EVOLUTION OF THE PRODUCT AND PROCESS REQUIREMENTS DURING THE PROJECT LIFETIME

Łukasz Rudolf[1,*], Marek Roszak[2], Lenka Kuchariková[3]

[1]School of Doctors, Department of Engineering Materials and Biomaterials, Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
[2]Department of Engineering Materials and Biomaterials, Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice, Poland
[3]Department of Materials Engineering, Faculty of Mechanical Engineering, University of Zilina, Zilina, Slovakia

*E-mail of corresponding author: lukasz.rudolf@polsl.pl

Łukasz Rudolf 0000-0001-9430-8513, Marek Roszak 0000-0002-4035-8360,
Lenka Kuchariková 0000-0002-2688-1075

Resume

The automotive industry, known for its dynamism and innovation, relies on effectiveness of product and process requirements management. Effective collaboration with OEM (Original Equipment Manufacturers) is essential for success. The article analyses how product and process requirements evolve during different project phases, following the APQP (Advanced Product Quality Planning) approach, depending on OEM type. The study focuses on Tier 1 organizations, direct suppliers to the automotive industry, and their diverse approaches to product development. It underscores the need for Tier 1 organizations to maintain flexibility in their operations and to be prepared for changes in OEM demands. The study emphasizes the role of effective communication and coordination among all the levels of the supply chain to ensure the successful implementation of the APQP approach.

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Nomenclature

OEM: Original Equipment Manufacturer is a company that manufactures components or products used by another company.

Tier: Refers to different levels within the supply chain.
Supply chain: is the network of people and entities involved in creating a product and delivering it to its consumer.

APQP: Advanced Product Quality Planning is a framework of procedures and techniques used to develop products, particularly in the automotive industry. It aims to ensure consistent quality from the product planning phase to its serial production

PPAP: Production Part Approval Process, procedure whose purpose is to ensure that parts manufactured by suppliers consistently meet quality expectations.

1 Introduction

The automotive industry, characterized by its dynamism and innovation, is pivotal in shaping modern transportation. Successful collaboration with Original Equipment Manufacturers (OEMs) hinges on a thorough grasp of product and process requirements. These requirements evolve throughout the automotive sector's project phases, guided by Advanced Product Quality Planning (APQP) principles. The following research analysis delves into the intricate dynamics between Tier 1 organizations and three distinct types of OEM customers, each contributing their unique approach to product development, specifically, the creation of cars. As direct suppliers to the automotive industry, Tier 1 organizations grapple with diverse product design strategies, testing methodologies, and risk management practices. The ripple effect of these decisions reverberates across the entire supply chain. Juggling multiple OEM collaborations simultaneously, Tier 1 suppliers adapt their approaches to cater to individual customer needs. This necessitates meticulous adherence to established quality planning standards, such as ISO 16494 or VDA requirements, alongside the strategic deployment of supplementary tools. By aligning with the APQP methodology, these suppliers enhance their efficiency in achieving project goals across subsequent phases [1-3].

2 Research object

This research, of significant importance, delved into a comparative examination of the elements that impact both the product and process prerequisites. Those factors, crucial to the efficiency and effectiveness of project execution, as per the APQP methodology, were studied within the automotive sector. The study was conducted for three distinct customer categories, with their respective characteristics outlined in Table 1. Notably, the research methodology was firmly rooted in the practical experiences and observations gathered within the Tenneco Automotive Eastern Europe organization, lending credibility and relevance to the findings.

The process of creating a car shock absorber, a testament to the complexity and innovation in the automotive industry, is unique. Its flexibility in design alterations allows the customer to modify certain specifications, referred to as “Tuning Parameters” in the context of the article, even after the product has moved beyond the design and development stage (also known as phase 2 in the APQP). These modifications can encompass a variety of elements, such as the damping characteristics, which control the speed and ease of motion, the parameters of the suspension springs, which contribute to the vehicle’s stability and comfort, or the rigidity of the rubber-metal components, which can affect the overall performance and durability of the shock absorber. This collaborative approach ensures that the final product aligns with the OEM’s requirements and expectations, while allowing adjustments based on the real-world performance and feedback. This iterative process is crucial in achieving a high-quality, reliable, and efficient shock absorber that meets the dynamic needs of the automotive industry.

However, one of the significant challenges, faced during this iterative process, is managing the variability of client requirements. Throughout the project lifecycle, customers may request changes due to evolving performance expectations, new regulatory standards, or advancements in competing technologies. Such variability can introduce complexity into the supply chain and necessitate agile and adaptive project management practices. The extent and quantity of potential modifications are mutually agreed upon between the organization and the OEM during the product planning and quality phase (Phase 1, according to APQP). This agreement ensures that both parties clearly understand the project’s scope and the flexibility allowed within the product’s specifications. Continuous communication and feedback loops are essential to navigate these changes effectively, ensuring that the project remains on track, while meeting the evolving needs of the customer. This dynamic interaction between the supplier and the client underscores the importance of maintaining flexibility and responsiveness within the automotive industry’s product development processes [4-7].

3 Research methodology

Research methodology employed in the study, focusing on the systematic approach taken to investigate the optimization of development processes for electronically controlled dampers within the automotive industry. The methodology integrates the Advanced Product Quality Planning (APQP) framework, a recognized standard in the automotive sector, to structure the project phases and ensure a comprehensive and iterative process [8-9]. The preparation of the analysis was divided into six stages (individual numbers correspond to the numbering in Figure 1):

1. *Project Phase Breakdown Structure:* The project was segmented based on the APQP methodology, which provides a structured path from the product planning and definition to product and process validation. This phase breakdown ensures that all the critical stages of development are meticulously planned and executed, adhering to industry best practices.
2. *OEM Client Classification:* To enhance the relevance and applicability of the research, OEM clients were classified according to specific criteria. This involved identifying distinct types of OEM clients and establishing clear criteria for their classification, enabling tailored approaches to different client needs and expectations.
3. *Data Collection from Selected Projects:* Data was collected from a variety of past projects conducted within the organization. This step was crucial for identifying the input data provided by OEM clients and the corresponding project phases (as per APQP), when these inputs were communicated. By analyzing the historical data, insights were gained into typical OEM interactions and data provision patterns.
4. *Tier 1 Supplier Response Analysis:* Responses from Tier 1 suppliers to the input data provided by OEM clients were collected and analysed. This analysis focused on the timeliness and adequacy of supplier responses, which are critical for maintaining project timelines and ensuring quality outcomes.
5. *Defect Occurrence Curve Development:* Based on the collected data, a curve, representing the moment of defect occurrence during the project

implementation, was developed. This curve illustrates when defects typically occur, although they often remain undetected at the time of occurrence, providing insights into potential areas for process improvement.

6. *Defect Removal Costs Curve:* Utilizing the 1-10-100 rule, a curve, depicting the potential costs of defect removal, depending on the project phase in which they were detected, was drawn. This rule highlights the escalating costs of defect resolution as the project progresses, emphasizing the importance of early detection and intervention.

4 Tenfold rule basic principles

Figure 2 presents an analysis that identifies factors that impact product or process requirements and pinpoints the potential instance of defect origination. This is correlated with a curve that represents the cost implications of rectifying these defects, contingent on the phase of their emergence. One of the key principles of quality management is the 1-10-100 rule, also known as the tenfold rule (firstly published by George Juran, a quality management expert in his book Juran on Quality by Design [10]). This rule describes how the costs of finding and fixing a defect increase exponentially with each stage of the production process. For example, let us assume that the cost of detecting and removing a defect at the stage of preparing the technical documentation were 1 euro. Then, if the same defect was found at the stage of creating the prototype, the costs of correcting it will rise to 10 euros. If the defect was discovered at the mass production stage, the cost will soar to 100 euros. If the defect is detected at the stage of product operation, the cost will reach

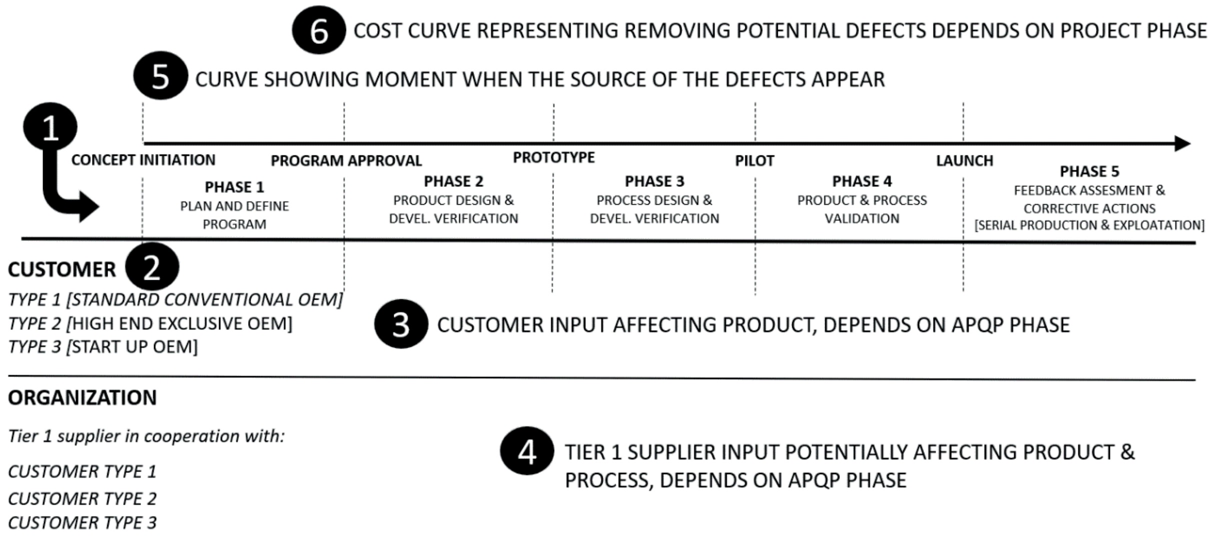

Figure 1 *Steps how data was collected and organized for analysis and assessment*

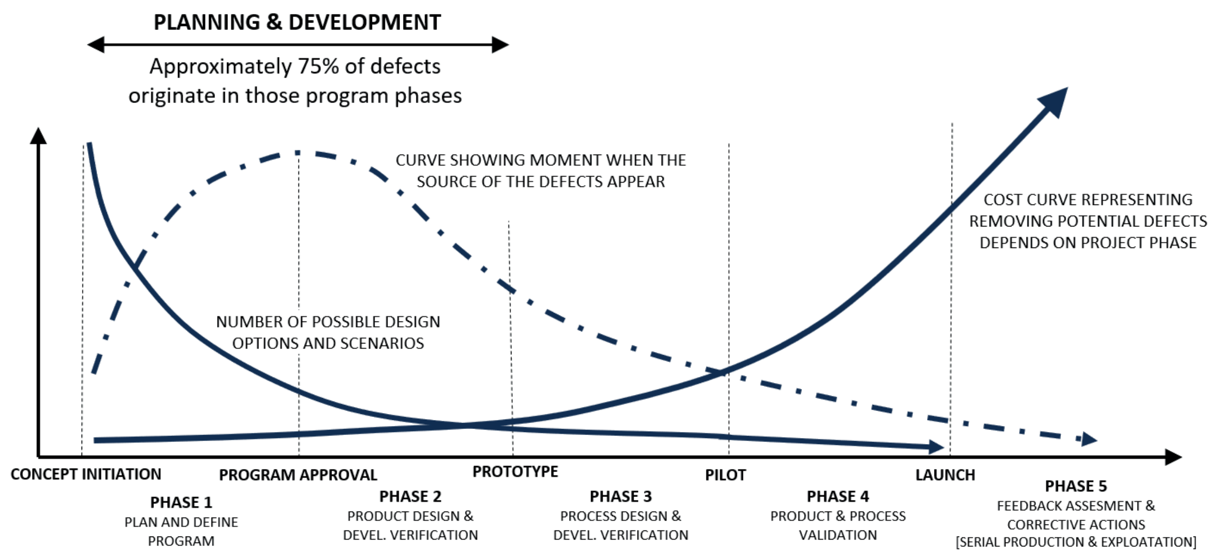

Figure 2 *Basic principles of 1-10-100 rule (tenfold rule) in correlation with defect origin moment and level of freedom with choosing different design proposals and scenarios (own elaboration based on [5])*

Table 1 *Definition of the three types of OEM customers*

CUSTOMER	DEFINITION
CUSTOMER 1 STANDARD CONVENTIONAL OEM	Standard conventional OEMs (Original Equipment Manufacturers) produce reliable, affordable cars designed for a wide range of consumers. These manufacturers focus on mass-market vehicles, balancing quality, performance, and cost-efficiency to make them accessible to the average person. Highly structured and well-organized in their product development processes, they employ rigorous quality control measures and adhere to industry standards. This ensures that their vehicles are dependable and meet consumer expectations for functionality, safety, and value. Examples include Toyota, Ford, and Volkswagen, known for their strong market presence and commitment to everyday transportation needs.
CUSTOMER 2 HIGH END EXCLUSIVE OEM	High-end luxury car manufacturers create meticulously crafted vehicles using the finest materials and cutting-edge technology. Designed for power, speed, and sleek aesthetics, those cars offer an unparalleled driving experience. Despite their complexity, these companies maintain a highly structured development process. Leveraging extensive product development expertise, they ensure precision and consistency at every stage. Detailed planning outlines specifications, timelines, and resource allocation. By maintaining a methodical development process, luxury car manufacturers produce sophisticated vehicles that meet the highest standards of excellence, satisfying discerning customers.
CUSTOMER 3 START-UP OEM	Start-up car manufacturers are new companies known for their innovative approach to manufacturing, design, and features. They often focus on technologies like autonomous driving, advanced safety, and cutting-edge infotainment systems. Typically producing environmentally-friendly vehicles, powered by electricity or alternative fuels, their product development process is often less structured, with frequent design changes and feature modifications. Driven by rapid technological advancements and evolving requirements, these alterations usually occur in the latter project stages. This flexible approach aligns with APQP (Advanced Product Quality Planning), enabling start-ups to quickly adapt and integrate new features to enhance vehicle performance and sustainability.

1000 euros. These escalating costs impact the project's budget and pose significant risks to the project's timeline, customer satisfaction, and overall success.

The 1-10-100 rule emphasizes the importance of early defect detection and prevention in the project lifecycle. By identifying and eliminating defects as soon as possible, the project team can save time, money, and resources, as well as improve customer satisfaction and loyalty. Early defect detection also reduces the risk of product failure, legal liability, and reputational damage. Therefore, implementing the effective quality control and assurance methods at each stage of the production process is essential and highly beneficial, such as design reviews, testing, inspection, and feedback. These methods ensure the final product's quality and contribute to the overall success and reputation of the project and the organization [11-12].

5 Types of OEMs

Table 1 presents the authors' definition of three types of Original Equipment Manufacturer (OEM) customers in the Automotive industry. In most cases, the factors influencing cooperation with a given OEM are the sector's experience and know-how and the level of product advancement. The product is designed to meet the end user's requirements and/or expectations.

Customer 1 holds the largest market share. In most cases, they choose reliable, proven suppliers with considerable experience in the industry. Customers 2 and 3, on the other hand, are more interested in innovative solutions due to the high technological advancement of the final product and the end customer's expectations. These solutions will give them a competitive edge and a larger market share. Understanding different types of OEM customers, and the factors that influence their cooperation, is crucial for the industry's strategic planning and decision-making processes.

6 Results and discussion

The analysis depicted in Figures 3 and 4 is paramount as it outlines the factors that influence product or process requirements and indicates the potential stage of defect origin. This is further correlated with a curve that illustrates the costs of removing the defects that have emerged, depending on the phase in which they occurred.

Upon careful analysis of the data, it becomes evident that there are potential risks that an organization (tier 1) might have to face when collaborating with a specific type of Original Equipment Manufacturer (OEM). The most significant risk is associated with a start-up type OEM, where the intense focus on innovation and new technologies often hinders a structured product development process [13].

It is important to note that the risk of partnering with a start-up type OEM is more than just a theoretical concept. It stems from their intense focus on rapid

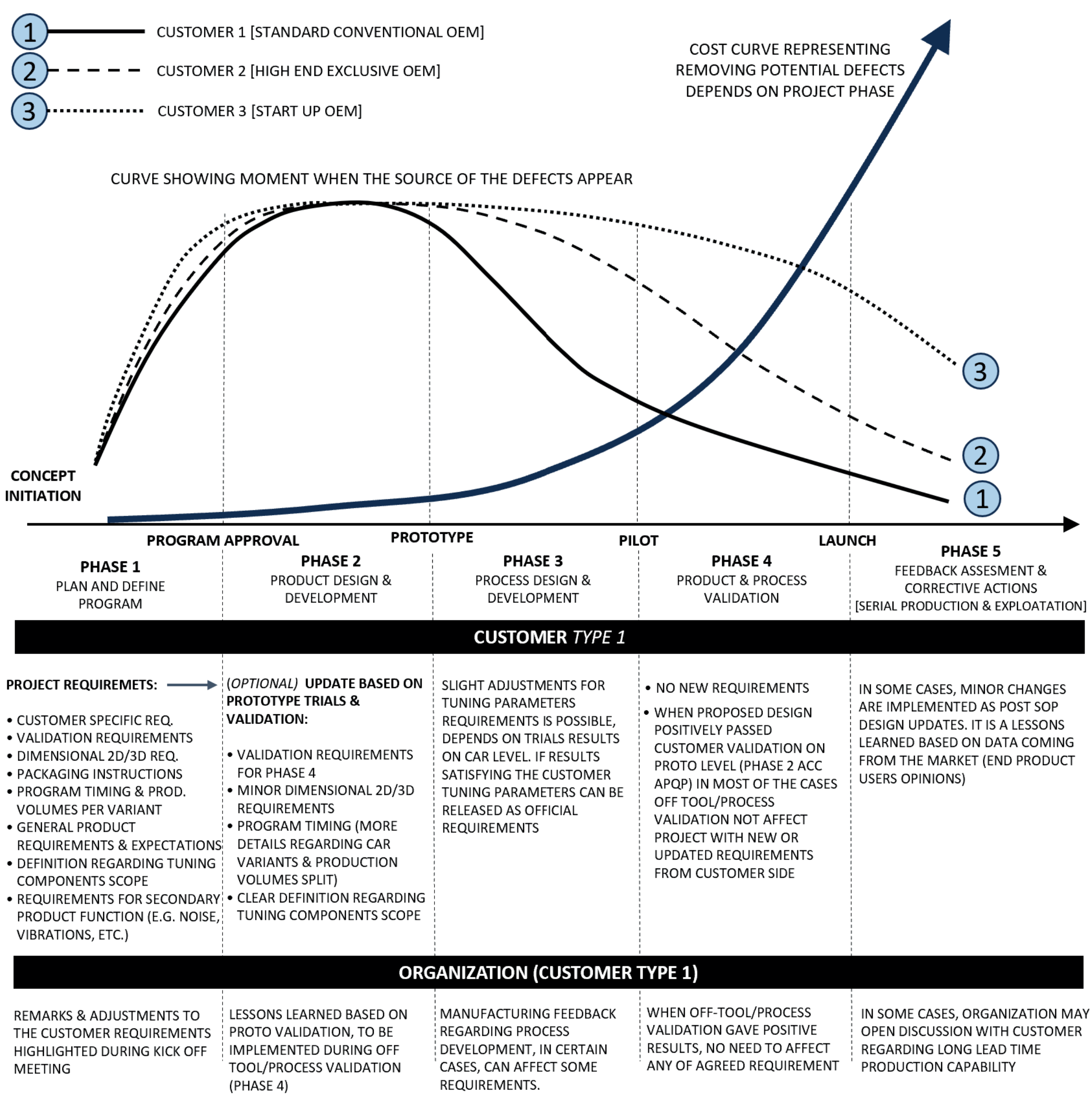

Figure 3 *Comparative analysis of the factors potentially influencing product and process requirements during the project lifetime for OEM Customers type 1 (based on [4-6])*

innovation and adoption of new technologies. While this can lead to groundbreaking products and services, it can also result in a lack of structure and predictability in the product development process. This can pose significant challenges for tier 1 organizations that require stability and predictability in their supply chain.

Furthermore, the start-up-type OEMs may need more established processes and resources of more mature OEMs. This can lead to potential issues with quality control, production capacity, and timely delivery. Additionally, start-ups often face higher business volatility, including financial instability, which can pose additional risks to the tier 1 organization.

According to the research results, most product quality problems originate at the design and development stage. It is not connected to the OEM type. It relates to how dynamic and structured the development process is in an organization. A model way to detect the potential defects early in the project is the product validation based on prototypes (phase 2 according to APQP), often preceded by computer simulations. This is the optimal time to make changes to the project, as it is associated with relatively low costs. However, a necessary condition is for the customer to specify the requirements for the product to be created as soon as possible (already in phase 1 according to APQP), and the supplier should scrutinize them meticulously, emphasizing all the inconsistencies or requirements that are not fully defined. Incomplete or improper requirements increase the risk of late defect detection, which can negatively affect the schedule and profitability of the project [14-18].

ALL ITEMS LISTED FOR CUSTOMER 1 ARE VALID FOR CUSTOMER 2 & 3, BELOW ONLY ADDITIONAL ONES

CONCEPT INITIATION **PHASE 1** PLAN AND DEFINE PROGRAM	PROGRAM APPROVAL **PHASE 2** PRODUCT DESIGN & DEVELOPMENT	PROTOTYPE **PHASE 3** PROCESS DESIGN & DEVELOPMENT	PILOT **PHASE 4** PRODUCT & PROCESS VALIDATION	LAUNCH **PHASE 5** FEEDBACK ASSESMENT & CORRECTIVE ACTIONS [SERIAL PRODUCTION & EXPLOATATION]
CUSTOMER *TYPE 2*				
• TUNING COMPONENTS SCOPE INCLUDE MORE PARAMETERS, COMPARED WITH STANDARD CONVENTIONAL PRODUCT • POSSIBLE AMOUNT OF PRODUCT VARIANTS IS BIGGER COMPARE WITH CUSTOMER 1 • MORE TECHNICAL ASPECTS MUST BE DISCUSSED AND AGREED WITH POTENTIAL SUPPLIER, COMPARE WITH CUSTOMER TYPE 1	**UPDATE BASED ON PROTOTYPE TRIALS & VALIDATION:** • UPDATE FOR 2D/3D DOCUMENTATION • PROGRAM TIMING (MORE DETAILS REGARDING CAR VARIANTS & PRODUCTION VOLUMES SPLIT) • MORE DETAILED DEFINITION REGARDING TUNING COMPONENTS SCOPE • UPDATES OF VALIDATION REQUIREMENTS FOR PHASE 4 MAINLY FOR DURABILITY TESTS LOADS	• BASED ON VEHICLE LEVEL TRIALS & TESTS, FINAL SCOPE & SPECIFICATION OF TUNING PARAMETERS CAN BE DEFINED • AT THIS STAGE OF THE PROJECT, THE VEHICLE HAS REACHED A SUFFICIENT LEVEL OF MATURITY TO EVALUATE ELEMENTS RELATED TO SECONDARY PRODUCT FUNCTIONS, SUCH AS NOISE AND VIBRATIONS	CAN CONTINUE IN THIS PHASE	• MINOR CHANGES ARE IMPLEMENTED AS POST-SOP DESIGN UPDATES, BASED ON LESSONS LEARNED FROM MARKET DATA, CORRELATING END-USER OPINIONS WITH VALIDATION RESULTS • POST SOP DESIGN CHANGES ARE AUTOMATICALLY IMPLEMENTED AS INITIAL REQUIREMENTS FOR NEXT PRODUCT VARIANTS (ACORDING CUSTOMER SOP TIMELINE)
ORGANIZATION (CUSTOMER TYPE 2)				
DEFINE TECHNICAL, TIMING & COMMERCIAL STRATEGY HOW TO PROCEED WITH TUNING COMPONENTS & PRODUCT VARIANTS	STRATEGY HOW TO PROCEED WITH PROCESS DEVELOPMENT WHILE SOME COMPONENTS HAS STILL NO DESIGN FREEZE	MANUFACTURING FEEDBACK REGARDING PROCESS DEVELOPMENT (IN CERTAIN CASES CAN AFFECT SOME REQUIREMENTS)	APPROVE & PROCEED WITH FINAL PPAP STRATEGY, DUE TO LONG PRODUCT DEVELOPMENT NOT POSSIBLE TO GATHER ALL QUALITY EVIDENCE FOR GREEN PPAP	• ACTIVITIES RELATED WITH GREEN PPAP SUBMISSION ONGOING • ORGANIZATION MAY OPEN DISCUSSION WITH CUSTOMER REGARDING LONG LEAD TIME PRODUCTION CAPABILITY
CUSTOMER *TYPE 3*				
• IN SOME CASES, REQUIREMENTS REGARDING VALIDATION, NOT AVAILABLE OR NOT FULLY CORRELATED WITH REALITY • TUNING PARAMETER SCOPE NOT DEFINED COMPLETELY AND MUST BE DEFINED BASED ON SUPPLIER KNOW HOW • DIMENSIONAL REQUIREMENTS IN 2D/3D ARE NOT COMPLETED AND MUST BE DEFINED BASED ON SUPPLIER EXPERTISE	**UPDATE BASED ON PROTOTYPE TRIALS & VALIDATION:** • UPDATE FOR DIMENSIONAL 2D/3D REQUIREMENTS • PROGRAM TIMING (MORE DETAILS REGARDING CAR VARIANTS & PRODUCTION VOLUMES SPLIT) • MORE DETAILED DEFINITION REGARDING TUNING COMPONENTS SCOPE • UPDATE FOR VALIDATION REQUIREMENTS IN SOME CASES, NEW REQUIREMENTS CAN APPEAR • MORE REALISTIC DURABILITY & STRENGTH TESTS LOADS	• BASED ON VEHICLE LEVEL TRIALS & TESTS, MORE DETAILED AND SUITABLE REQUIREMENTS CAN BE DEFINED TOWARDS THE PRODUCT • AT THIS STAGE OF THE PROJECT, THE VEHICLE HAS REACHED A SUFFICIENT LEVEL OF MATURITY TO EVALUATE ELEMENTS RELATED TO SECONDARY PRODUCT FUNCTIONS, SUCH AS NOISE AND VIBRATIONS	CAN CONTINUE IN THIS PHASE	• DEPENDS ON HOW MARKET REACT ON NEW START UP CAR, PROGRAM WILL BE CONTINUED OR NOT • IN MANY CASES, REQUIREMENTS FOR SECONDARY PRODUCT FUNCTIONS ARE FINALIZED BASED ON END PRODUCT USER OPINIONS
ORGANIZATION (CUSTOMER TYPE 3)				
• LIST OF REMARKS WITH POTENTIAL RISKS BASED ON NOT COMPLETED OR INCONSISTENCY CUSTOMER INPUT • DEFINE TECHNICAL, TIMING & COMMERCIAL STRATEGY HOW TO PROCEED WITH PROVIDED CUSTOMER INPUT	VALIDATION AND TRIALS CONDUCTED AT THE PROTOTYPE LEVEL USUALLY REVEAL GAPS IN THE DESIGN CONCEPT, GENERATING NEW OR CHANGED REQUIREMENTS RELATED TO THE PRODUCT	• STRATEGY HOW PROCEEDING WITH PROCESS DEVELOPMENT WHILE SOME COMPONENTS STILL HAVE NOT REACHED DESIGN FREEZE • MANUFACTURING FEEDBACK REGARDING PROCESS DEVELOPMENT	APPROVE AND PROCEED WITH THE FINAL PPAP STRATEGY. DUE TO THE LENGTHY PRODUCT DEVELOPMENT, IT IS NOT POSSIBLE TO GATHER ALL QUALITY EVIDENCE FOR GREEN PPAP. THE ORIGINAL SUBMISSION DATE FOR YELLOW PPAP IS ALSO AT RISK.	• ACTIVITIES RELATED WITH GREEN PPAP SUBMISSION ONGOING • QUITE OFTEN, ANOTHER REVISION OF REQUIREMENTS IS RELEASED DUE TO ADDITIONAL DATA COMING FROM THE MARKET

***Figure 4** Comparative analysis of the factors potentially influencing product and process requirements during the project lifetime for OEM Customers type 2 and 3 (based on [4-6])*

7 Conclusions

The costs of eliminating defects escalate as the project progresses. It is crucial to note that changing or introducing the new product requirements after the completion of phase 2, as per APQP, is a risky move. This is because most defects detected in the product occur during the product design and development phase. The later changes are made in the project, the higher the risk associated with late defect detection, which can lead to significant financial outlays to rectify those.

The flexibility in decision-making during the design phase, particularly in implementing various technical solutions, is directly tied to the phase in which the project is situated. In the initial stages, as per APQP (product planning and design), the costs of changing the concept or modifying project assumptions are manageable, reducing the additional costs that organizations might face in unforeseen situations.

To elaborate, the decision-making flexibility during the project's design phase is a critical aspect of a project management and execution. This flexibility, which includes the ability to implement various technical solutions, is intrinsically linked to the project's current phase.

As per the APQP approach, there is a greater degree of flexibility in the early stages of a project. During those stages, changes to the project's concept, or modifications to the project's assumptions, can be made relatively cheaply. This is because the project is still in its formative stages, and changes can be more easily integrated into the project plan without causing significant disruptions or delays. Therefore, maintaining the flexibility in decision-making during the design phase is not only beneficial but the cost-effective as well, as it allows for adjustments to be made early on, thereby reducing the potential for costly changes or corrections later in the project lifecycle. This approach, therefore, contributes to more efficient and effective project management, ultimately leading to the better project outcomes and success.

A Tier 1 organization must make every effort to secure the product development process, regardless of the type of customer with whom it collaborates. This is crucial to ensure the organization's highest quality and efficiency to be positively recognizable in the automotive industry.

Any deviation from good practices during the project implementation should be officially reported to the client, along with the consequences it carries. This allows control over costs and the project's schedule, strengthening the organization's market position.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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