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Original scientific paper

SPECIAL CHARACTERISTICS AS A KEY FACTOR IN DEVELOPMENT OF A ROBUST PRODUCTION PROCESS IN THE AUTOMOTIVE INDUSTRY

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A b s t r a c t: A critical, key or special characteristic is any of the characteristics of the product or production process throughout the life cycle, which if not in accordance with the specifications can cause a defectiveness or failure with serious consequences to life and limb, or it may result with non-conformities related to legal and regulatory requirements, as well as with the product's functionality. A special characteristic (SC) can be a feature of a material, production process or part, such as dimension, tolerance limit or finishing, the variation of which within the specified tolerance has a significant impact on safety, compliance with regulations, assembly or functionality of the product. Due to the seriousness of the consequences that the special characteristics would cause if not under a controlled state, their identification, classification, and implementation are planned while the product is at an early stage of its development. Their timely identification and correct classification enable the earliest detection of potential defects and unconformities which will contribute to the development of robust design and robust production process. In this research, through theoretical analysis accompanied with practical example from the operation of manufacturers in automotive industry will be presented the process of identification, classification, implementation, documentation, control and archiving of special characteristics throughout the lifecycle of the product.

Key words: special characteristics; automotive industry; new product development; risk management; quality management

СПЕЦИЈАЛНИТЕ КАРАКТЕРИСТИКИ КАКО КЛУЧЕН ФАКТОР ЗА РАЗВОЈ НА РОБУСТЕН ПРОИЗВОДСТВЕН ПРОЦЕС ВО АВТОМОБИЛСКАТА ИНДУСТРИЈА

А п с т р а к т: Критична, клучна или специјална карактеристика е секоја од карактеристиките на производот или производниот процес кои, во текот на целиот животен циклус, ако не се во согласност со спецификациите, можат да предизвикаат дефект со сериозни последици врз животот и здравјето на крајниот корисник или да предизвикаат неусогласеност со законските регулативи и функционалноста на производот и системот. Специјална карактеристика (SC) може да биде одлика на материјал, процес или дел, на пример димензија, толеранција или завршна обработка, чијашто варијација во рамките на наведената толеранција има значително влијание врз безбедноста, усогласеноста со законските регулативи, склопувањето во рамките на целиот синџир на добавување, перформансите, работниот век или производноста на производот. Поради сериозноста од последиците кои специјалните карактеристики би ги предизвикале доколку не се под осигурана контрола, нивната идентификација, класификација и имплементација се планираат додека производот е во рана фаза од неговиот развој. Нивната навремена идентификација и правилна класификација овозможува најрано откривање на потенцијални недостатоци и дефекти, што придонесува за развивање робустен дизајн и робустен производствен процес. Во овој труд, преку теоретска анализа и примери од работењето на компании кои произведуваат за потребите на автомобилската индустрија, се презентира начиот на процесот на идентификација, класификација, имплементација, документирање, контрола и архивирање на специјалните карактеристики низ целиот животен циклус на производот.

Клучни зборови: специјални карактеристики; автомобилска индустрија; развој на нови производи; управување со ризици; управување со квалитет

1. INTRODUCTION

The complexity of products which are part of the automotive industry imposes the highest degree of planning, control, and vision of the type of risks and accidents.

Complexity, in this context, refers to two interrelated aspects:

The first aspect concerns health and safety, functionality, and the maintenance of compliance with national and international laws and regulations. On the one hand, safety must be guaranteed to the end user of the motor vehicle, including the environment. On the other hand, the safety of all participants in the vehicle creation process must be 100% covered, including the environment. The client's needs and requirements, on the third hand, should be fully understood and satisfied. In doing so, care must be taken that the laws and regulations are constantly complied with. In order compliance of requirements to be achieved, although business competitors, major motor vehicle manufacturers (OEMs), and their component's suppliers (tiers), work together through various associations, committees, and standardization associations such as VDA, AIAG and IATF, sharing experiences, highlighting needs, discussing challenges, etc., in creating and updating quality standards. Special characteristics are an integral part of the standard requirements.

The second aspect of product complexity concerns product's composition and structure. Each product consists of a set of components, elements, and features. Some of these features have an impact on the safety, regulatory or functionality. In parallel, each production process consists of a series of operations and parameters, and the variability of some of them may negatively affect the process, thus creating conditions for consequences on safety, functionality, or incompliance with regulations. To eliminate or minimize the harmful effects, a classification of the characteristics based on their negative impact must be conducted, and for special characteristics will be considered those that have a high impact of negativity. For such characteristics there is a necessity for a separate, increased control to be provided. That being said, a critical, key or special characteristic is any of the product or production process characteristics, throughout the entire life cycle, which if not complied with the specifications may cause a defect with serious consequences for the life and limb of the end user, and/or cause noncompliance with the regulatory, and/or functionality of the product and the system [1, 13].

2. SPECIAL CHARACTERISTICS

Product characteristics which are inadequately robust, difficult to comply or control during production, and which, in the event of deviations lead directly to serious consequences, can be identified as special characteristics [2].

Categories of special characteristics

Special characteristics are a subset of the total characteristics of the product and the production process. They are reviewed, treated, and controlled separately. Their basic categorization is according to the range of adverse effects they affect – safety, functionality, or legal regulations. To separate the special from the standard characteristics, they should be properly marked in the product and process documentation. Table 1 presents the categorization as well as the SC markings and lists the potential classification criteria.

Table 1

Classification of special characteristics [2]

Class and marking	Description	Potential criteria
cc/s – critical characteristic/safety	Safety/security requirements/product safety/safety-relevant consequences with immediate danger to life and limb.	Protection for passengers in accidents. Prevention of: Momentary loss of sight of the road; Brake failure; Steering failure; Drive function failure; Sudden loss of power; Uncontrolled drive; Leakage of fuel / risk of fire; Insecure loads / trailers / parts; Injury when traveling or when using the vehicle in any way.
cc/h – critical characteristic / homologation	Homologation relevant, legal, and public authority requirements at the time the product is introduced to the market.	Registration-related (e.g., locking system, headlights); Homologation (e.g., exhaust gases, vehicle emissions, regulations issued by vehicle registration authorities); Legislation-related (recycling, warranty).
sc/f – significant characteristic / function	Functions and requirements	Important functional requirements (4 f (Form, Fit, Function and performance), tolerances, etc.).

Special characteristics validation and classification methods

Two basic methods are used in the classification and validation of special characteristics [2]:

– Failure Mode and Effect Analysis (FMEA).

– Fault Tree Analysis (FTA).

In the case-study analyzed in this research, this operation is performed with the FMEA method.

Application of FMEA for classification and validation of special characteristics

The FMEA method is considered one of the most complex, but, if properly guided, one of the most effective methods for detecting potentially risky characteristics of a product and production process. It is also the most applied tool or approach for risk management in companies in the automotive sector.

The most important elements in all risk analyses are [2]:

– Function.

– Characteristics.

– Possible failure modes; deviations; non-conformities.

– Possible effects of failure modes.

– Risk assessment.

– Specifying appropriate actions.

The method of analysis and validation of the characteristics evaluated with a high priority index (RPN), which is the product of S, O and D, within the P- and D-FMEA process is explained in the diagram presented in Figure 1.

The DFMEA process is based on the valorization of the product concept and all its constituent elements. The aim is to anticipate any potential risks, defects or inconveniences in the design and construction of the product, and to eliminate them in the final design phase. This is called a robust design [1].

So, in the first step, following the process flow diagram in Figure 1 – valorization of potential defects, is all the characteristics to be analyzed. In the analysis, preference is given to the features with high risk of non-conformity and injuries, regulatory compliance, as well as functionality

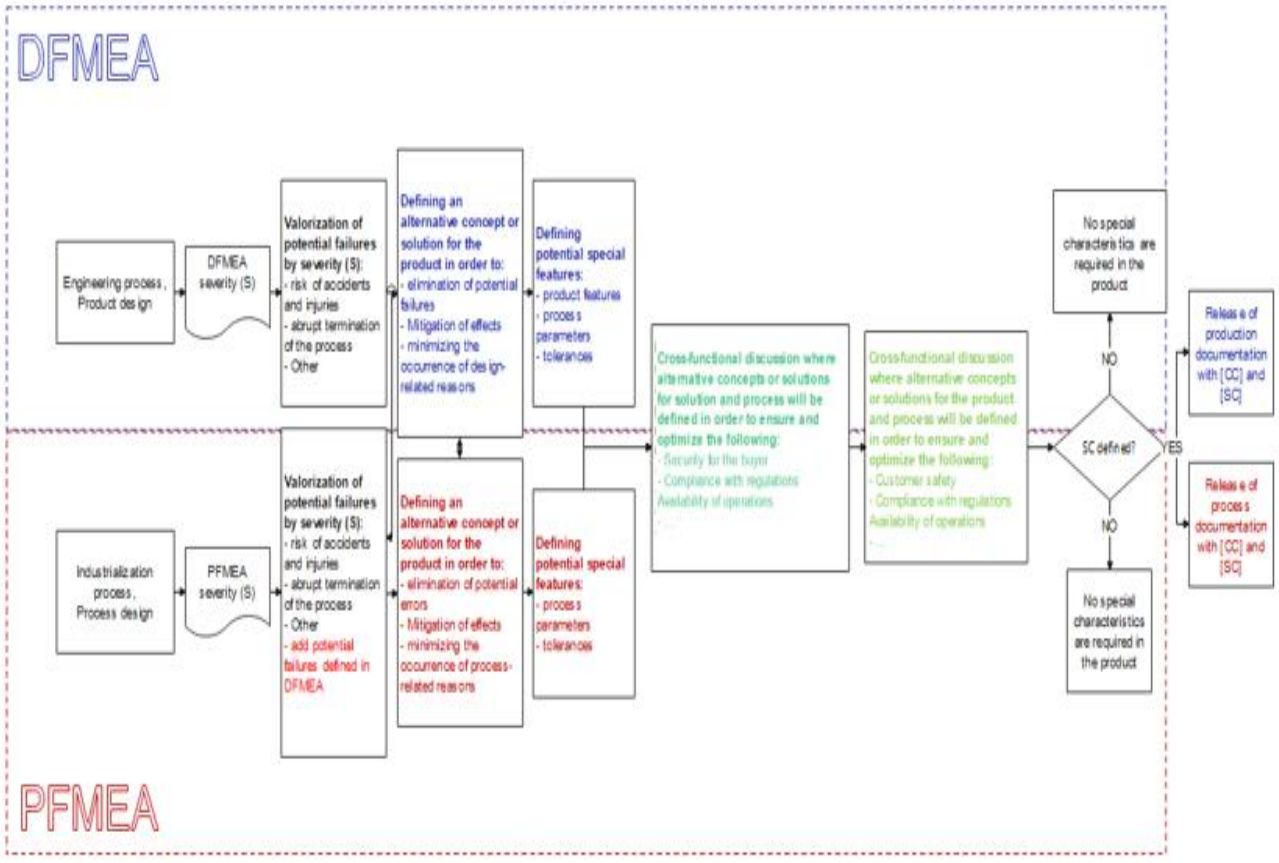

Fig. 1. Process flow diagram for validation of SC trough FMEA [4]

The analysis, usually, consists of answering the following key questions [3]:

– What is the potential risk, defect, or non-conformity?

– How can it occur / what are the causes of the potential risk, defect, or non-conformity?

– What is the effect of the potential risk, defect, or non-conformity?

The answers to these three key questions should, in fact, result in a preliminary list of potentially critical, significant, key or, in a word, specific characteristics.

The next step – **defining an alternative concept or solution for the product**, refers to the defined potential SCs from the previous step. Namely, the team focuses on changes in the concept for them to be eliminated in the best case, and in the optimal case – mitigated.

Defining of potential special characteristics is a step that follows considering all the options for changing the concept and after ascertaining the real picture for the further development of the project. Defined product characteristics, process parameters and tolerances in proportion to the characteristics are outputs from this step.

Next, **a cross-functional discussion defining alternative concepts or solutions for the product and process** is, in fact, the final stage of analyzing and filtering out specific characteristics. This step should define all possible changes in the concept and adopt the characteristics of the product that will have a special status.

The outputs of this process are defined special characteristics, which are specified in the next step. Following is adopted:

– Classification [CC] and [SC].

– Product features and tolerances.

– Process parameters and tolerances.

– Appropriate control methods.

Releasing production documentation with [CC] and [SC] is the final step where they should be loaded into all technical documentation.

P-FMEA takes place in the same steps, but instead of design, valorization of potential risks, defects and non-conformities of the process is performed. The difference is that in the second step, the defined SC from D-FMEA.

Risks valorization and determination of special characteristics

Each detected failure poses a risk to the overall design and process. However, not all risk, defect, or non-conformity have the same effect. Therefore, there is a priority risk index – RPN (Risk Priority Number) which is calculated by valorizing the risks based on three attributes:

Severity, which reflects the severity of the effect on the defect on the sub-system, system, or customer. In the FMEA the document is marked with **S**.

Occurrence, which indicates the probability of the cause of a defect that may occur. In the FMEA the document is marked with **O**.

Detection, which assesses the potential / ability to detect a defect. In the FMEA the document is marked with **D** [3].

There are criteria and numerical valorization for each of the three attributes, on a scale of 1–10. The RPN index is calculated according to the equation: **RPN = S × O × D.**

3. NEW PRODUCT DEVELOPMENT PROCESS OF AN AUTOMATIC-TRANSMISSION GEARBOX WHICH CONTAINS SPECIAL CHARACTERISTICS

In this research, the process of development of a mechatronic module – gearbox with automatic transmission will be explained. The development of the complete product is large-scale and contains business confidential information. Therefore, reliable parts of the whole process will be presented. Reliable refers to parts which contain identification, classification, and implementation of special characteristics from the cc/h–class – special characteristics related to compliance with legislation.

Figure 2 shows the stages and activities of planning new projects in a company that produces for the needs of the automotive industry.

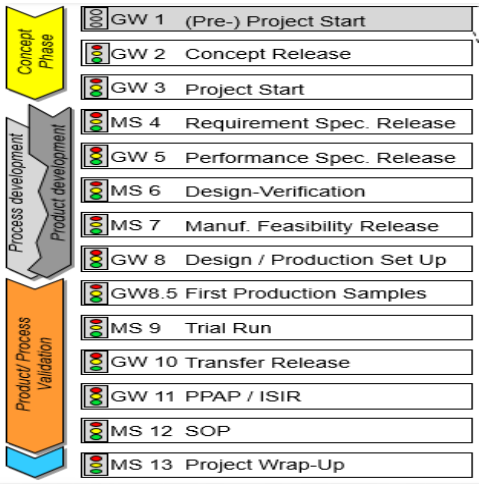

Fig. 2. Phases and activities of project planning [5]

GW 1: Pre-project start

The initial phase of planning a new project consists of the following activities:

Setting the project on the Jira = platform.

Forming a team:

– Project manager.
– Project leader.
– Design and construction engineer.
– Electrical engineer.
– Process optimization engineer.
– Production planning engineer.
– Quality planning engineer.
– Production planner.
– Machine maintenance engineer.

Concept defining trough:

– Customer requirements.
– Requirements from the quality standards.
– Legal/legislation/regulatory requirements.

GW 2 – GW 3: Concept release and Project start

In this phase the following activities take place:

– Checked and updated basic requirements specification.
– CAD-simulations and testing of the concept (Figure 3).
– Main timing plan.
– Required specification.
– Concept.
– Pre-calculation, economical check, rough make or buy decision.
– Approval of quotation.
– Test plan validation.
– D-FMEA analysis.
– Risk analyzes for purchased parts and suppliers.
– Implementation of security plan.
– Logistics concept.
– Warranty concept.
– APQP process for critical purchased parts started.

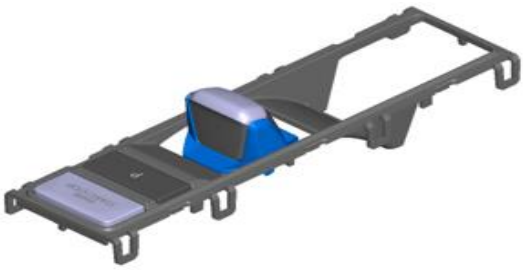

Fig. 3. Development of CAD-model of a gearbox

MS 4 – MS 6: Requirement specification release. Performance specification release. Design verification

Through these phases, the following activities should be conducted:

– Checked and updated requirements specification.
– DFMEA-analysis release.
– List of special characteristics for DFMEA.
– Defining the complete product architecture and the final list of components for the product (Bill of Material list).
– List of components for in-house production and (buy-parts) from external suppliers.
– Initiate necessary qualification of production and test technology.
– Manufacturing feasibility draft.
– Initiate necessary qualification of production and test technology.
– Result of technical calculations and simulations.
– Results of prototype validation.
– Functional dimension analysis / tolerance stack-up analysis.

DFMEA-analysis release

Potential risk number 1: The module does not meet the flammability criteria for DIN 75200 and/or FMVSS 571,302.

Clarification note: DIN 75200 is a German national standard for determination of burning behavior of interior materials in motor vehicles.

FMVSS 571.302. is an American standard that specifies burn resistance requirements for materials used in the occupant compartments of motor vehicles.

Both standards have the same purpose, which is to eliminate the risks injury to passengers in motor vehicles caused by fires, e.g., fires triggered inside the vehicle by sources such as matches or cigarettes.

The standards require a flammability test and the specification is that the burning rate should not exceed 100 mm/min, i.e. if the material stops burning before 60 s have elapsed from the start of combustion and if it has not burned more than 51 mm from the point where the combustion started, it will be considered to meet the requirements for the combustion speed [6].The burn rate is calculated from the formula $\mathbf{B = 60 \times (D/T)}$, where [6]:

– B is the burn rate (mm/min),

– D is the length the flame travels (mm) и

– T is the time (s)] for the flame to travel D.

Potential risk number 2: The module does not meet the criteria according to ISO 2575, ECE-R 121, FMVSS 101, FMVSS 102, CMVSS 102, ADR-42.

Clarification note: ISO 2575 – Symbols for controls, indicators and tell-tales, is an international standard that specifies symbols (i.e. conventional signs) applicable on controls, indicators and signals for the use of passenger vehicles. It also contains instructions on color illumination of the optical signs that inform the driver of the proper operation or malfunction of the devices [7]. For a gearbox with automatic transmission, the symbols on Figure 4 are applicable.

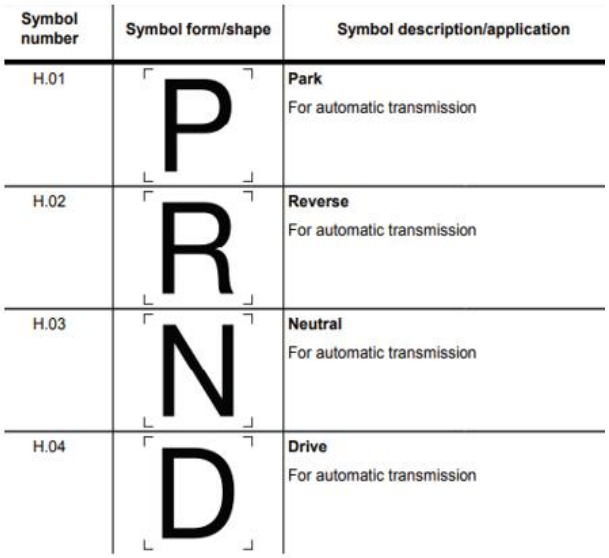

Fig. 4. Symbols and their meanings applicable to gearbox with automatic transmission [7]

ECE-R 121 – Regulation No 121 of the Economic Commission for Europe of the United Nations (UN/ECE) Uniform provisions concerning the approval of vehicles with regard to the location and identification of hand controls, tell-tales and indicators [8].

FMVSS 101 – Controls and displays is a standard which specifies the requirements for the location, identification, color and illumination of controls, symbols, and indicators for motor vehicles [9]. Essentially with similar requirements as in the previous two standards.

FMVSS 102/CMVSS 102 – This standard specifies requirements for the transmission shift lever sequence and shift lever position labeling, a starter interlock, and requires a braking effect of automatic transmissions at speeds below 40 km/h [10].

FMVSS are U.S. federal vehicle regulations that specify the design, construction, performance, and durability requirements of motor vehicles and regulated car safety components, systems, and design features. Canada has a system of analogous rules called the Canadian Motor Vehicle Safety Standards (CMVSS), which essentially overlap in content and structure with FMVSS. FMVSS/CMVSS requirements differ significantly from UN international requirements, so that private imports of foreign vehicles not originally manufactured to North American specifications are difficult or impossible [1].

ADR-42 – Australian Design Rule 42/00 – General Safety Requirements, is an Australian standard that specifies design and construction requirements for the safe operation of vehicles, including standard automatic transmission controls relevant to the product under development [11].

Potential risk number 3: The module does not meet the criteria for illumination of symbols according to the standards ISO 2575, ECE-R 121, FMVSS 101.

Clarification note: In ISO 2575, ECE-R 121 and FMVSS 101, in addition to the requirements for symbols for manual controls, indicators and benchmarks, lighting modes are defined, as well as the colors with which they should be illuminated. In terms of coloring, the following colors have the following meaning:

Red: danger to persons or very serious damage to equipment.

Yellow/amber: caution, outside the normal operating limits, vehicle system malfunction, vehicle damage or other condition that may cause long-term danger.

Green: safe, normal working condition [7].

Regarding the lighting of the gearbox indicators, a requirement has been set for them to be mandatory, but it is not specified with what color. Most often, their illumination is white.

Potential risk number 4: The module does not meet the criteria of EU ECE R21.

Clarification note: Regulation No 21 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to their interior fittings, contains the only provisions regarding the approval of vehicles in relation to their internal parts [12].

The detected risks, the reasons for their occurrence, the consequences of the impact of the event, and the defined actions for their elimination or mitigation are loaded in the FMEA document which is available in the master's thesis referenced [1, 13].

From the potential risks listed above, potential risks 2, 3 and 4 are eliminated through design revision and successful establishment of design robustness in relation to markings and illumination of the driving mode indicators (parking, neutral position, reverse movement, parking brake).

Also, the requirements of ECE-R 121 have been complied in terms of ergonomics as well as other requirements relating to the internal parts of motor vehicles. As the project develops further, the D–FMEA analysis has been updated (detailed FMEA analysis is available in the master's thesis referenced [1]).

List of special characteristics for DFMEA

As for potential risk number 1, it concluded that it is impossible to eliminate it in the design development phase and it will be appropriated in the analysis of potential risks for the production process. This risk is from the category of product features that require special attention and control and is, therefore, included in the list of special characteristics of the cc/h class (Figure 5).

Project name:
List of Special Characteristics

Article number	Description	Sequence	Atribut	Specification	Clasification
10343xxx	Gearbox	2	Material (Product)	Material flammability	L

Fig. 5. Segment of the list of SC for D–FMEA [1]

A failure to comply with the flammability regulation of the material brings the risk of serious damage and consequences for the life and limb of the user and passengers in case of fire, so this feature also affects safety. Fire prevention and protection is the primary goal of creating standards for control of flammability of materials.

At the company, for special characteristics are used the following markings:

S (Safety) – special characteristic related to Safety requirements / product Safety.

L (Legal) – Special characteristic related to Legal and Regulatory requirements (at the time the product is placed on the market).

F (Function) – Special characteristic related to Functions and requirements.

In the context of meeting the flammability requirement, in addition to the product (gearbox) as a whole, risks are also located on the components through their material specification. The segment of the D–FMEA analysis where they are listed is shown in the research of the master's thesis [1]).

MS 7 – MS 11: Manufacturing feasibility release. Design/Production set-up. First production samples., Trial run. Transfer release. PPAP

In the phases from MS 7 to MS 11, the following activities should be undertaken and performed:

– Assembly line layout.
– Plant layout.
– Complete equipment for production process is defined.
– Test instruction (pre- / end of line test).
– Control pan.
– Complete measuring equipment is defined.
– Capacity study for tools.
– Capacity study for assembly line.
– Implementation and release of PFMEA analysis.
– Defining a list of special characteristics for PFMEA.
– Trial run.
– Production capability studies.
– Conducting a PPAP process.

PFMEA-analysis release

Special characteristics from design FMEA are transferred to the process FMEA.

To eliminate the risk of fire and to meet the requirements of the regulations on flammability of materials, the following measures and activities have been adopted and implemented:

– During the procurement process of material (granulate), a specification of the material to the suppliers is defined.

– Checking the specification of the material upon goods receipt, as well as visual inspection at the beginning of preparations for the injection molding process.

– Conducting a flammability test on 10 pieces of each of the components for which SC is defined within the PPAP process.

PPAP process conduction and start of production

Measures 1 and 2 are loaded into the control plan as part of the ongoing quality assurance process. Through production of trial runs they are validated and transferred to the control plan for serial production. In GW 11 a PPAP process is initiated to validate and release the production by the client. The third measure is performed on-site – conduction of the flammability test as defined in FMVSS 571.302.

The actual status of the PPAP process is approved and released by the client and the product is already being produced in series quantities. The special characteristics are marked in the technical documentation (control plan, drawings, FMEA-analyses), and a sample of the original documents is presented in Figure 6.

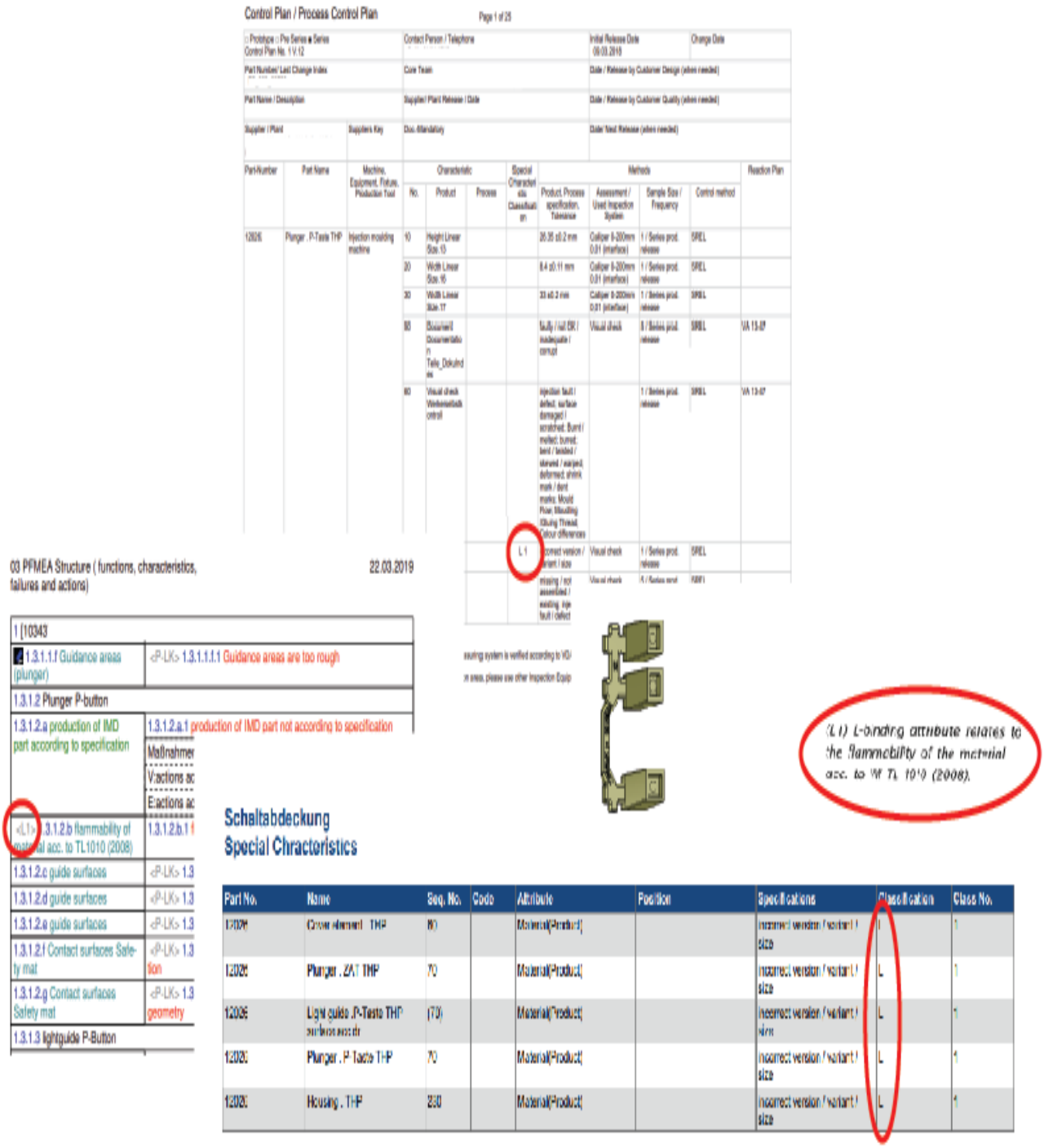

Fig. 6 -Special characteristics marked into the process documentation

Project wrap-up

In the final stage of new product development, the following is implemented and documented:

– Final reports.

– Measurement and evaluation of effectiveness.

– Error recording.

– Lessons learned.

– Monitoring of serial production.

Archiving special characteristics

Special characteristics, due to the level of severity of the bandwidth they affect, also have a longer archiving life. In the company, it is defined that the special characteristics have a retention period of 15 years after the end of the production of the product. The purpose is that 15 years after the end of production it can still be said that the part was OK in terms of the set parameters.

Basically, two types of documents or information need to be stored (digitally or as a hard-copy document):

– The definition of what is a special characteristic – the control plan archived in PPAP and in SAP.

– The customer drawing (external special characteristics of the customer).

– The coversheet of the control plan (documentation about additional internal special characteristics).

The data and results of the tests and inspections to prove that the specifications acc. to the control plan have been fulfilled.

These are project-specific definitions depending on the product.

Determination in the project depending on requirements, specification, data and conditions.

To identify a document which contains SC, it is provided with the symbol "D" in the header area (Figure 7, highlighted in yellow).

6	DOC02232505	Requirement specification
5	DOC02196933	Requirement specification
4	DOC02070611	Mentor graphics PCB 4+4
3	DOC02070634	Mentor graphics PCB 3+4
2 (L1)	DOC01804630	Brennverhalten n. DBL 5307.10 2008-03 (D) flammability due to DBL 5307.10 2008-03 (D)
1	DOC02021167	WEB 2020 Initial material sampling
lfd. Nr. item	Nummer no.	Benennung name
Mitgeltende Dokumente other applicable documents		

Fig. 7. The D-symbol for identifying a document with special archiving

In addition, the document should include a description of the SC (Figure 7 underlined in red).

CONCLUSION

The rapidly growing technology is a fact whose impact is directly reflected in all branches of industry, including the automotive. Certain features of the vehicle that two or three years ago were considered advanced are now integrated as standard. It is an endless cycle of repetition, which directly dictates the pace of development to OEMs as well as their suppliers. Many of these features serve the primary function of the vehicle to facilitate and complement it, but also many of them are, simply put, unnecessary luxury. In order to separate the vital from the trivial features, the manufacturers use different filters. When it comes to features that affect safety, regulatory compliance, or functionality, such features are unquestionably vital, and as such, have their own way of being managed.

In this research, the essential characteristics are analyzed and presented, and from the case-study can be concluded that successful management plays a key role in projecting and building a robust, capable, and feasible product and process with minimal number of defects.

In the end, all products, as well as all production processes are characterized by pre-set characteristics that must fundamentally comply with the given specification. Special characteristics are characteristics that require special care and are not controlled by other processes. The special care obligation must be fully met, as deviations in this part may seriously affect the safety of the product and its user, the life of the product, the ability to assemble, the functionality or it may be outside the legal framework and regulations. Timely identification, definition, marking, execution, and control of special characteristics, considering the areas where they have an impact, as well as the amount of damage that would be done in case of non-compliance, ranks special characteristics in the group of key factors for robust design as well as robust manufacturing process development in the automotive industry.

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