. Zero Emission Vehicle (ZEV) Mode: The vehicle operates entirely on electric power, with no input from the internal combustion engine. This mode is typically used in urban environments or during low-speed driving to maximize efficiency and minimize emissions.

2. Hybrid Modes: The powertrain operates with a combination of ICE and electric power. These modes vary depending on whether the vehicle is prioritizing efficiency (series hybrid) or performance (parallel hybrid), and can dynamically shift between these states based on real-time demands.

3. ICE-only Mode: The vehicle relies solely on the internal combustion engine, typically during high-speed cruising or when the battery charge is low.

The subsystem plays an important role in selecting the appropriate DLS based on real-time driving conditions and driver input. It continuously monitors data such as vehicle speed, load demands, and driving environment factors (such as inclines or declines) and the information received from HPEO (Hybrid Powertrain Energetic Optimization) to adjust the gear ratios accordingly [15]. For example, during low-speed urban driving, the system may select a DLS that prioritizes electric drive based in the information coming from HPEO, maximizing energy efficiency and reducing emissions. On the highway, where higher speeds and torque are required, PGSP would engage a DLS that optimizes the use of the internal combustion engine, possibly in parallel with electric motors to provide additional power during acceleration.

In regard to functional interaction, PGSP engages in close collaboration with other critical subsystems. While the Powertrain Torque Management (PTM) subsystem provides overall torque demand guidelines, the subsystem adjusts the gear ratios and selects the appropriate DLS to meet these torque requirements while maintaining fuel efficiency and minimizing emissions. Additionally, It interfaces with the *Electric Drive System*, which provides electric torque during various driving conditions, and *PKM (Perform Kinematic Mode)* ensuring that the electric motor and ICE outputs are synchronized. This cooperation prevents power surges or losses during transitions between DLS, maintaining the smooth operation of the vehicle.

PSTC - Powertrain State and Target Coordinator :
This component consolidates the shift request, meaning it calculates the state of the transmission line and coordinates the coupling/decoupling phases during start/stop situations, including elements like the clutch and the power sources that influence this interaction with the gearbox. Shift requests from the gear lever are taken into account, and actions within the powertrain are coordinated.

EAD/ENDR - Environment And Driver :
This component consolidates the powertrain operating mode requested by the driver and calculates the environmental conditions that impact the powertrain torque or the state of the transmission line.

C. System S42 - Hybrid Management

The description and understanding of the S42 Hybrid Management system is fundamental for integrating the logical architecture into engine operation. The overall mission of this system is to manage the specific characteristics of the hybrid vehicle and assign sizing requirements to other systems affected by hybridization, such as the internal combustion engine, generators, and electric motors. This system is structured into main missions that outline its operational objectives [16], as described below. It is important to note that special emphasis will be placed on explaining the *PKM* subsystem, as it falls under the direct responsibility of the author during their internship period.

The importance of a meticulous performance evaluation in this system includes the precise determination of the required functionality of critical components such as the internal combustion engine, gearbox actuators, electric motors, and the battery system, as well as the expected performance when using different fuels, if applicable. This process is not limited to evaluating the individual capability of the components but also extends to transmitting operational constraints to the systems across the entire vehicle. It is carried out through the software associated with these components in the ECU HEVC (Hybrid - Electrical Vehicle Controller), which is directly connected to the HECM (Hybrid Engine Control Module) [17].

HPEO - Hybrid Power-train Energy Optimization :
One of the key missions of this subsystem is the energy optimization between the internal combustion engine (ICE), electric motors (EM), and the hybrid drive line state (DLS) which essentially refers to each of the gears the system can engage, considering both those on the internal combustion engine's drive shaft as well as the gears related to the electric motors. This is achieved by managing battery energy to reach the best possible balance between several critical variables, such as fuel efficiency (FE), CO2 emission targets, engine thermal performance, pollutant emission objectives, and the vehicle network's power demands.

THEO - Trip Hybrid Energetic Optimization :
This system module includes the optimization of the energy route, which involves determining the optimal energy management throughout a journey to maximize the efficiency and effectiveness of the hybrid system. This is achieved by developing algorithms that consider the engine's performance characteristics, the driving mode set by the user, and the specific conditions the vehicle will encounter along the expected route called .$^{\mathrm{En}}$av”.

PKM - Perform Kinematic Mode :
The PKM subsystem is a key component within the S42 Hybrid Management system. The primary mission of this subsystem is to manage the gear-shifting mechanisms and to control actuators within the powertrain system. Its role is particularly significant in hybrid powertrains where both electric machines and internal combustion engines (ICE) operate in tandem. It ensures smooth transitions between different driveline states (DLS), facilitating torque management and gear selection during shifts [3].

The subsystem is responsible for controlling multiple actuators such as engagement actuators, and selection actuators in the powertrain environment. These actuators work in unison to achieve the targeted gear-shifting behavior based on inputs from various sensors, such as valve position sensors and shaft speed sensors. The PKM gathers this data to regulate the speeds of the powertrain components and to engage or disengage gears safely and effectively.

In order to illustrate the operation of the subsystem, Figure 4 describes how it executes the requested kinematic mode change based on the current state.

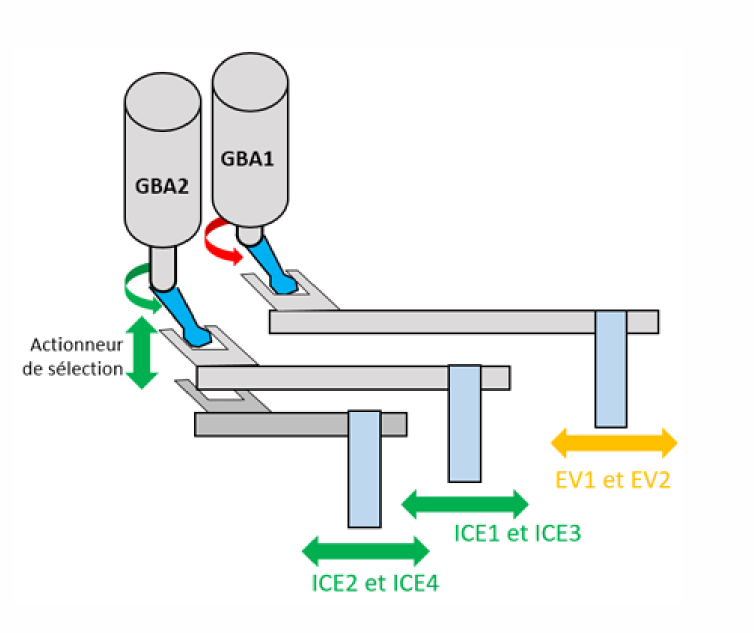


Fig. 4. Control Kinematic Mode Transition [3].

Expressions found in the above description such as ICE2, ICE4, EV2, etc. refer to the different DLS (states of different combustion and electric engine-related changes) possible for the power plant at that transition. This function is divided into several subfunctions to control the gearbox actuators (GBA). In this configuration, there are three actuators in the powertrain:

- The selection actuator, specific to the ICE, to enable selection between the even line (Neutral, ICE2 and 4) and the odd line (Neutral, ICE1 and 3).

- GBA1 engagement actuator to engage gears linked to the electric machine (right / EV2, EV Neutral or left / EV1).
- The GBA2 engagement actuator, which engages the gears linked to the ICE (right / ICE3 / ICE4, ICE Neutral or left / ICE1 / ICE2).

The core mission of the subsystem is to facilitate secure gear shifting, which involves coordinating the torque and speed requirements of the different powertrain elements. The subsystem controls the gearbox actuators directly, relying on data consolidated from the sensors. [17]. This allows it to regulate speed during gear transitions, ensuring that the torque delivered by the powertrain remains within safe and smooth operational limits. The PKM also responds to driver input, triggering appropriate gear engagements when required. This means that the subsystem is not an isolated entity but works closely with other subsystems within the hybrid management framework. It operates in close coordination, ensuring the overall functionality of the hybrid powertrain. It works in conjunction with the *Powertrain Torque Management (PTM)* subsystem, which provides DLS targets and manages internal combustion engine (ICE) torque generation. This collaboration allows the PKM to adjust gear-shifting behavior based on torque demands and safety protocols. Additionally, with the *Gear Ratio Actuation (GRA)* subsystem, responsible for the mechanical aspects of the gearbox, including actuator position and claw positioning sensors, provides real-time feedback to the PKM. This feedback enables the PKM to synchronize torque and speed during gear transitions, ensuring smooth and efficient operation.

Finally, another crucial function is sensor learning and calibration. The system consolidates sensor data to improve the precision of actuator movements, ensuring accurate control over the dog clutches (Gearbox configuration for Etech) during gear shifts. The subsystem constantly evaluates and memorizes the positions of these sensors and actuators, using diagnostic tools and feedback loops to adjust for any deviations. In the event of system failures or malfunctions, It is equipped with a fail-safe mode to manage gearbox faults. This mode degrades performance safely, informs other subsystems of the failure, and inhibits further transitions to avoid exacerbating the issue [3].

D. Euro 7 Regulation and Its Impact on the Industry

The regulatory and political framework influencing some of the design requirements for this project is based on the Euro 7 standard. This is a significant regulatory framework that sets stricter emissions limits for vehicles across the European Union, targeting reductions in pollutants like nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter. It also introduces stricter controls on CO2 emissions, particularly from internal combustion engine (ICE) vehicles. This regulation is established by the European Union and is built upon the ideals of effectively mitigating the negative impacts of human activity that contribute to climate change, with the goal of becoming a carbon-neutral continent by 2050 [18]. The final proposal for this standard was presented in late 2022. However, due to its controversial restrictions, it has been a subject of debate for several years, leading to various versions. The result has stirred strong emotions among radical environmental advocates in Europe, who argue that the standard is not strict enough, as well as from organizations representing vehicle manufacturers, who contend that adapting to this regulation poses an unprecedented challenge. What is clear is that the adoption of this standard will likely mean that conventional internal combustion engine cars will not be homologated for use in many specified areas of Europe starting in 2035, leading to significant economic impacts [19].

The implementation of Urban Mobility Plans also plays a crucial role in this process. These plans are being rapidly adopted across Europe to transform urban transport systems into more efficient ones, reducing congestion and pollution [20]. The impact of these initiatives limits the use of combustion engines in designated areas, thereby emphasizing the viability of hybrid propulsion technologies and requiring effective coordination between different sectors, including transportation, urban planning, and energy management analysis. Therefore, the use and development of new technologies focused on energy optimization offer opportunities to enhance the production of transportation systems by reducing costs and environmental impact, while also providing a quick and efficient response to unforeseen events in energy usage prediction in vehicles, determining which driving mode will be necessary for different scenarios [21].

IV. METHODOLOGY

The methodology adopted for the development of the project is directly based on the processes stipulated in the RENAULT Design System, a structured and systematic approach by the company that serves as the backbone for synchronizing and coordinating engineering within the Renault Group. This system is supported by previously established and defined federative processes to synchronize research initiatives, promote cohesive development, and achieve technical and economic feasibility in project development, aligning with profitability goals and expected outcomes from stakeholders. It also emphasizes the reuse and generation of input data for subsequent project phases, optimizing resources and promoting standardization whenever possible. Additionally, it prepares interns to engage with established processes and develop innovative solutions that are technically and economically viable.

A simplified schematic summarizing the main interactions of this process is presented in Figure 5.

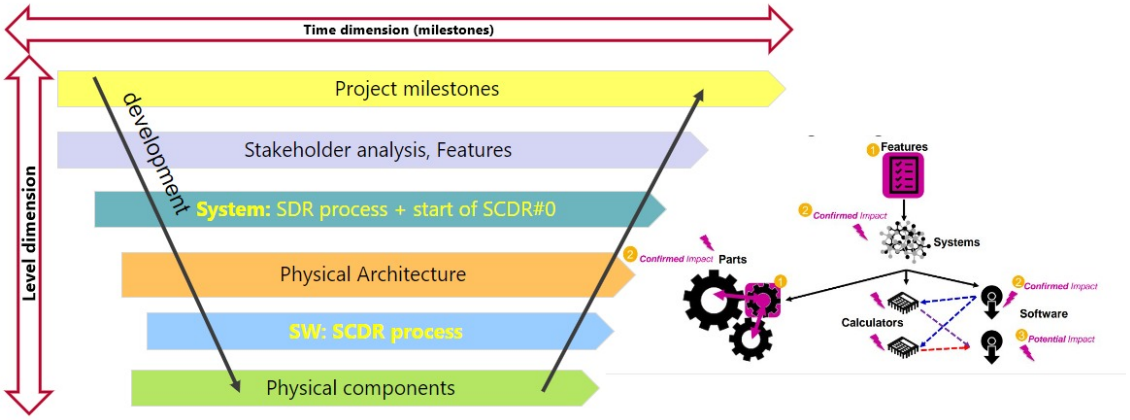


Fig. 5. RENAULT Design System overview [1].

Below, some of the main concepts that outline the expected development process in the project will be described:

A. Federative Process O53 - Design and Validation of Systems

This process, known as O53, plays a crucial role in formalizing the design and validation activities of systems, outlining the responsibilities and deliverables necessary for successful development, aligned with profitability and customer satisfaction goals. It does not operate in isolation but closely interacts with other federative processes to create a rational vehicle design, structured around vehicle features that meet specified objectives. Essentially, it formalizes activities through deliverables among the actors involved, ensuring effective development at the systems engineering level. By interacting with other federative processes developed in conjunction with the macro project, the aim is to achieve a comprehensive, logical, and systematic design that addresses the needs of each branch of the project, as well as the Quality, Cost, and Delivery (QCD) objectives established by the vehicle program in which it is intended to be implemented [22].

B. Systems Design Reviews (SDR)

Systems Design Reviews (SDR) are key instances for assessing the design and progress of the system, forming an essential part of the deliverables expected in process O53, in general, these documents delineate the project activities and are presented by the AMS. These are scheduled reports that allow for a comprehensive evaluation to identify and address systemic concerns early, establish a solid functional foundation for the system, and validate that the initial requirements are met within the stipulated budget and timeline [22].

This concept includes a numbered hierarchy depending on the project phase in which the review takes place. During the timeframe of the internship, two Systems Design Reviews (SDR) will be executed and experienced: SDR 0 and SDR 1. These reviews are critical points in the early phase of the project, focusing on a systematic and thorough evaluation to identify and resolve risks in the initial stages. They also aim to ensure the functional baseline of the system and set reasonable expectations for meeting initial requirements within the assigned schedule.

SDR#0 Foundations and Initial Definition :

It marks the beginning of the design cycle, focusing on defining the initial proposal and establishing a contextual framework for the project. This step is crucial for laying the groundwork for the expected innovation and precisely defining the impact of the requirements on the system. At this stage, the maturity level of the technology and the needs of the involved systems are assessed, a basic conceptual proposal is established, and the associated risks of its implementation are identified. The SDR 0 stage of the project is characterized by the following key phases:

- Context and Framing: Based on the current project timeline and the determined scope of application.
- Level of Innovation and Impacted Systems: The degree of innovation introduced by the new function in the S34 and S42 systems is evaluated, considering the system requirements through an analysis of the current state and areas for improvement.
- Operational Review: Stakeholder requirements will be assessed, and an operational view of the project will be developed by analyzing operational scenarios to anticipate system performance under various operating conditions.
- Functional and Technical Decomposition: A breakdown of the system's functions and subfunctions will be carried out, evaluating needs and objectives.
- Achievement Level and Success Conditions: A technical knowledge baseline is established, defining the necessary studies to achieve a successful implementation, ensuring that the proposed changes meet or exceed the required needs and expectations.

SDR#1 Analysis and Detailed Development :

In this phase, the work completed in the previous stage is built upon to provide a more detailed analysis and development. The focus intensifies on reviewing and updating the progress made so far: progress is updated, the impact of the proposals on the system architecture is examined, and a thorough safety and risk management analysis is conducted. Additionally, regulatory documentation is reviewed to confirm compliance with the applicable regulations up to that point. Finally, a quality assessment is performed to ensure conformity with design standards. This stage of the project is characterized by the following:

- Aspects of previous stages: The results and decisions made during this stage will be reviewed to ensure continuity, considering any necessary adjustments.
- Impact on the System's Functional Architecture: A detailed evaluation of the impact of the modifications introduced by the inclusion of the new function in the specific systems. Backup solutions and alternatives will also be considered to ensure effective integration. This includes a breakdown of the systems at the functional level to ensure alignment with stakeholder requirements.
- Safety and Risk Management Analysis: A risk analysis is conducted for each new or modified function.
- Design-to-Quality Synthesis: A quality check of the SDR content will be performed and classified based on its degree of compliance.
- Conclusion: The findings will be summarized, and future actions will be proposed, including the creation of a risk mitigation plan and the identification of additional research needs based on feedback from area experts.

Although SDR 2 is beyond the scope of the internship, foundations and recommendations for subsequent steps and reviews will be established in other phases of the project.

C. System Control Design Review (SCDR)

This is a structured process with the primary goal of ensuring the quality and robustness of software development in complex systems, such as those used in the automotive industry, which are a fundamental piece of the work during the internship. This process is part of the systems engineering methodology presented previously and is used to review and validate design decisions, ensuring that system requirements are properly translated into software specifications and that the developed software meets the proposed expectations [4]. The SCDR was designed by the company as an extension of the general design review process, known as SDR, which was previously introduced. While SDR focuses on the overall system architecture and its components, SCDR specifically targets software quality and its interfaces with the system . The goal of this process is to ensure that software development not only meets technical requirements but is also safe, reliable, and compliant with current regulations (see Figure 6).

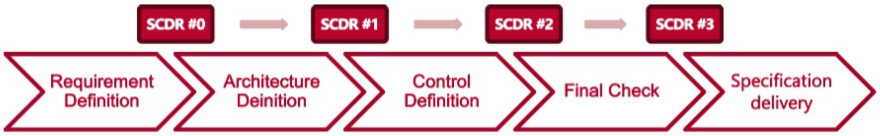


Fig. 6. System Control Design Reviews.

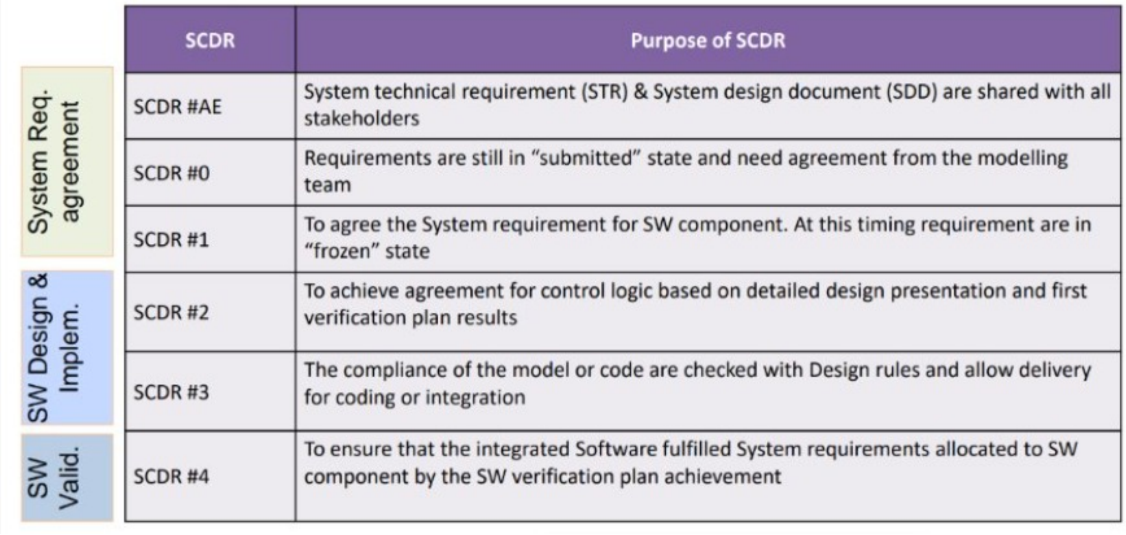
The process begins with SCDR 0, where the PFS plays a crucial role. From there, additional iterations, such as SCDR 1 and SCDR 2, are developed by the software team, but always under the approval and supervision of the PFS. Each stage is structured to review critical aspects of development, from requirement definition to algorithmic design validation and final software verification.

SCDR0 - Created and presented by the PFS :

The main objective of this document is to convey the system requirements to the software teams, enabling them to proceed with the development of the necessary solutions. The justification for system evolution requests, such as CO2 reduction, regulatory compliance, or meeting market demands, can be among the fundamental reasons for creating this document. In it, the initial system requirements are defined, including the variants to be considered, the interactions between the HEVC and HECM control systems (Engine and Powertrain Management) and their environment with other modules. It also addresses the different use cases that will guide the system requirements validation process. At this stage, these requirements are in a "draft"state and are synthesized from the demands of other systems and stakeholders, such as regulations or product specifications.

Furthermore, the purpose of the document is not only to present the requirements but also to initiate a discussion with the software team to ensure they fully understand the scope of the system's needs. Functional and physical diagrams are provided to show how the various system functions will interact and be implemented in the software. Additionally, the document includes analysis of side effects, technical safety requirements, and use cases for validation.

In summary, the main objective of each of the SCDRs is illustrated in Figure 6 below.



	SCDR	Purpose of SCDR
System Req. agreement	SCDR #AE	System technical requirement (STR) & System design document (SDD) are shared with all stakeholders
	SCDR #0	Requirements are still in "submitted" state and need agreement from the modelling team
	SCDR #1	To agree the System requirement for SW component. At this timing requirement are in "frozen" state
SW Design & Implem.	SCDR #2	To achieve agreement for control logic based on detailed design presentation and first verification plan results
	SCDR #3	The compliance of the model or code are checked with Design rules and allow delivery for coding or integration
SW Valid.	SCDR #4	To ensure that the integrated Software fulfilled System requirements allocated to SW component by the SW verification plan achievement

Fig. 7. SCDR Purpose [4].

V. EVOLUTION OF THE INTERNSHIP

Initially, the internship purpose was designated to focus on system modeling, applying Model-Based Systems Engineering (MBSE) concepts within the Research and Development environment of Renault's powertrain engineering design process. The objective was to model the interaction of systems involved in the new functions developed for high-voltage systems and power torque management in hybrid vehicles, particularly this work was to take place within the broader framework of the company's powertrain development for hybrid vehicles and its E-TECH engine platforms. Using MBSE methodologies, the goal was to optimize and streamline the design, integration, and management of complex powertrain systems, ensuring that the interactions between various subsystems were effectively represented and aligned with the overall design objectives.

However, due to the evolving nature of engineering operations within FEV Iberia and subsequent changes resulting from the task division between the Renault group and Horse, the role was redefined to take on the responsibilities of a System Function Pilot (PFS). As part of this change, the focus transitioned from pure system modeling to overseeing two critical subsystems: PKM (Perform Kinematic Mode), which is part of the S42 Hybrid Management (HM) system, and PGSP (Powertrain Gear Set Point), which is part of the S34 Powertrain Torque Management (PTM) system. Both systems are described in greater detail in previous sections of this document. The transition in responsibilities, exemplifies the malleable nature of engineering roles in response to the evolving demands of the organization.

In this context, the primary responsibility was to guarantee the appropriate integration, validation, and functionality of these essential components within the powertrain architecture as well as the integration of the systems affected by new functions created. As previously stated, PKM plays an essential function in regulating actuators and facilitating seamless gear transitions. In contrast, PGSP is responsible for the arbitration of the optimal driveline state (DLS) based on real-time torque demands and prevailing driving conditions. It is thus necessary to guarantee that these subsystems operated in a harmonious manner within the overall powertrain, in order to maintain optimal performance, efficiency, and safety.

The following sections delineate the evolution of the tasks and responsibilities throughout the internship. It is important to note that, although this work addresses multidisciplinary duties and may require extensive contextualization to understand some of the developments mentioned below, sensitive information related to the development of new functionalities, as well as specific modifications in the functional architecture of the systems and adaptations in software code such as Simulink, will not be described in detail due to the confidentiality agreements established with the brand during the course of the project.

A. Software Incidents (SI)

An IS (Software Incident) is a software malfunction detected during bench testing or functional testing in the vehicle. This type of anomaly can manifest itself in a variety of ways, such as algorithm execution errors, user interface errors, or unwanted system behaviour. The severity of an IS is classified using a severity grid known as K1, K2, K3, K4, where each category represents a level of impact:

- K1: Critical failures that affect the safety or core functionality of the system and require immediate correction.
- K2: Serious errors that significantly affect performance but do not compromise the safety of the system. They require prioritised intervention.
- K3: Moderate anomalies that do not interrupt the essential operation of the system, but must be corrected to ensure long-term stability.
- K4: Minor anomalies or inconveniences that do not significantly affect system performance and can be resolved in future maintenance cycles.

The Table I outlines the IS (issue software) that were identified and resolved during the placement period:

TABLE I
IS DESCRIPTION

IS Number	Level of Impact	System Affected	Perimeter
1	K3	S34 PTM Drive Mode	PGSP - PTSP
2	K3	S34 PTM Drive Mode	PGSP - WTSP
3	K2	S34 PTM Drive Mode	PGSP - ENDR
4	K1	S34 PTM Drive Mode	PGSP - DLS

IS N.º1 - Need for specific NVH (Noise, Vibration and Harshness) constraints in SOC (State of Charge) management for eSave/Towing mode :

1. Problem Description: This IS arises from the need to implement specific NVH-related constraints in SOC management when the vehicle operates in eSave mode or when the towing mode is activated through the LGE (Law of Energy Management).

2. Test Context: The issue was detected during vehicle testing on a test trip. In this context, the SOC management system should adapt to the specific conditions of eSave and towing modes, where NVH characteristics are crucial to maintaining adequate comfort and vehicle functionality. However, the system fails to correctly differentiate configurations in these modes.

3. Expected Behavior: The SOC management is expected to apply specific NVH constraints when the vehicle is in eSave mode or detects towing mode. This would allow the vehicle to automatically adjust its parameters, optimizing noise, vibration, and harshness levels without compromising the State of Charge.

4. Observed Behavior: Currently, the system is unable to distinguish between eSave mode and towing mode in SOC management. The prioritization of SOC management over eSave or towing requests prevents NVH constraints from being properly applied. This means that the vehicle is not optimized to mitigate noise and vibrations in these modes, potentially leading to a less comfortable driving experience and compromising performance under certain conditions.

5. Proposed Solution: The identified solution to this problem is a calibrated system validation. This solution involves adjusting the calibration values in the interface of the SOC management to recognize and apply specific NVH constraints when the vehicle is this scenario.

IS N.º2 - The curve lock specification should not bypass the Fast Off function :

1. Problem Description: The IS N.º2 addresses the need to ensure that the curve lock in the system does not inhibit the functionality of Fast Off. Currently, when the dynamic correction function for curve locking is activated, Fast Off availability is automatically blocked, which is inconsistent with the intended driving dynamics. This behavior affects the vehicle's ability to respond quickly to certain maneuvers, which may compromise the expected dynamic performance.

2. Test Context: The problem was detected during controlled vehicle tests. It was observed that under certain conditions, the activation of the curve lock interferes with Fast Off, a critical feature that allows the vehicle to reduce power or decelerate quickly and efficiently without manual driver intervention. This interference affects the vehicle's ability to adapt to situations requiring agile and dynamic responses.
3. Expected Behavior: The system is expected to allow the use of Fast Off even when the curve lock is activated. This would ensure that the vehicle can respond quickly and effectively, maintaining agility and control in dynamic situations such as tight curves or deceleration maneuvers, without compromising stability.
4. Observed Behavior: In the current configuration, when the curve lock function is activated, the Fast Off feature is disabled. This behavior interferes with the intended driving dynamics, reducing control and safety in complex driving scenarios.
5. Proposed Solution: Calibrated system validation is included in the identified solution. This will entail modifying the control logic to allow the curve lock function and Fast Off to coexist without interference.

IS N.º3 - SOC Management Should Not Be Bypassed in Case of KD (Kick Down Accelerator Function) :

1. Problem Description: The IS N.º3 refers to the unintended exit from SOC management when the Kick Down (KD) function is activated. It was observed that when a Kick Down action is performed, the system stops managing the SOC, which is not the expected behavior. The issue stems from an error in the specification, where an accelerator handling condition needs adjustment to prevent this situation.
2. Test Context: The issue was detected during ongoing tests with hybrid vehicles in a specific mission, the SOC management system is designed to optimize battery usage and maintain the state of charge within certain limits, even during high-demand situations,

such as when the Kick Down function is applied to the accelerator. However, it was observed that the system exited SOC management during this maneuver, compromising energy efficiency and vehicle performance.

3. Expected Behavior: The expected behavior is for SOC management to remain active even when the vehicle performs a Kick Down. This would ensure that the system continuously manages the state of charge, maintaining control over battery usage and optimizing the vehicle's energy performance at all times, regardless of accelerator demand.

4. Observed Behavior: In the actual configuration, when the driver performs a Kick Down maneuver, the system exits SOC management mode, leading to a temporary loss of control over the battery's state of charge.

5. Proposed Solution: The proposed solution for this issue is a modification to the specification. It was identified that the error lies in the accelerator handling condition threshold, where a strict comparison "$<$"should be replaced with a less restrictive comparison "$\leq$"to prevent the system from exiting SOC management mode during Kick Down. This adjustment will ensure that the system continues managing SOC even under high accelerator demand..

IS N.^{o}4 - Issue with calculation of predicted speeds resulting in vehicle stop :

1. Problem Description: This IS describes an error in the calculation of anticipated speeds, resulting in the vehicle's inability to maintain speed or accelerate properly under high-demand conditions, such as towing a heavy load on a steep incline in high external temperatures. During a specific test, the system failed to manage gear changes correctly between the DLS Hyb21 and Hyb11 modes, leading to a loss of speed and eventual immobilization of the vehicle due to battery depletion.

2. Test Context: The problem was detected during a test on a hybrid vehicle towing a

heavy load on a steep incline in high ambient temperatures, considered a worst-case scenario. In this scenario, the vehicle was in Hyb21 mode because Hyb11 mode was unavailable due to the maximum allowable speed. However, as the vehicle lost speed due to the load and incline, Hyb11 mode became available but could not be selected in time due to a delay in the calculation of anticipated speeds. As a result, the vehicle oscillated between requests to activate Hyb11 mode and staying in Hyb21, unable to complete the shift, which ultimately led to battery depletion and vehicle immobilization.

3. Expected Behavior: PGSP subsystem is expected to efficiently manage DLS transitions between Hyb21 and Hyb11 modes based on anticipated speeds and the vehicle's operating conditions. When Hyb11 mode becomes available, the system should select the appropriate gear without unnecessary delays or inhibitions that cause oscillations in the shift request.

4. Observed Behavior: In the observed test, the system failed to shift to Hyb11 in time due to incorrect calculation of anticipated speeds, leading to repeated oscillation between gear change requests and the current gear. The issue was that the system incorrectly considered Hyb11 gear as available but could not complete the shift before the vehicle's speed increased again, causing a repetitive cycle. This inefficiency led to battery depletion and vehicle immobilization.

5. Proposed Solution: This involves a software correction. Specifically, it is suggested to modify the software specifications in that area to prevent the system from maintaining an unnecessary delay in gear transitions when a gear is considered current or available. The software should adjust the anticipated speed calculations and remove the holdover delay associated with the gear in use when a new gear becomes eligible. This will allow for faster and more efficient transitions between the DLS, preventing the observed oscillations and ensuring the vehicle maintains the required speed.

B. SCDR0: Integration of Derating for Calculation of Acceleration Constraints

The integration of derating for calculating acceleration constraints during up-shifts and downshifts in the powertrain was another development carried out during the internship as part of a different project line.

Since it was conceived as an SCDR, this function was modified based on an existing functionality and by order of a Change Request (CR), with the aim of optimizing vehicle performance during gear shift transitions in response to external conditions such as atmospheric pressure, ambient temperature, and battery state of charge. This adjustment stemmed from previous complications in the calculation of this decision factor when analyzing the full pedal range. The goal is to ensure an appropriate response to driver demands, even when the decision characteristics between each DLS (Driveline State) are very narrow.

The objective is to introduce a reduction factor that applies to both up-shifts and downshifts, adjusting to external conditions as mentioned earlier. This factor will allow the system to maintain optimal control of vehicle acceleration, responding to demands without compromising DLS selection.

Additional Context :
Currently, vehicle acceleration is limited by a maximum static value set in one of the considered variables. This implies that, in some cases, there is no noticeable difference in powertrain response when the pedal is between 60 % and 100 %, even with the activation of Kick Down (KD), as can be seen in the simulations illustrated in Figure 8. In other words, this leads to a loss of pedal range when the vehicle is in this situation, resulting in inappropriate DLS selection, which may not correspond to the actual pedal demand and, consequently, the driver's intent. In these cases, the engine operates at high speeds despite low pedal positions, increasing the likelihood of unnecessary downshifts.

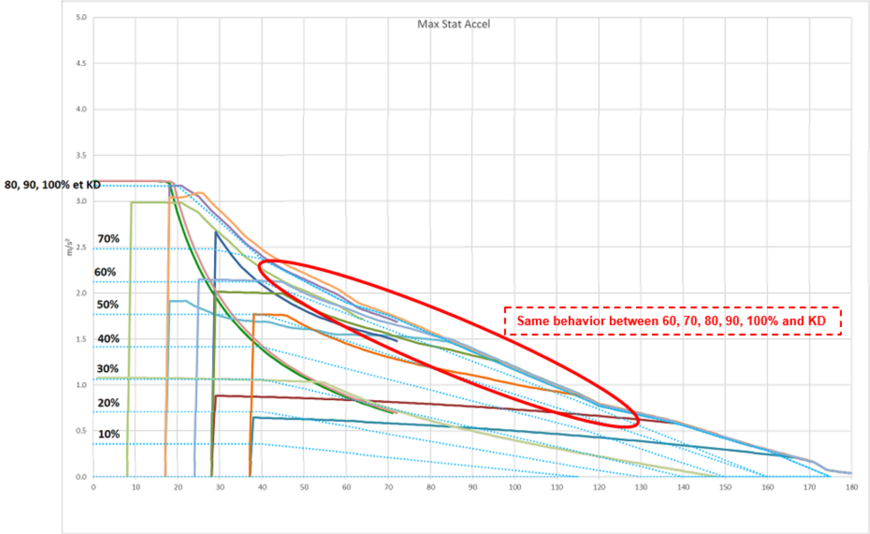


Fig. 8. System Background and Simulation.

Implications of the Derating Factor and the Proposed Solution :
With a higher derating factor, the pedal range loss becomes more pronounced, preventing the system from properly distinguishing between moderate and high acceleration demands. This not only affects the driving experience but can also cause the gear shift subsystem (PGSP) to select inappropriate gear ratios, unnecessarily increasing engine speed and downshifts when they are not needed. To avoid this, the system must intelligently integrate derating, ensuring a precise correspondence between pedal demand and system behavior.

In the proposed solution, the system should calculate acceleration constraints for both up-shifts and downshifts using an integrated factor based on:

- A variable established for the derating of the internal combustion engine (ICE), which will depend on environmental conditions such as atmospheric pressure and temperature.
- Another value that considers the derating of electric machines, determined by the temperature of the electrical system components.
- Additionally, variables dependent on the high-voltage battery, calculated based on the state of charge (SOC) and battery temperature.

Finally, the minimum reduction factor will be the lowest value among these three elements, allowing the system to adjust acceleration conditions based on operational circumstances.

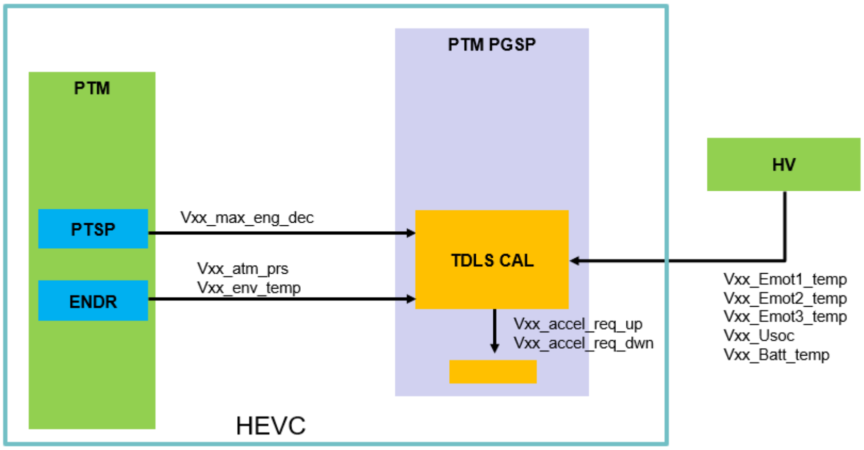


Fig. 9. Functional Block Diagram .

The proposed functional architecture for this development is shown in Figure 9, which illustrates the simplified relationship between each of the subsystems involved in this calculation. It is noted that this function should offer the ability to select the value provided by different sources (such as PTSP or PGSP), allowing flexible and redundant configuration according to the vehicle's needs and external conditions. This is expected to ensure proper acceleration management and powertrain performance in the situations described.

C. SDR0: Gearshift Inhibition Request Consolidation for Fuel Change Transition

This development is part of one of the projects frequently undertaken during the internship. The initiative focuses on studying the functional architecture and creating new functions necessary to adapt Liquefied Petroleum Gas (LPG) as an alternative fuel in a new line of vehicles (Etech HR18 LPG).

LPG is considered a cleaner fuel than gasoline, leading to lower emissions of pollutants and a reduced carbon footprint. The inclusion of the LPG in these motors, and vehicles similar to the gasoline versions in the company's hybrid line, is strategically positioned as a solution to emission reduction. These vehicles are equipped with a dual-fuel system, including an alternative fuel tank and several additional components, designed to avoid affecting interior space or trunk volume while maintaining engine performance and power. This will enable fuel savings and grant the vehicle an ECO label, ensuring it can operate without issues in Low Emission Zones (LEZ) implemented in European cities.

The main goal of this phase of the project is to study the requirements for adapting LPG in hybrid engines, focusing on the systems under the responsibility of the PFS, and analyzing and identifying potential risks associated with the new engine configuration to ensure proper functionality. Additionally, it seeks to assess the viability of using this technology to meet Euro 7 regulations, with the expectation that the results will contribute to its implementation in the industry within the coming years.

LPG as an Alternative Fuel :

By analyzing the combustion characteristics of LPG, we find that it exhibits a faster flame propagation speed and a shorter combustion period compared to gasoline. This is mainly due to its lower density and its ability to mix more uniformly with air when introduced into the combustion chamber, allowing for a more efficient and complete combustion [23]. Additionally, LPG has a relatively high octane rating, which reduces the risk of early detonation in the engine and enables smoother and more efficient operation. Figure 10 shows one of the studies conducted in collaboration with the combustion system team, comparing the performance of LPG and gasoline across different engine revolution zones. Fuel efficiency takes precedence over torque production in the powertrain, however, it is important to highlight that from these analyses, some issues were identified and will be discussed below.

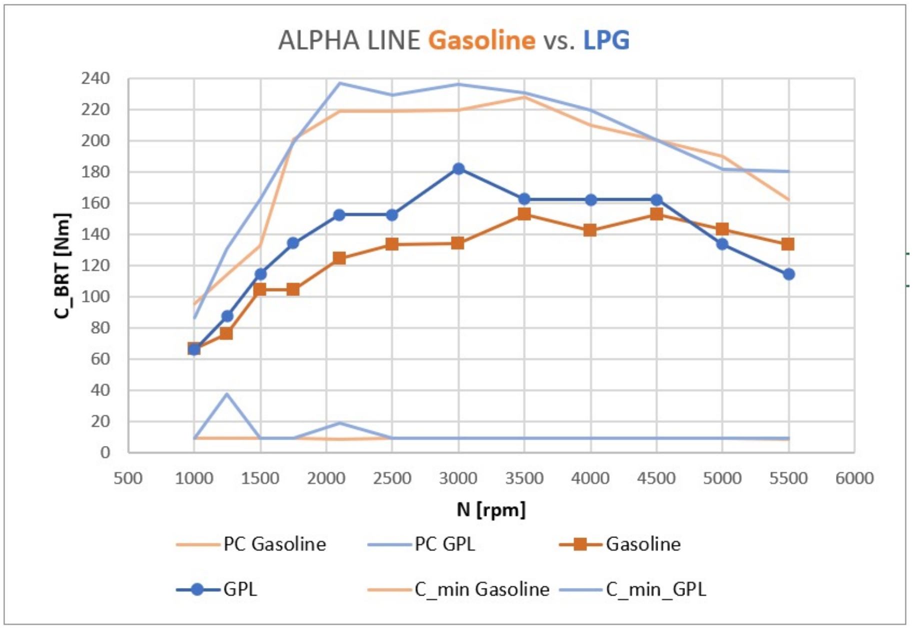


Fig. 10. Alpha Line: LPG Combustion Efficiency.

In comparison to other fuels, LPG generates a lesser quantity of post-combustion particle emissions when utilized under optimal conditions. Nevertheless, a challenge inherent to the use of this fuel is its diminished performance in specific operational circumstances, such as low engine loads or during cold starts. Some findings have shown that this behavior is due to the vaporization and mixing characteristics of LPG, which can vary depending on its composition and distribution efficiency.

Main Stakeholders Requirements :

From the previous tests, it was determined that during fuel mode transitions (from gasoline to LPG and vice versa), there is a significant risk of loss of precision in the torque structure, associated with the instability characteristics of LPG under certain conditions. This can cause issues when shifting gears or during transitions between different DLS (Drive Line Status) related to this, especially when internal combustion engine (ICE) shafts are involved. In a normal transition from gasoline to LPG, or back to gasoline due to low pressure, greater precision in the torque structure is expected. However, in situations involving re-condensation, the precision of the torque structure decreases, which can result in noticeable jerks felt by the driver, negatively affecting the driving experience.

As a result, stakeholders established requirements emphasizing that torque precision must be maintained within acceptable limits during fuel transitions. However, it has been observed that the precision may be lower compared to a stable single-fuel state, raising concerns about the stability and smoothness of gear shifts and DLS transitions. Therefore, it is essential that torque precision is maintained during these changes to avoid performance and safety issues. The Power-train Management System (PTM) must be capable of preventing gear changes when a decrease in torque precision is detected during fuel transitions, thereby protecting the vehicle's integrity and the driving experience.

The risk of not meeting these requirements during fuel transitions necessitated adjustments to the system to ensure this condition is met.

Functional Needs :

To effectively meet the functional requirements, the implementation of a new function in the communication protocol between the S32 CB (combustion system) and S34 (PTM) systems is required to fulfill operational needs.

The communication protocol involved would affect the messages sent and received by the various ECUs (Electronic Control Units) that manage each system, as shown in the diagram in Figure 11.

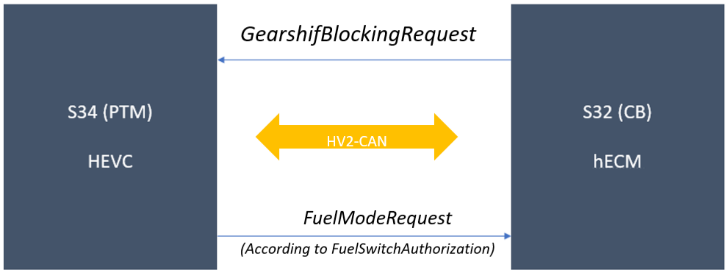


Fig. 11. Proposed Communication Protocol.

Specifically, this interaction occurs between the HEVC (Hybrid and Electric Vehicle Controller) and the hECM (Hybrid Engine Control Module). For this process, it was proposed that:

- The HEVC sends an ongoing gear shift request to the hECM, blocking any fuel transition during the gear shift, based on the information provided by the PTM system.
- In turn, the hECM can request that the HEVC delay or block the gear shift when a fuel transition is taking place, based on information received from the combustion system.

This ensures that if a fuel mode transition is underway, the gear shift is delayed to maintain system stability and vehicle performance.

Impact on System Characteristics :

In this proposal, the primary impact on the system's characteristics arises from the requirement that, during a fuel transition, the combustion system (S32) sends a gear shift lock request. This will affect the DLS transitions managed by the PTM, inhibiting gear shifts when synchronization with the internal combustion engine (ICE) is needed. The lock request will be managed by PGSP and consolidated to ensure robust gear shift management. Currently, the PTM system does not incorporate information from the combustion system for these processes, necessitating a redesign of the functional architecture to better coordinate fuel transitions and gear shifts, affecting both the CB and PTM systems as well as other subsystems involved.

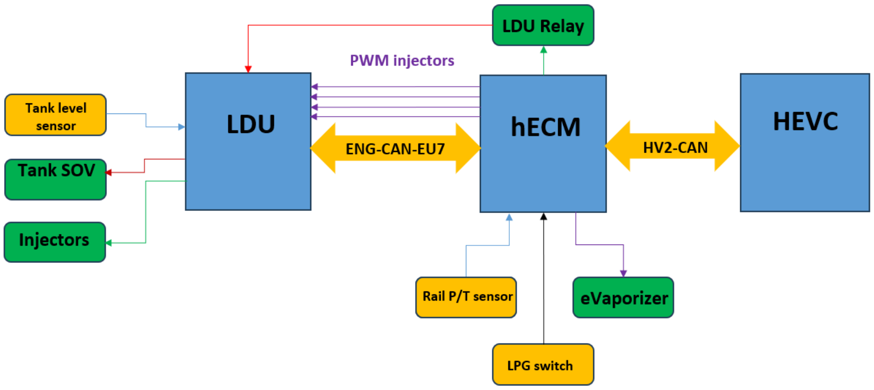


Fig. 12. LPG Project Physical Architecture.

The physical architecture of the components in this system is illustrated in Figure 12.

It is important to note that this diagram is a sketch and does not intend to detail the exact configuration of the powertrain.

Effect of Novelty on Functional Architecture :

The impact of the innovation in the functional architecture means that the S32 combustion system must function as the information manager, acting as the master in the decision-making process for fuel changes. It must consider the information sent by the HEVC through the FuelModeRequest signal, which includes prohibiting fuel changes during a gear shift or a DLS system transition. This is done only when the primary shaft is involved, using the information received from the PTM system.

On the other hand, the S34 PTM (PGSP) system must consider the gear shift lock request sent by the combustion system (S32) to delay a gear shift or a DLS transition during a fuel mode transition. In other words, the system must be able to block a DLS shift in the event of a fuel transition, ensuring greater stability and coordination between the systems during these events.

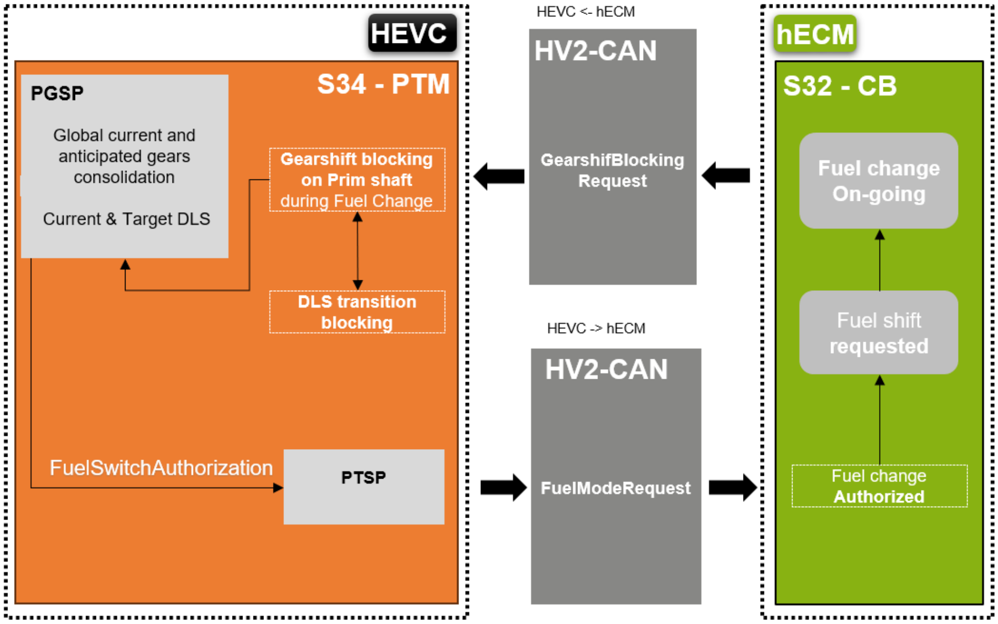


Fig. 13. System Functional Architecture Overview.

Figure 13 shows the proposed functional architecture to develop this functionality. The proposed signals for fuel change processes and their coordination with the PGSP subsystem are as follows:

1. *FuelSwitchAuthorization*: This signal indicates authorization to perform a fuel change. It is activated when the necessary conditions to allow a transition from one fuel type to another are met, considering factors such as engine synchronization and system stability. It is transmitted through the information flow between the PGSP and PTSP modules within the S34 system. This proposal was structured in this way to optimize the signals, considering that other functions are related to other systems within the engine.
2. *GearshiftBlockingRequest*: This signal is sent by the combustion system (S32) to the powertrain management system (S34) to request a gear shift lock or delay during a fuel transition.
3. *FuelModeRequest*: This signal is sent by the powertrain management system (S34) to the combustion system (S32) to indicate the power requirements associated with the current fuel mode. It provides the necessary information to coordinate fuel transitions when more power is required by the powertrain. This signal is developed as part of another function described in later sections.

D. SDR0: Shift to GAS for Performance Based on SOC

In the same project context, another function was developed to address engine performance needs under specific conditions. After conducting engine bench tests and simulations, the results shown in Figure 14 were determined, where a power production deficiency is observed when the powertrain is in LPG mode. Under normal conditions, the vehicle compensates for this situation by regulating and distributing torque through the functionality of the PTSP subsystem, as described in previous sections B.

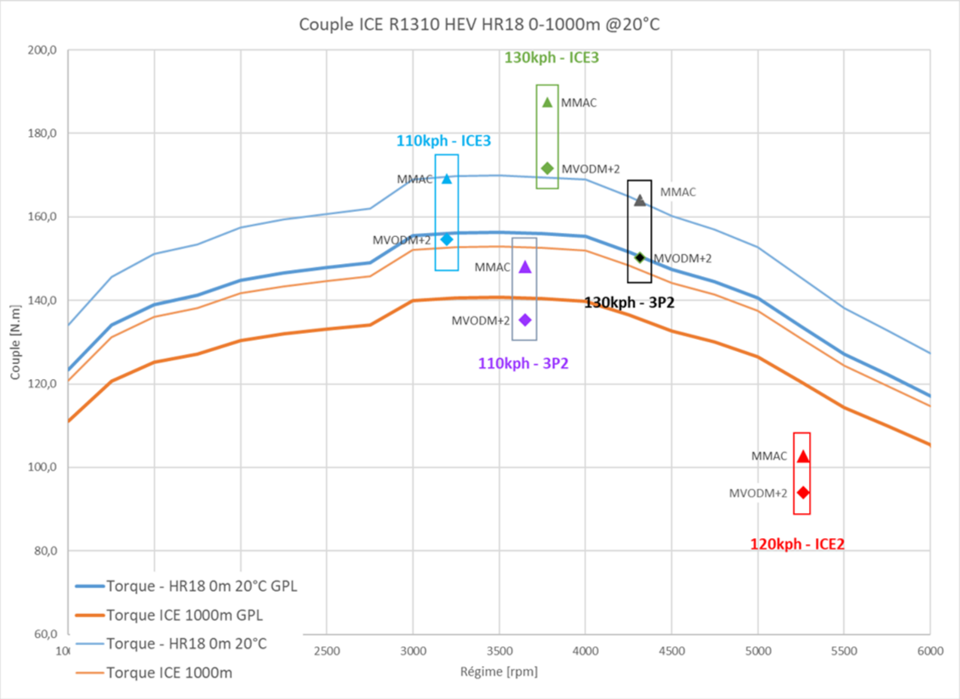


Fig. 14. LPG Low Engine Performance Condition.

However, when in LPG mode and the state of charge (SOC) of the battery is low, the available traction power from the high-voltage system (HV system) is limited, meaning that electric motor assistance cannot be used. This means LPG alone cannot meet the driver's demands. In such circumstances, it is necessary to switch to gasoline mode to meet both the driver's traction demands and the need to recharge the battery through the hybrid starter generator (HSG) when necessary. This switch to gasoline ensures that the vehicle can maintain its performance under low battery charge conditions.

Another important aspect of implementing this function is that when the driver's demand exceeds the maximum torque that LPG can provide, vehicle performance is affected, resulting in a decrease in maximum speed, which worsens on inclines. These conditions, requiring assistance from the electric motors, can also lead to an increase in temperature of +30 degrees, due to the increase in energy flow (400 Wh) needed for specific maneuvers.

Impacts on System Features: :

The impacts on the system's characteristics involve the following responsibilities for the various subsystems:

- S32 CB: Responsible for providing S34 with the current active fuel. It also manages the switch between fuel modes and displays the active fuel mode when LPG is activated.
- S42 HM: Has the function of providing S34 with the user's battery state of charge (SOC), which is essential for energy management.
- S34 PTM: Processes the driver's demand and, based on that information, requests a fuel mode change as necessary.

The relationship between these subsystems is better illustrated in the diagram shown in Figure 15.

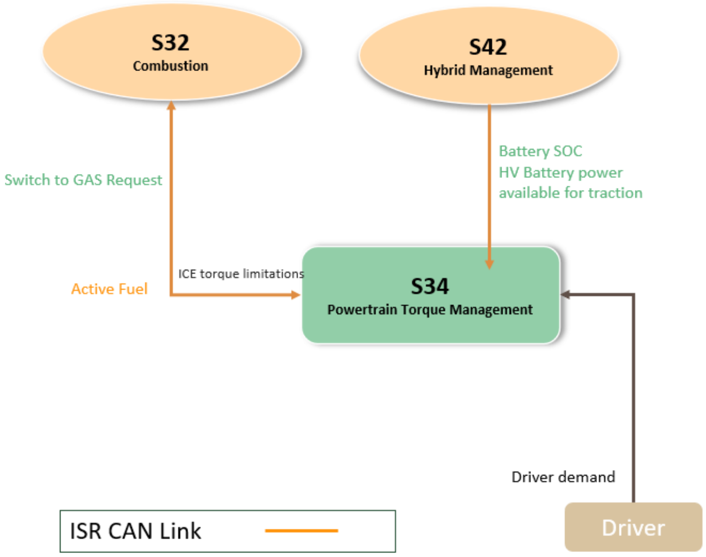


Fig. 15. Environment Diagram and Operational Overview.

These subsystems work together to effectively manage fuel transitions, ensuring that the system delivers the necessary performance according to driving conditions and the driver's traction requirements.

Effect of Novelty on Functional Architecture :

The needs analysis within the context of the functional architecture is reflected in the proposal illustrated in Figure 16, which complements the logic presented in the previous function. It further demonstrates how the S32 combustion system must meet performance requirements, including fuel efficiency (FE), CO2 targets under the test cycle, and maintaining high acceleration performance, striving for sustainable and consistent operation.

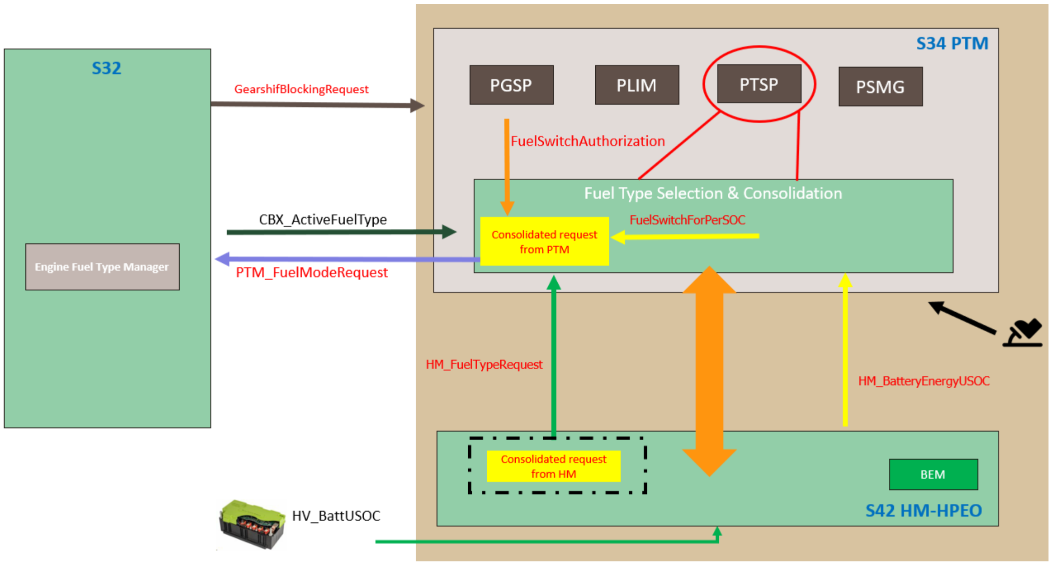


Fig. 16. Functional Architecture and Inter-System Communication.

The intercommunication needs between the systems establish that the S34 PTM system must provide S32 with the requested (necessary) fuel mode to meet the driver's demands and power requirements. Additionally, this subsystem must request a switch to gasoline if full charge mode is required and the battery's state of charge (SOC) falls below a certain threshold in the power reduction zone. In this way, S34 must request a return to LPG when the battery's SOC is restored, as requested by the driver, thereby ensuring sustainability and efficiency in the system's operation.

In conclusion, both developments related to the LPG project represent a significant advancement in efficient fuel management and powertrain performance, focusing on maximizing the applicability of this modification in the systems under the author's responsibility.

This is achieved while ensuring that stakeholder needs and system limitations are appropriately managed as the project evolves. However, since validation processes have yet to be carried out, there are still challenges to overcome to ensure the system's functionality and robustness.

Looking ahead, these new functions and developments will be evaluated in a physical prototype, with implementation planned for next year. Real-world testing will be crucial to confirm the expected performance, identify any necessary adjustments, and ensure that the system responds correctly to the dynamic and complex demands proposed. After validation, these improvements are expected to contribute to enhanced performance, energy efficiency, and an optimized driving experience in the vehicles commercialized with this technology in the coming years.

VI. CONCLUSIONS

Throughout the internship as a System Function Pilot (PFS) at FEV Iberia, working closely with the Renault Group, significant progress was made in the integration and modification of the subsystems under the author's responsibility for the projects undertaken, specifically within the S34 Powertrain Torque Management (PTM) and S42 Hybrid Management (HM) systems. As part of the services provided, the responsibilities were focused on ensuring the proper functioning and coordination of these systems, as well as synergistically proposing and solving the necessary changes for the implementation of new functions. The main achievements during this period include:

1. Subsystem development and integration: The author played a key role in the integration of critical subsystems for the powertrain, such as PKM and PGSP, which are essential for optimizing the interaction between the internal combustion engine and the electric motors during gear transitions.

2. Development of new functions: As part of the Liquefied Petroleum Gas (LPG) integration project in Etech powertrains, the challenges related to fuel transitions and torque management were addressed. This involved pioneering functions for adapting the engine from a system operations perspective.

3. Modifications in the functional architecture: Modifications were proposed and implemented in the existing functional architecture of the systems to support new functionalities (HNF) and change requests (CR) in line with the needs of stakeholders.

4. assessment and system robustness: Through a detailed analysis, the author identified key risks associated with the introduction of these changes into the hybrid system. The modifications ensured that the system could meet performance demands while maintaining stable transitions between different operating modes.

During the internship, the specific objectives were met, which included identifying stakeholder needs, analyzing the functional architecture of the existing systems, and proposing modifications to support the projects conducted during the internship period. Furthermore, collaboration with other systems, such as the combustion system, highlighted the importance of cross-functional cooperation and the need for precise integration within the powertrain.

The next steps include extensive testing in the validation process of the developed functions, which will allow for an evaluation of the system's performance under various conditions. These tests will help identify any additional adjustments necessary to ensure system efficiency.

Ultimately, this internship provided practical experience in managing and integrating complex systems in a dynamic engineering environment. The knowledge gained through the PFS-related functions underscores the importance of adaptability, technical expertise, and collaboration across all sectors to meet the final project goals within the company. Although the transition from a role focused on MBSE modeling to the responsibility of a PFS was not initially part of the internship proposal, it demonstrated the flexibility required in the field of engineering, particularly when working in the ever-changing landscape of the automotive industry.

REFERENCES

[1] M. Garcia, “SYSTEMS ENGINEERING TRAINING,” FEV Internal Training Document, February 2024, confidential Document.

[2] “Principles of Requirements Engineering or Requirements Management 101,” March 2024. [Online]. Available: https://www.inflectra.com/Ideas/Whitepaper/Principles-of-Requirements-Engineering.aspx

[3] F. Iberia, “PKM - S42 System Training,” Internal Document, May 2024, confidential Document.

[4] M. Garcia, “SDCR PROCESS & REQUIREMENTS,” FEV Internal Document, February 2024, confidential Document.

[5] M. Pichler, N. Krenmayr, E. Schneider, and U. Brand, “EU industrial policy: Between modernization and transformation of the automotive industry,” *Environmental Innovation and Societal Transitions*, vol. 38, pp. 140–152, 1 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2210422420301441

[6] Renault, “ E-Tech full hybrid - Renault.” [Online]. Available: https://www.renault.es/e-tech-full-hybrid.html

[7] S. Defoort, M. Balesdent, P. Klotz, P. Schmollgruber, J. Morio, J. Hermetz, C. Blondeau, G. Carrier, and N. Bérend, “Multidisciplinary Aerospace System Design: Principles, Issues and Onera Experience.” 5 2012. [Online]. Available: https://hal.science/hal-01184311/

[8] Renault, “System Function Pilot (PFS) Job Description,” Internal Report, November 2020, confidential Document.

[9] Horse, “Checklist PFS Job,” Internal Report, November 2020, confidential Document.

[10] M. D. ARAUJO, “Leader ingénierie Système ATG & CBG,” FEV Internal Training Document, March 2021, confidential Document.

[11] B. Nuseibeh and S. M. Easterbrook, "Requirements engineering: a roadmap." in *ICSE - Future of SE Track*, A. Finkelstein, Ed. ACM, 2000, pp. 35–46. [Online]. Available: http://dblp.uni-trier.de/db/conf/icse/future2000.html#NuseibehE00

[12] L. A. Macaulay, *Requirements engineering.* Springer Science & Business Media, 2012.

[13] J. Dick, E. Hull, and K. Jackson, *Requirements engineering.* Springer, 2017.

[14] Renault, "S34 – Powertrain Torque Management," Internal Documents, September 2016, iD Cards.

[15] A. Lefèvre, "Kit de communication ASC Hybrides," Internal Confidential Report, November 2018, confidential Report, Renault.

[16] Renault, "S42 – Hybrid Management," Internal Documents, December 2018, iD Cards.

[17] L. Houssin, "System Hybrid Management," FEV Internal Training Document, February 2024, confidential Document.

[18] Z. Krobot, B. Kopilakova, P. Stodola, and J. Stodola, "Analysis of the Euro 7 emission standard," in *2023 International Conference on Military Technologies (ICMT)*, 2023, pp. 1–4.

[19] K. Mihailova, "The Feasibility of Achieving Objectives of the Euro 7 Standards in the Baltic Countries," *Acta Prosperitatis*, vol. 14, no. 1, pp. 129–143, 2023.

[20] J. Damidavičius, M. Burinskienė, R. Ušpalytė *et al.*, "A monitoring system for sustainable urban mobility plans," *The Baltic Journal of Road and Bridge Engineering*, vol. 14, no. 2, pp. 158–177, 2019.

[21] K. Nowicka, "Cloud computing in sustainable mobility," *Transportation Research Procedia*, vol. 14, pp. 4070–4079, 2016.

[22] M. Garcia, "SYSTEMS ORGANIZATION AND SDR PROCESS TRAINING," FEV Internal Document, February 2024, confidential Document.

[23] J. Wang, Y. W. Chen, J. Sun, and S. J. Liu, “Experimental Study on Combustion Characteristics of LPG and Gasoline,” *Applied Mechanics and Materials*, vol. 448, pp. 3350–3353, 2014.