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Uniting ASPICE Rigor with MBPLE for Variant Management

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MBSE-Driven Engineering Excellence: Uniting ASPICE Rigor with MBPLE for Variant Management

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Abstract.

Modern automotive development must address the dual complexity of meeting stringent process standards such as ASPICE, while efficiently managing increasing product variability across a wide range of configurations. Traditionally, these two challenges—process compliance and variant engineering—are handled in isolation, redundant effort, and inconsistent traceability across the product lifecycle. This work presents a unified modeling approach that directly integrates ASPICE-aligned system engineering processes with Model-Based Product Line Engineering (MBPLE) techniques using an MBSE tool (Catia Magic Draw)

Model-Based Systems Engineering (MBSE), when augmented with Model-Based Product Line Engineering (MBPLE), offers a transformative solution—enabling structured, variant-aware modeling aligned with process standards such as ASPICE. This paper explores a comprehensive MBSE-driven methodology realized in Catia Magic Draw, unifying ASPICE process rigor with configurable architectures that promote reusability and faster adaptation to product feature diversity. A real-world Headlamp Control System case study illustrates the methodology. The results demonstrate that MBSE+MBPLE unification improves compliance, reduces engineering effort, and prepares organizations for future-ready systems engineering.

Keywords. MBSE, MBPLE, ASPICE, Variant Management, Automotive Systems Engineering, Cameo Systems Modeler, Requirements Traceability, Process Compliance.

1. Introduction

The transition toward software-defined vehicles has intensified the complexity of automotive systems. OEMs and Tier-1 suppliers are now tasked with delivering highly variable, feature-rich platforms under increasing time and quality pressures. Automotive SPICE® (ASPICE) remains the Defacto process standard to ensure development rigor, mandating structured requirements elicitation (SYS.1), requirements analysis (SYS.2), and architectural design (SYS.3). However, ASPICE primarily focuses on "what" must be achieved without prescribing "how" to manage the growing variability across product lines.

Model-Based Systems Engineering (MBSE), enhanced with Model-Based Product Line Engineering (MBPLE), provides the missing operational framework. MBSE brings structured modeling discipline and digital continuity, while MBPLE offers systematic handling of product variants via feature models and variation points. This paper proposes a practical, unified approach using Catia Magic Draw (Cameo Systems Modeler) with an MBPLE extension. A Headlamp Control System case study validates the methodology, showing how automotive programs can simultaneously achieve ASPICE compliance and reuse-driven efficiency.

2. *Problem Statement and Scope*

The Core Problem

Modern automotive development demands rapid configuration and delivery of feature-rich products, often tailored for specific OEMs or markets. Without an integrated variant management strategy, teams operate in silos, causing duplication, inconsistent traceability, and compliance risks. Manual processes further compound these challenges by increasing the risk of missed variant-specific requirements and audit gaps. An MBSE+MBPLE framework centered on ASPICE framework for system stages addresses these issues by enabling structured reuse, early validation, and scalable configuration.

Scope of the Paper

This paper focuses on the integration of Model-Based Systems Engineering (MBSE) and Model-Based Product Line Engineering (MBPLE) methodologies to support compliance with Automotive SPICE (ASPICE) for the system-level processes of SYS.1 (Stakeholder Requirements Elicitation), SYS.2 (System Requirements Analysis), and SYS.3 (System Architectural Design). The scope includes demonstrating how MBPLE can be effectively leveraged within an MBSE environment to manage product variants, using a headlamp control system case study featuring Adaptive Driving Beam (ADB) and Advanced Front-lighting System (AFS) functionalities as a practical illustration.

3. *Methodology*

The methodology adopted is applied to a configurable LED Matrix Headlamp system, focusing on adaptive lighting functionalities (ADB, AFS) to ensure Automotive SPICE (ASPICE) SYS.1–SYS.3 process compliance, while leveraging Model-Based Product Line Engineering (MBPLE) practices to systematically handle product variability. This enforces model integrity while minimizing human error during variant definition or compliance assessment. By embedding MBPLE practices at the core of ASPICE SYS.1 to SYS.3, the approach achieves engineering consistency across variants

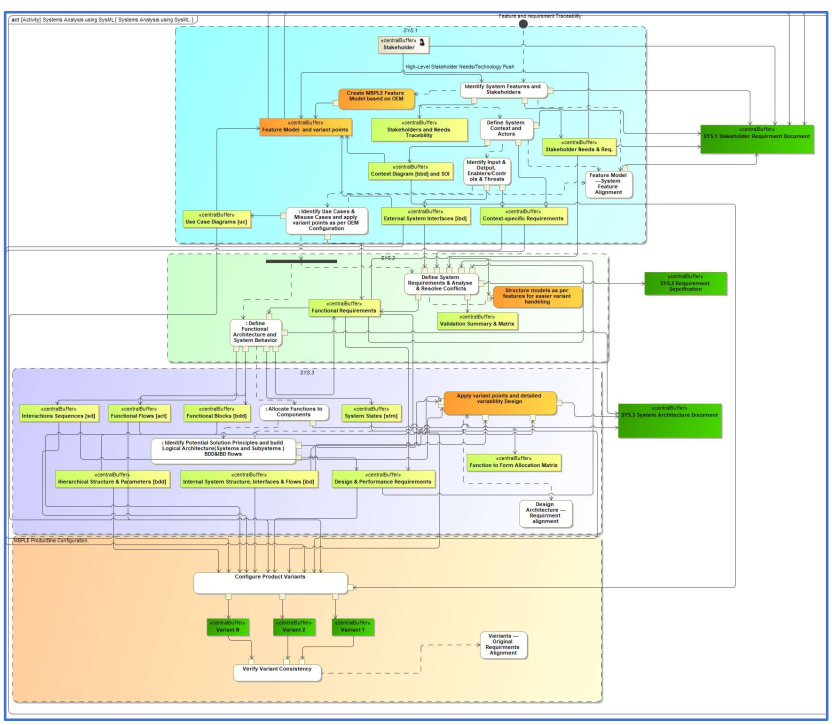
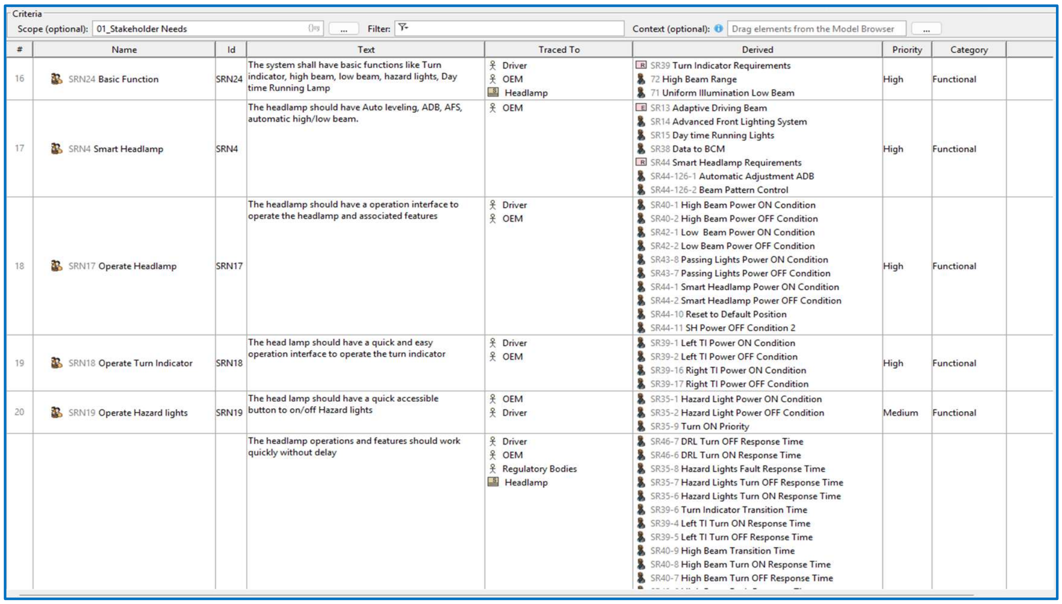


Fig -1 ASPICE –SYS.1-SYS.3 integrated MBPLE Workflow

3.1 ASPICE SYS.1 Activities (Requirements Elicitation)

The ASPICE SYS.1 process focuses on capturing stakeholder needs in a structured, complete, and traceable manner.

- **Elicitation of Stakeholder requirements** from the stakeholder needs Fig 2.a
- **Context Models** were developed to define external interactions clearly Fig 2.b
- **Operational Analysis** to Support early behavior of the System with use cases and Activity charts. Fig2.c



Criteria
Scope (optional): 01_Stakeholder Needs | Filter: | Context (optional): Drag elements from the Model Browser

#	Name	Id	Text	Traced To	Derived	Priority	Category
16	SRN24 Basic Function	SRN24	The system shall have basic functions like Turn indicator, high beam, low beam, hazard lights, Day time Running Lamp	Driver OEM Headlamp	SR39 Turn Indicator Requirements 72 High Beam Range 71 Uniform Illumination Low Beam	High	Functional
17	SRN4 Smart Headlamp	SRN4	The headlamp should have Auto leveling, ADB, AFS, automatic high/low beam.	OEM	SR13 Adaptive Driving Beam SR14 Advanced Front Lighting System SR15 Day time Running Lights SR38 Data to BCM SR44 Smart Headlamp Requirements SR44-126-1 Automatic Adjustment ADB SR44-126-2 Beam Pattern Control	High	Functional
18	SRN17 Operate Headlamp	SRN17	The headlamp should have a operation interface to operate the headlamp and associated features	Driver OEM	SR40-1 High Beam Power ON Condition SR40-2 High Beam Power OFF Condition SR42-1 Low Beam Power ON Condition SR42-2 Low Beam Power OFF Condition SR43-8 Passing Lights Power ON Condition SR43-7 Passing Lights Power OFF Condition SR44-1 Smart Headlamp Power ON Condition SR44-2 Smart Headlamp Power OFF Condition SR44-10 Reset to Default Position SR44-11 SH Power OFF Condition 2	High	Functional
19	SRN18 Operate Turn Indicator	SRN18	The head lamp should have a quick and easy operation interface to operate the turn indicator	Driver OEM	SR39-1 Left TI Power ON Condition SR39-2 Left TI Power OFF Condition SR39-16 Right TI Power ON Condition SR39-17 Right TI Power OFF Condition	High	Functional
20	SRN19 Operate Hazard lights	SRN19	The head lamp should have a quick accessible button to on/off Hazard lights	OEM Driver	SR35-1 Hazard Light Power ON Condition SR35-2 Hazard Light Power OFF Condition SR35-9 Turn ON Priority	Medium	Functional
			The headlamp operations and features should work quickly without delay	Driver OEM Regulatory Bodies Headlamp	SR46-7 DRL Turn OFF Response Time SR46-6 DRL Turn ON Response Time SR35-8 Hazard Lights Fault Response Time SR35-7 Hazard Lights Turn OFF Response Time SR35-6 Hazard Lights Turn ON Response Time SR39-6 Turn Indicator Transition Time SR39-4 Left TI Turn ON Response Time SR39-5 Left TI Turn OFF Response Time SR40-9 High Beam Transition Time SR40-8 High Beam Turn ON Response Time SR40-7 High Beam Turn OFF Response Time		

Fig 2.a Stakeholder Requirements

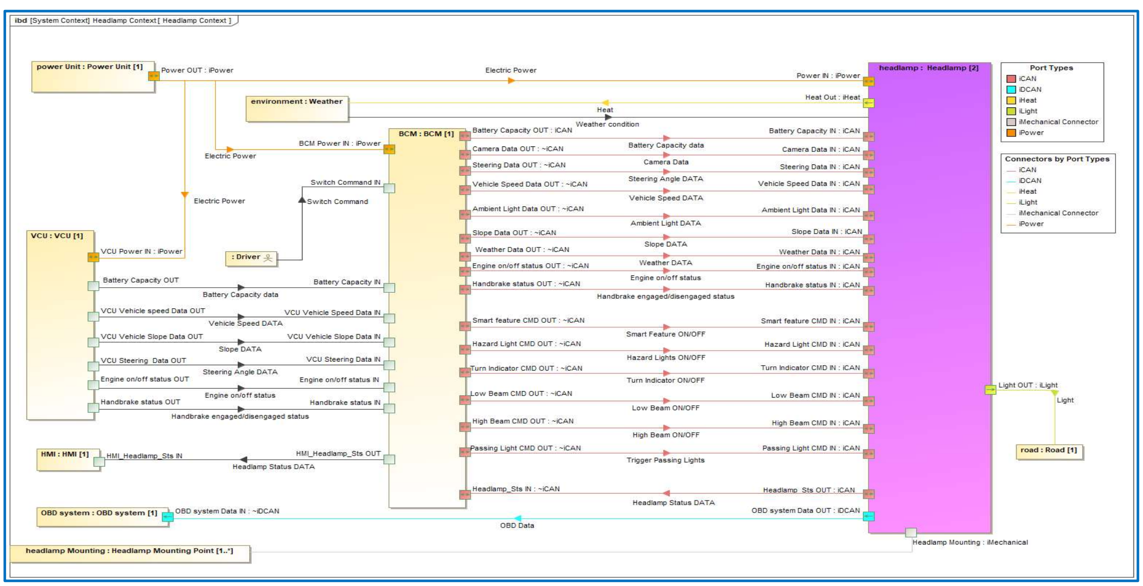


Fig 2.b System Context Model

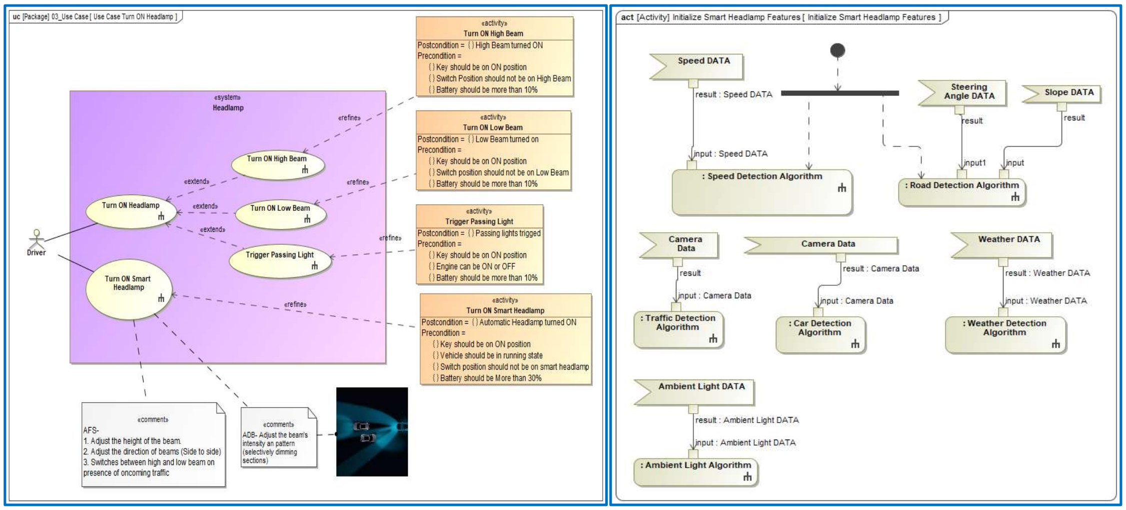


Fig 2.c Operational Analysis

The output fulfills the ASPICE SYS.1 mandatory work product: **Stakeholder Requirements Elicitation (WP1)**.

3.2 ASPICE SYS.2 Activities (System Requirements Analysis)

Following the elicitation of stakeholder needs, the ASPICE SYS.2 process requires the systematic derivation of system requirements.

- **Requirement Table** was created, capturing both mandatory and feature-conditional requirements.
- Requirements were linked back to stakeholder needs and future architectural elements through **Derive** and **Satisfy** relationships.

#	Name	Text	Categories	Derived From	Traced To	Remark
106	SR39 Turn Indicator Requirements			SRN24 Basic Function	Operate Turn Indicator	
107	SR39-1 Left TI Power ON Condition	The system shall turn ON Left turn Indicator light when user press left turn ON switch / touch screen option.	Functional	SRN18 Operate Turn Indicator	Turn ON Left Turn Indicator Turn ON Right Turn Indicator	Assumption: it will have switch or an option on touch screen
108	SR39-2 Left TI Power OFF Condition	The system shall Turn OFF Left Turn Indicator light when user press left turn ON switch/ touch screen option.	Functional	SRN18 Operate Turn Indicator	Turn OFF Left Turn Indicator Turn OFF Right Turn Indicator	Assumption: it will have switch or an option on touch screen
109	SR39-3 TI Battery Capacity Turn ON Constraint	The system shall not turn ON Turn Indicator if battery capacity is less than 20%.	Functional	SRN21 Low Power protection	Turn ON Left Turn Indicator Turn ON Right Turn Indicator Turn ON Left Turn Indicator(classifier be Turn ON Right Turn Indicator(classifier	Assumption: 20% limit value is assumed
110	SR39-4 Left TI Turn ON Response Time	The system shall turn ON Left Turn Indicator under 5 ms after receiving Left Turn Indicator ON command.	Functional	SRN20 Quick Response	Turn ON Left Turn Indicator Turn ON Right Turn Indicator	Assumption: 5 ms value is assumed
111	SR39-5 Left TI Turn OFF Response Time	The system shall turn OFF Left Turn Indicator under 5 ms after receiving Left Turn Indicator OFF command.	Functional	SRN20 Quick Response	Turn OFF Left Turn Indicator Turn OFF Right Turn Indicator	Assumption: 5 ms value is assumed
112	SR39-6 Turn Indicator Transition Time	The system shall switch under 5 ms when its directly triggered from one indicator ON state to another indicator ON state	Functional	SRN20 Quick Response	Turn ON Left Turn Indicator Turn ON Right Turn Indicator	Assumption: 5 ms value is assumed
113	SR39-7 Turn Indicator Precedence Notification	If hazard lights are already ON, the system shall send a message to the Human-Machine Interface (HMI) to turn them OFF when turn indicator ON command received.	Functional		Turn ON Left Turn Indicator Turn ON Right Turn Indicator Send message to HMI to turn off Hazar Send Message on HMI to turn off Hazar	
114	SR39-8 Blinking Rate	The system shall turn ON TI LEDs for 1 second and keep turn OFF for 1 second,with transition time of 10 ms	Functional		Turn ON Left Turn Indicator Turn ON Right Turn Indicator Start Flashing Left Turn Indicator(conte Start Flashing Right Turn Indicator(cont	Assumption: 1 sec on and off is assumed value.
115	SR39-9 Turn Indicator intensity	The system shall have Minimum 100 candela (cd) in any direction & Maximum 1,000 cd to avoid glare Minimum ,OR Luminous Intensity: 100 candela (cd) for the front and rear indicators. Maximum Luminous Intensity: 1,000 candela (cd) to prevent excessive glare, according to SAE J579 & ECE R112 respectively	Non-Functional	SRN2 Luminous Intensity	Turn ON Left Turn Indicator Turn ON Right Turn Indicator	Assumption: Candela values are assumed based on data available on INTERNET
116	SR39-10 TI & HL Communication	The system shall support communication with the hazard light control subsystem.	Non-Functional		Send message to HMI to turn off Hazar Send Message on HMI to turn off Hazar Turn ON Left Turn Indicator Turn ON Right Turn Indicator	
117	SR39-11 TI Diagnostic Tool support	The system shall support diagnostic tools for fault detection and troubleshooting.	Non-Functional	SRN3 Low Maintenance	Turn OFF Left Turn Indicator Turn OFF Right Turn Indicator Turn ON Left Turn Indicator Turn ON Right Turn Indicator	
118	SR39-12 TI Activation History	The system shall record the activation history of the Turn Indicator for diagnostic purposes.	Non-Functional	SRN3 Low Maintenance	Turn ON Left Turn Indicator Turn ON Right Turn Indicator	

Figure 3. System Requirement Analysis SYS.2

This step generates the **System Requirements Specification (WP2)**, satisfying ASPICE SYS.2 outputs and ensuring traceability for variant-specific behaviors.

3.3 ASPICE SYS.3 Activities (System Architecture with Variation Points)

ASPICE SYS.3 focuses on decomposing system requirements into a logical and functional architecture that defines the system's technical solution.

- Define **Block Definition Diagrams (BDD)-Fig 4.a** and **Internal Block Diagrams (IBD) -Fig 4.b** modeled logical components and their interfaces.
- **Variation Points** were embedded directly into logical architecture models, representing feature-driven differences structurally.
- Define System Functional Behavior of the Headlamp –**Fig 4.c:** Functional Architecture
- Signal exchanges, control flow, were systematically mapped- **Fig 4.d: ICD interface Description File**

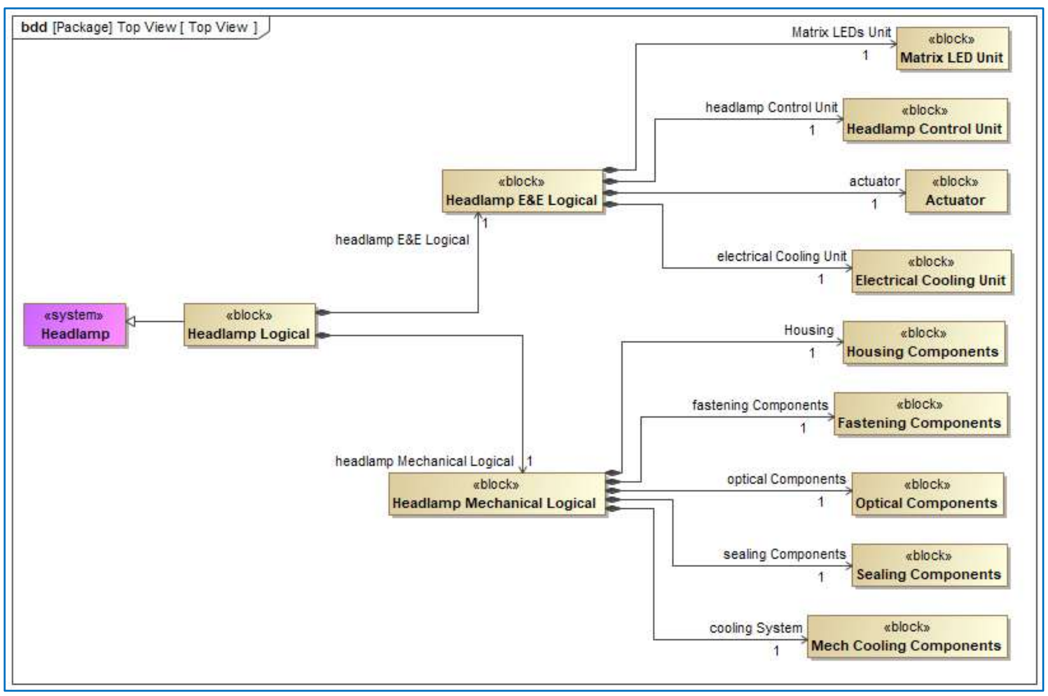


Fig 4.a System Block Diagram

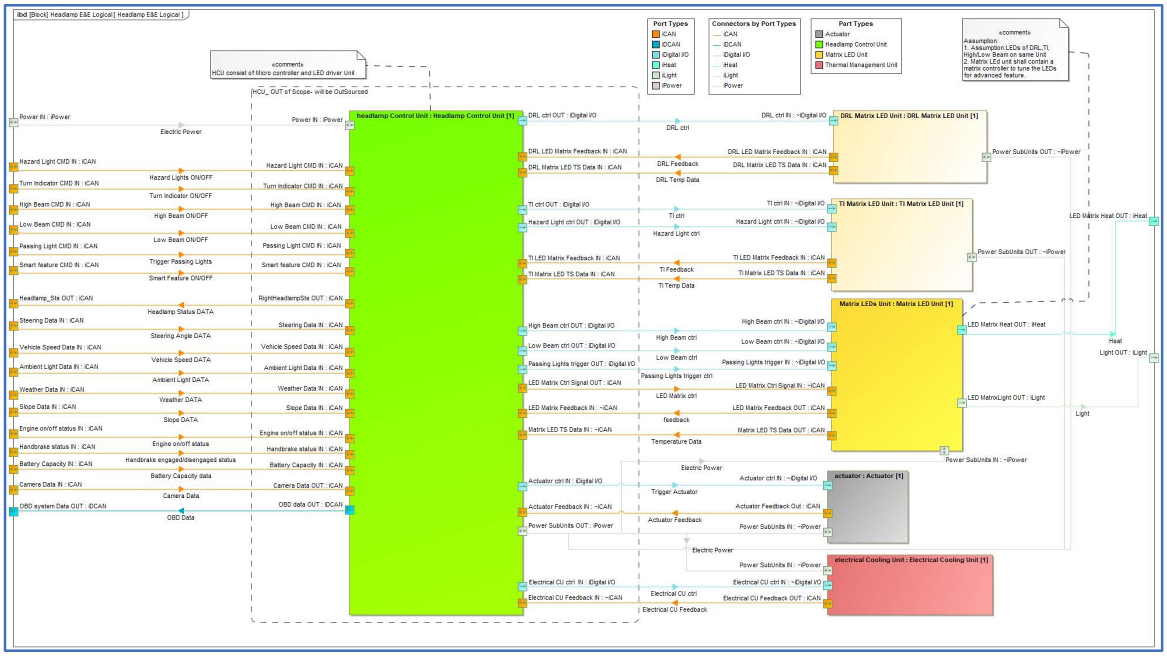


Fig 4.b System Internal Block Diagram

Criteria

Element Type: Connector … Context: Headlamp E&E Logical … Filter:

#	Part A	Port A	Item Flow	Port B	Part B
1	Headlamp E&E Logical	inout Ambient Light Data IN : iCAN	▶ Ambient Light DATA	inout Ambient Light Data IN : iCAN	headlamp Control Unit : Head...
2	Headlamp E&E Logical	inout Weather Data IN : iCAN	▶ Weather DATA	inout Weather Data IN : iCAN	headlamp Control Unit : Head...
3	Headlamp E&E Logical	inout Power IN : iPower	▶ Electric Power	inout Power IN : iPower	headlamp Control Unit : Head...
4	headlamp Control Unit : Headlamp Contr...	out OBD data OUT : iDCAN	▶ OBD Data	out OBD system Data OUT : iDCAN	Headlamp E&E Logical
5	headlamp Control Unit : Headlamp Contr...	inout Power SubUnits OUT : iPower	▶ Electric Power	inout Power SubUnits IN : ~iPower	electrical Cooling Unit : Electri...
6	headlamp Control Unit : Headlamp Contr...	inout RightHeadlampSts OUT : iCAN	▶ Headlamp Status DATA	inout Headlamp_Sts OUT : iCAN	Headlamp E&E Logical
7	Matrix LEDs Unit : Matrix LED Unit [1]	out LED MatrixLight OUT : iLight	▶ Light	out Light OUT : iLight	Headlamp E&E Logical
8	Headlamp E&E Logical	inout Slope Data IN : iCAN	▶ Slope DATA	inout Slope Data IN : iCAN	headlamp Control Unit : Head...
9	Headlamp E&E Logical	inout Steering Data IN : iCAN	▶ Steering Angle DATA	inout Steering Data IN : iCAN	headlamp Control Unit : Head...
10	Headlamp E&E Logical	inout Vehicle Speed Data IN : iCAN	▶ Vehicle Speed DATA	inout Vehicle Speed Data IN : iCAN	headlamp Control Unit : Head...
11	Headlamp E&E Logical	inout Battery Capacity IN : iCAN	▶ Battery Capacity data	inout Battery Capacity IN : iCAN	headlamp Control Unit : Head...
12	Headlamp E&E Logical	inout Engine on/off status IN : iCAN	▶ Engine on/off status	inout Engine on/off status IN : iCAN	headlamp Control Unit : Head...
13	Headlamp E&E Logical	inout Handbrake status IN : iCAN	▶ Handbrake engaged/disengaged stat	inout Handbrake status IN : iCAN	headlamp Control Unit : Head...
14	actuator : Actuator [1]	in Actuator ctrl IN : ~iDigital I/O	◀ Trigger Actuator	out Actuator ctrl IN : iDigital I/O	headlamp Control Unit : Head...
15	headlamp Control Unit : Headlamp Contr...	inout Hazard Light CMD IN : iCAN	◀ Hazard Lights ON/OFF	inout Hazard Light CMD IN : iCAN	Headlamp E&E Logical
16	headlamp Control Unit : Headlamp Contr...	inout High Beam CMD IN : iCAN	◀ High Beam ON/OFF	inout High Beam CMD IN : iCAN	Headlamp E&E Logical
17	headlamp Control Unit : Headlamp Contr...	inout Low Beam CMD IN : iCAN	◀ Low Beam ON/OFF	inout Low Beam CMD IN : iCAN	Headlamp E&E Logical
18	headlamp Control Unit : Headlamp Contr...	inout Passing Light CMD IN : iCAN	◀ Trigger Passing Lights	inout Passing Light CMD IN : iCAN	Headlamp E&E Logical
19	headlamp Control Unit : Headlamp Contr...	inout Smart feature CMD IN : iCAN	◀ Smart Feature ON/OFF	inout Smart feature CMD IN : iCAN	Headlamp E&E Logical
20	headlamp Control Unit : Headlamp Contr...	inout Turn Indicator CMD IN : iCAN	◀ Turn Indicator ON/OFF	inout Turn Indicator CMD IN : iCAN	Headlamp E&E Logical
21	Matrix LEDs Unit : Matrix LED Unit [1]	in High Beam ctrl IN : ~iDigital I/O	◀ High Beam ctrl	out High Beam ctrl OUT : iDigital I/O	headlamp Control Unit : Head...
22	Matrix LEDs Unit : Matrix LED Unit [1]	in Low Beam ctrl IN : ~iDigital I/O	◀ Low Beam ctrl	out Low Beam ctrl OUT : iDigital I/O	headlamp Control Unit : Head...
23	Matrix LEDs Unit : Matrix LED Unit [1]	in Passing Lights trigger IN : ~iDigital I/O	◀ Passing Lights trigger ctrl	out Passing Lights trigger OUT : iDigital I/O	headlamp Control Unit : Head...
24	Headlamp E&E Logical	inout Ambient Light Data IN : iCAN		inout Ambient Light Data IN : iCAN	headlamp Control Unit : Head...
25	Headlamp E&E Logical	inout Battery Capacity IN : iCAN		inout Battery Capacity IN : iCAN	headlamp Control Unit : Head...
26	Headlamp E&E Logical	inout Camera Data IN : iCAN		inout Camera Data OUT : iCAN	headlamp Control Unit : Head...
27	Headlamp E&E Logical	inout Camera Data IN : iCAN	▶ Camera Data	inout Camera Data OUT : iCAN	headlamp Control Unit : Head...
28	electrical Cooling Unit : Electrical Cooling ...	inout Electrical CU Feedback OUT : iCAN	▶ Electrical CU Feedback	inout Electrical CU Feedback IN : ~iCAN	headlamp Control Unit : Head...
29	Headlamp E&E Logical	inout Engine on/off status IN : iCAN		inout Engine on/off status IN : iCAN	headlamp Control Unit : Head...
30	Headlamp E&E Logical	inout Handbrake status IN : iCAN		inout Handbrake status IN : iCAN	headlamp Control Unit : Head...

Fig 4.d Interface Description Table

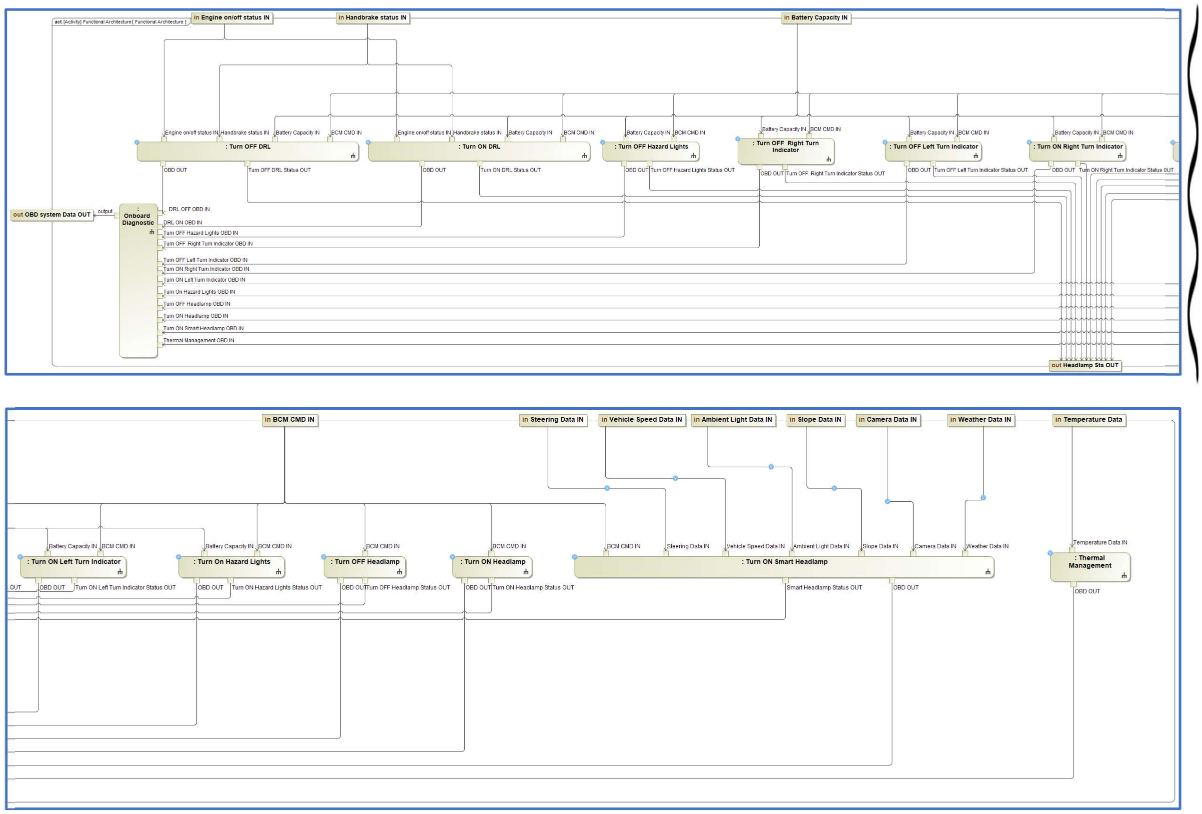


Fig 4.c Functional Architecture

The resulting **System Architectural Specification (WP3)** demonstrates full traceability to SYS.1–SYS.2 artifacts while explicitly managing variability at the design level.

3.4 Role of MBPLE Variant Management

Managing Product Complexity with Model-Based Product Line Engineering (MBPLE)

Model-Based Product Line Engineering (MBPLE) extends the principles of MBSE to specifically address the challenges of managing product complexity and variability across a product line. It enables the development of a family of similar products from a common base, addressing the increasing complexity and variations prevalent in automotive systems. MBPLE integrates MBSE with Product Line Engineering (PLE) approaches, emphasizing the systematic reuse of engineering assets. This approach enables significant reuse of engineering artifacts and reduces the effort needed to develop and maintain multiple product variants.

Feature models are central to MBPLE, providing a structured way to represent the common and variable features of a product line. These models, often represented as UML class models, define all possible features, with features that can be either present or absent modeled as Boolean properties and features with multiple exclusive choices modeled as properties with enumerated types. The root of the feature model is typically a class stereotyped as «RootFeatureGroup», and features can be organized into subgroups using classes with the «FeatureGroup» stereotype. Based on the feature model, specific product configurations are defined, essentially selecting a subset of features to represent a particular variant.

In the system architecture model, variability is managed through the use of variation points. These points demarcate parts of the system that differ across variants. For instance, an Existence Variation Point is used when a model element may or may not be present in a specific variant. Feature impacts define which features from the feature model influence a particular variation point, and conditions (often expressed as Boolean expressions) determine when a variation point is active based on the selected features in a given configuration. By leveraging commonalities and managing variations systematically, MBPLE enables significant asset reuse, reducing redundancy and rework, and improving the time-to-market for new product variants.

MBPLE techniques were integrated post-SYS.1–SYS.3 to manage multiple product variants efficiently:

- A **150% System Model** was created containing all possible feature configurations.
- A **Feature Model** was established separately, defining optional and mandatory features (custom: ADB and AFS).
- **Configuration Rules** automatically instantiated specific system variants based on selected feature sets.

Without MBPLE, maintaining traceability and consistency across multiple headlamp variants would require significant manual duplication and error-prone processes, directly risking ASPICE non-compliance【2】【3】.

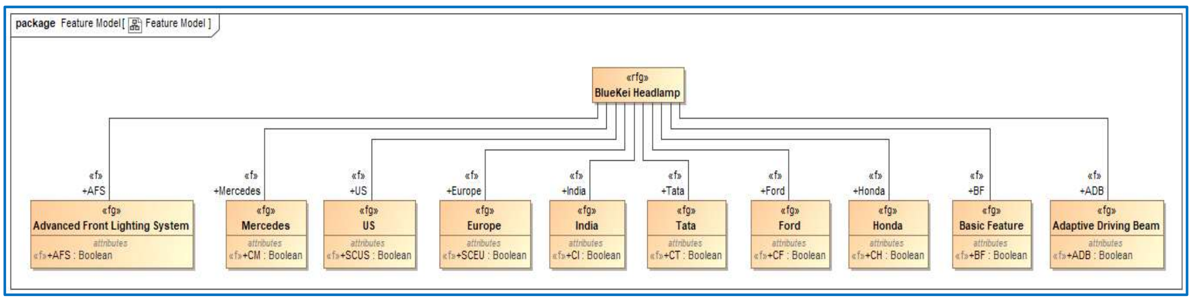


Fig 5.a Feature Model

Criteria

Classifier: BlueKei Headlamp ... Scope (optional): Variant Config. ... Filter:

#	Name	BF.BF : Boolean	ADB.ADB : Boolean	AFS.AFS : Boolean	Honda.CH : Boolean	India.CI : Boolean	Ford.CF : Boolean	Mercedes.CM : Boolean	Tata.CT : Boolean	Europe.SCEU : Boolean	US.SCUS : Boolean
1	blueKei Headlamp_Basic Feature	true	false	false							
2	blueKei Headlamp_BF+ABD	true	true	false							
3	blueKei Headlamp_BF+AFS	true	false	true							
4	blueKei Headlamp_BF+ADB+AFS	true	true	true							
5	blueKei Headlamp_ Project Honda_BF+ADB	true	true	false	true	true	false	false	false	false	false
6	blueKei Headlamp_ Project Ford_AF	true	true	true	false	true	true	false	false	false	false
7	blueKei Headlamp_Project_TATA_BF	true	true	true	false	true	false	false	true	false	false

Fig 5.b Variant Configurations

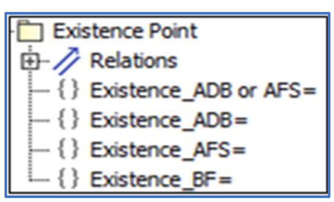


Fig 5.c Existence Point

In Fig 5.a, the Feature Model uses a «RootFeatureGroup» class with Boolean and enumerated properties to represent ADB and AFS. Variation points like Fig 5.c (Existence Point) are directly linked to these features, enabling selective instantiation in subsequent diagrams.

The Feature Model defines optional system features such as ADB and AFS. Configuration rules enable conditional activation of specific blocks and behaviors during variant selection. These variation points are explicitly embedded in architecture, linking features to their realization of structure and behavior. This approach showcases how MBPLE concretely supports ASPICE SYS.1-SYS.3 expectations.

229	SR44-43 Trigger Car detection above 100	The system shall tirgger "Trigger Car Detection_HS" when speed is >= 100 kmph	ADB & AFS
230	SR44-44 Trigger Ambient light detection below 55	The system shall trigger "Trigger Ambient Light Detection" when speed is <=55 kmph	ADB & AFS
231	SR44-45 Trigger Ambient light detection b/w 555-100	The system shall trigger "Trigger Ambient Light Detection" when speed is >55&&<100 kmph]	ADB & AFS
232	SR44-46 SH SDA Fault Notification	The system shall send Speed Detection System Fault message when fault is detected	ADB & AFS
233	SR44-47 SH SDA Fault Log	The system shall save Speed Detection System Fault log after fault is detected	ADB & AFS
234	SR44-48 SH Re initiate Speed Detection	The system shall reinitiate speed detection after tiggering other algorithms	ADB & AFS
235	SR44-49 SH Road detection algorithm	The system shall have road detection algorithm which includes road cuvature & slope detection	AFS
236	SR44-50 SH Road Cuvature detection	The system shall have road curvature detection algorithm	AFS
237	SR44-51 SH Receive Steering Data	The system shall receive steering angel data form BCM	AFS
238	SR44-52 SH Road cuvature detection	The system shall detect road curvature form steering angel data	AFS
239	SR44-53 SH reset actuator 1 position	The system shall Reset Actuator 1 to Original Position when steering angel is 0.	AFS
240	SR44-54 SH RCD left actuation	The system shall actuate light left via actuator if steering angle is positive	AFS

221	SR44-43 Trigger Car detection above 100	The system shall tirgger "Trigger Car Detection_HS" when speed is >= 100 kmph	ADB & AFS
222	SR44-44 Trigger Ambient light detection below 55	The system shall trigger "Trigger Ambient Light Detection" when speed is <=55 kmph	ADB & AFS
223	SR44-45 Trigger Ambient light detection b/w 555-100	The system shall trigger "Trigger Ambient Light Detection" when speed is >55&&<100 kmph]	ADB & AFS
224	SR44-46 SH SDA Fault Notification	The system shall send Speed Detection System Fault message when fault is detected	ADB & AFS
225	SR44-47 SH SDA Fault Log	The system shall save Speed Detection System Fault log after fault is detected	ADB & AFS
226	SR44-48 SH Re initiate Speed Detection	The system shall reinitiate speed detection after tiggering other algorithms	ADB & AFS
227	SR44-78 SH Car detection algorithm	The system shall have car detection algorithm	ADB
228	SR44-79 SH Car detection	The system shall detect Car from camera data	ADB
229	SR44-80 SH Receive Camera data	The system shall receive camera data form BCM for car detection	ADB
230	SR44-81 SH CD trigger from high speed & Ambient Light de	the system shall receive two trigger "Trigger car detection_HS" from speed detection algorithm and "Trigger car detection_HB" from Ambient light detection algorithm for weather detection	ADB

Fig 5.d System Requirements for Basic + ADB feature, no AFS Feature

Fig 5e System Internal Block Diagram after Selection of Basic + ADB variant

Traceability for ADB Feature

- Stakeholder Requirement: The headlamp should have Auto leveling, ADB, AFS, and automatic high/low beam.
- System Requirement: "The ADB system shall optimize high beam performance by selectively blocking portions of the beam to avoid blinding other drivers while maintaining maximum illumination, also adjust lighting patterns dynamically based on vehicle speed, steering angle, and detected objects.
- Logical Architecture: A logical block named (e.g., Headlamp Control Unit, Matrix LED Unit) is responsible for processing sensor input and controlling LED segments.

- Variation Point: The `Existence`-ADB variation point activates only when the `ADB` feature is selected.
- Feature Model Mapping: The `ADB` Boolean feature is defined in the feature model and linked to the variation point using a `Feature Impact` relationship.

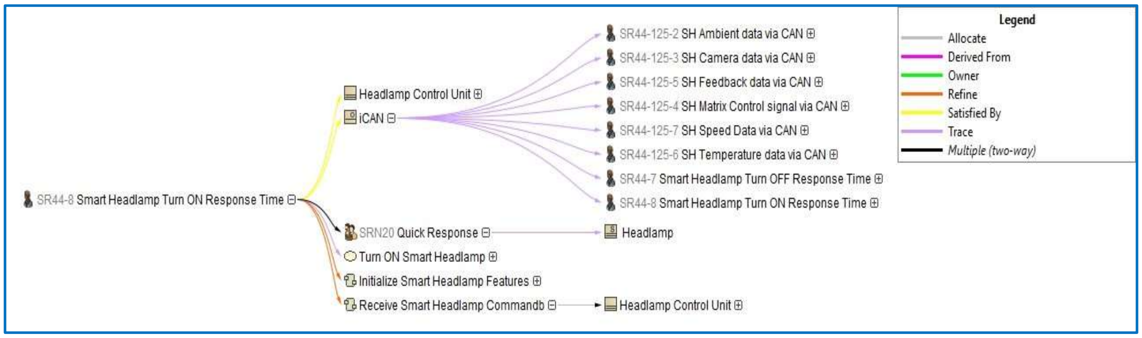


Figure 5.f: Complete Traceability from Stakeholders to System Architecture for ADB System Requirement for response time

3.5 Importance of Traceability Across SYS.1–SYS.3 for ASPICE Compliance

Consistent traceability from stakeholder needs to system requirements to system architecture is a fundamental ASPICE compliance expectation.

- **Satisfy relationships** from features to requirements to design elements.
- **Derive relationships** linking system-level decomposition.
- **Variant-specific traceability**, critical for demonstrating completeness during ASPICE assessments【1】【4】.

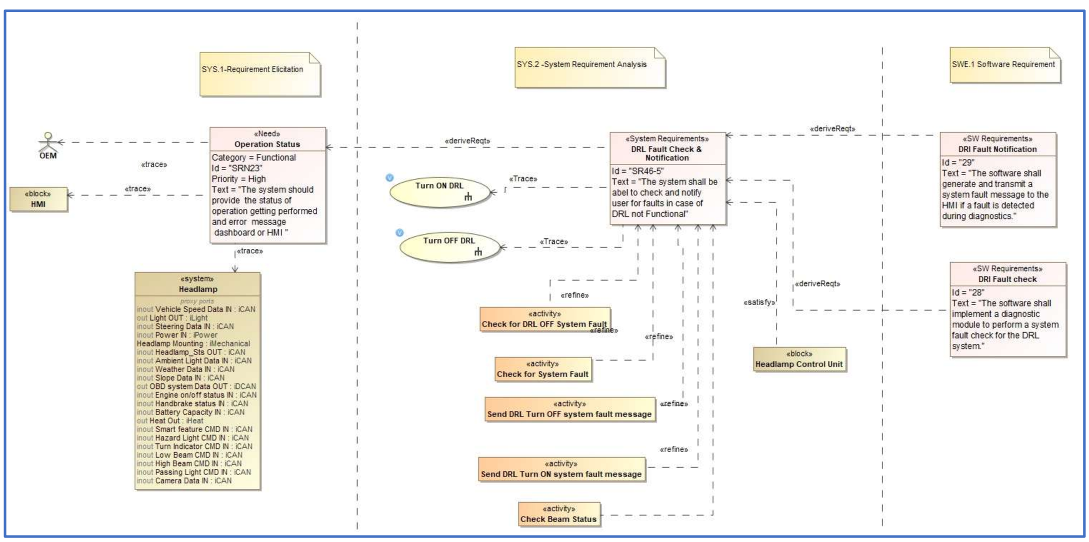


Figure 6: Complete Traceability from Stakeholders to System Architecture Compliance for ASPICE SYS.2-SYS.3 WP

This approach enabled rapid variant generation without duplicating models, preserving traceability, consistency, and ASPICE SYS.1–SYS.3 compliance throughout the system lifecycle【2】【4】.

ASPICE Process	**Variant Management Expectation**	**Source in ASPICE 4.0**	**Evidence**
SYS.1 Stakeholder Requirements Elicitation	Capture and document stakeholder-driven variability needs (e.g., optional features like ADB, AFS).	SYS.1 BP2, Automotive SPICE® 4.0 PAM (2023)	Figure –2.a-2.d Stakeholder Requirement Specification (Operational Analysis &System Boundary and Stakeholder Requirement Table)
SYS.2 System Requirements Analysis	Derive system requirements considering variant-specific conditions, and document traceability to stakeholder variability.	SYS.2 BP2, Automotive SPICE® 4.0 PAM (2023)	Figure3 –System Requirement Table & Figure 6&Figure 5.e–Traceability Matrix
SYS.3 System Architectural Design	Develop logical architecture that accommodates variant-specific functional behaviors and variation points across components.	SYS.3 BP2, Automotive SPICE® 4.0 PAM (2023)	SYS.3 System Architecture and Design Figure 4.a-4.d
SUP.8 Configuration Management	Manage versioning and baselining of models and documents. No explicit Mention of Variant configuration mentioned.	SUP.8 BP3, Automotive SPICE® 4.0 PAM (2023)	Baseline Evidence version control History

4.Benefits and Value Proposition

The proposed MBSE+MBPLE methodology not only aligns with ASPICE SYS.1–SYS.3 rigor but also delivers quantifiable improvements, validated through the Headlamp Control System case study:

Technical Benefits:

- **Accelerated Engineering Reviews**: As shown in Section 3.5, the model-based traceability framework reduced manual review loops by 30–40% due to automated «derive» and «satisfy» relationships (Fig. 4).
- **Reusability Realized**: Section 3.4 demonstrates ~50% shared feature structure (ADB/AFS) using a unified 150% model, minimizing redundant development within headlamp LED Matrix technology.
- **Time-to-Market Gains**: The integration of variation points directly in architectural models (Fig.4a-4d) enabled rapid adaptation to new OEM configurations with minimal effort.

Process Benefits:

- **Reduced Risk in Variant Handling**: Fig. 5d-5e shows how configuration-driven variant pruning helped avoid missed features, enhancing audit readiness and lowering late defect risks.
- **Improved Traceability**: SYS.1–SYS.3 artifacts maintain bidirectional links, ensuring process alignment and simplifying ASPICE assessments.
- **Scalable Compliance**: By embedding variation directly in models, the methodology supports multiple OEM variants with a single, coherent trace model.

  These benefits are direct outcomes of structuring engineering data through MBPLE logic, ensuring that ASPICE-required artifacts are produced with consistency, accuracy, and minimal duplication.

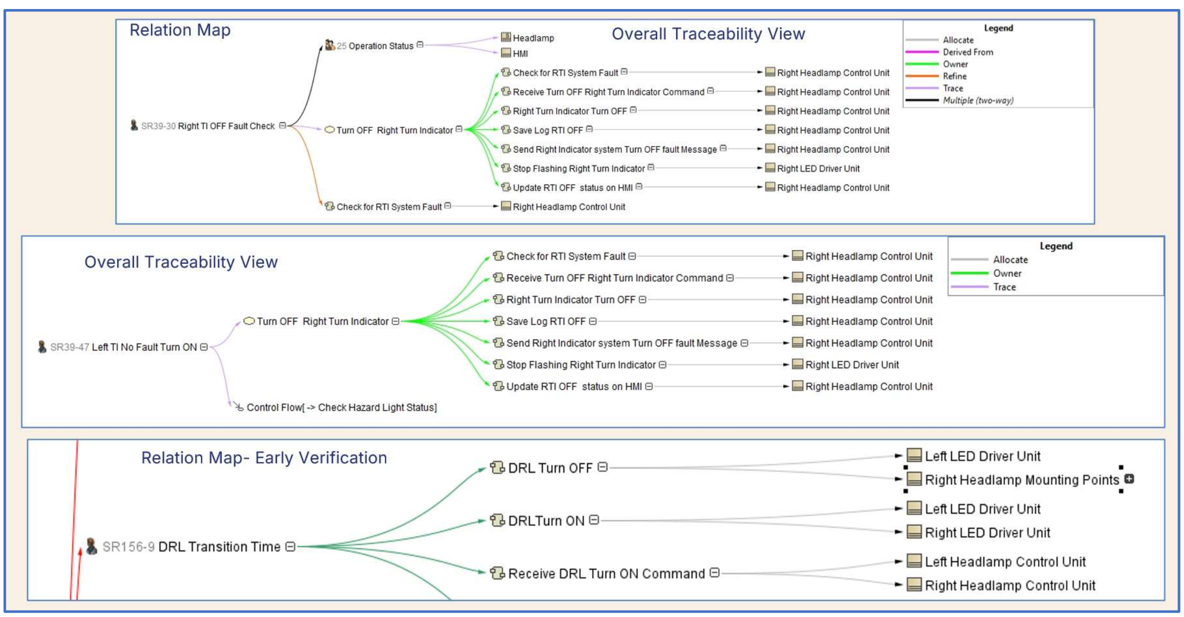


Figure 7 Early Benefits

5.Conclusion and Recommendations

The integration of ASPICE and MBPLE offers a powerful synergy for efficient and compliant automotive development. MBSE provides the structured and visual means to model all aspects of the system, ensuring better clarity, consistency, and traceability, which are fundamental to ASPICE compliance. MBPLE extends these benefits by providing a systematic approach to manage product variability through feature models and variation points, enabling significant asset reuse and reducing the effort required to handle the diversity of product offerings in the automotive sector. Early defect detection, facilitated by the rigorous processes of ASPICE and the modeling capabilities of MBSE and MBPLE, can lead to substantial reductions in development costs and improvements in product quality.

6.Future Scope

Future research can focus on extending the integration of MBSE and MBPLE to other ASPICE process areas, such as verification and validation (VAL.1), to achieve a more holistic model-based development lifecycle for variant-rich automotive systems. Further work could also explore the integration of functional safety (ISO 26262) and cybersecurity (ISO/SAE 21434) analyses within the MBPLE framework, ensuring that safety and security considerations are inherently managed across all product variants. Additionally, investigating the automation of variant-driven test case generation from system models would be a valuable area for future exploration.

7.References

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Biography

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