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Methodology for the Development of Production Systems in the Automotive Industry

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Abstract: The goal of this research was creation and validation of a methodology for the development of production systems of suppliers of the automotive industry. The theoretical starting points analyze the available literary sources and point to the insufficient treatment of the issue by a comprehensive industry standard representing a gap in the current state of knowledge. The practical part of the research is divided into two stages. The subject of the first stage is the standardization of the methodology through a structured scientific procedure in intensive cooperation with a panel of experts. The subject of the second stage is testing the methodology on authentic projects of the application sector using case studies. The results of the testing showed that in all projects managed using the proposed methodology there was an increase in performance compared to projects managed in a traditional way. The successful confrontation of the proposed solution with reality (practice) is underlined by the confrontation with the current state of knowledge (theory). The practical benefits of the research are the possibility of implementing the methodology into the pedagogical process at training workplaces and, above all, its application into engineering practice to develop new production systems of suppliers of the automotive industry.

Keywords: automotive industry; development; methodology; production system; project management; quality assurance; standardization

1 INTRODUCTION

Over the past few decades, the automotive sector has experienced significant development. There's been a rise in pressure to lower car prices and speed up development time, while at the same time, products are becoming more complex and demanding due to increased competition and higher expectations from consumers. As a result, car makers (OEMs) are increasingly moving ever larger portion of the development and production towards suppliers. Suppliers took over much of the research and development as well as production, leading to an overall increase of up to 80%. This shift has created intricate supplier networks and car production heavily reliant on suppliers. This change has also defined a new set of qualifications for suppliers, who now must take full responsibility for product development, production systems, launch, and meeting the specified requirements and costs set by car manufacturers [15, 16, 22, 35]. This presents new challenges for suppliers.

The key to success is mastering the development stage, including activities from product quality design, through design, implementation and verification of the capability of production systems, to the course of verification production and the release of the process and product into serial production. The reason is the fact that in the development phase there are many more non-conformities (up to 75%) than in the implementation phase and serial production itself.

Moreover, practical experience indicates that addressing non-conformities during the development phase requires significantly lower costs than addressing them during product realization and usage (referred to as The Rule of Ten). By identifying and eliminating non-conformances early, suppliers can minimize cost and resource consumption, leading to improved project outcomes. In this context, modern project management (PM) methods and procedures tailored to efficiently handle intricate, time- and resource-constrained tasks with long durations and high levels of uncertainty, such as development activities, become crucially significant. However, for project management methods and procedures to be truly effective and capable and represent the best current solution, they need to be standardized. Despite today's existence of thousands of suppliers for one car manufacturer (for example, the supply network of the Volkswagen concern includes more than forty thousand suppliers), today there is a lack of a comprehensive industry standard that would serve suppliers as a solid basis for the standardization of development activities. Such a standard would provide automotive industry suppliers with a robust framework for standardizing development activities [35]. The results of the research on the current state of knowledge show that both academic and industrial social groups are quite extensively engaged in the planning and development of new products. However, the same does not apply to studies related to the issue of planning and development of new production systems, which also require extensive care and the mastery of which is considered a strategic competence of enterprises [2, 3]. The primary objective of the research was to address this deficiency in the current state of knowledge and create a comprehensive industry standard that will help automotive industry suppliers effectively manage production system development activities, prevent non-conformities in time, reduce the costs of their elimination and increase the probability of success of new projects.

2 THEORETICAL FRAMEWORK

The initial step of the theoretical part of the research was a traditional examination of the current state of knowledge, the purpose of which was to verify, whether some resource had already dealt with the issue, to what extent and in what place it is possible to follow up on the research. A systematic literature review (SLR) served this purpose. Due to the very limited formal scope of this article, only publications dedicated solely to planning and managing the quality of production systems within the automotive sector are listed. Other relevant sources are mentioned in Chapter 4.1.

2.1 Web of Science

The systematic literature review was launched in the Web of Science (WoS) global scientific database. The search string employed variations of the terms: production / manufacturing, process / system, creation / development, methodology and automotive. The search terms were organized by the use of search (Boolean) operators, parentheses and truncation symbols to maximize the relevance of the outputs. In addition, the research was limited to contributions published since 2010 in order to eliminate out-of-date contributions. Based on the entered search terms and restrictions, the search engine returned 377 articles (gross hits) subsequently sorted according to relevance. After excluding duplications and non-relevant papers, a total of 12 studies remained for a closer examination. This showed that only article entitled "Reference model for the implementation of new assembly processes in the automotive sector" by the authors Emilio C. Baraldi & Paulo C. Kaminski (2018) [4] corresponded to the research objectives in its focus.

2.1.1 Reference Model for the Implementation of New Assembly Process in the Automotive Sector

The analysis of the article showed that the authors were led to the research by the absence of literature and studies dealing with the development of production systems in the automotive sector. The research was thus initiated by the same motive as the research presented in this article. As Baraldi and Kaminski state: "The purpose of the research was to present a consistent and effective reference model for the implementation of new assembly processes in the automotive sector". The study of the article showed that the proposed reference model is the result of the analysis and synthesis of five literary sources that describe with different approaches and objectives the various activities that must occur during the production process development. The five sources are: 1. APQP by AIAG (1995), 2. ABNT ISO/TS 16949 (2010), 3. The product development process (PDP) model by Rozenfeld et al. (2006), 4. VDI 5200 Factory planning (2011) and Proposal of framework to manage the automotive product development process (PDP) by Silva and Kaminsky (2017).

The resulting reference model takes the form of a graphical model embedded in the timeline. The model is vertically divided into two levels. The higher of the two levels (level N) forms a basic axis divided into five phases of different lengths depending on their duration. The individual phases are bounded by quality gates. The lower of the two levels (level N-1) contains the activities that need to be completed within each stage to move from one quality gate to another. The authors list a total of 52 activities. The activities are processed in the form of a simplified Gantt chart and each activity is provided with an acronym explained in a legend placed below the model. The legend lists the full names of phases, quality gates and individual activities, for which it also lists the responsibilities for execution. Individual phases and their content are color coded. The model mentions two auxiliary techniques supporting development activities, which are PFMEA and Control plan. The graphic model is accompanied by a simple text of 1.5 pages briefly describing the content of the individual phases. The paper can be briefly characterized as a basic guide rather than as a full-fledged methodology applicable to the effective management of complex projects.

In an effort to find more relevant articles, the authors decided to change the search string and perform a new search round with variations of the terms: production / manufacturing, process / system, quality, planning and automotive. This time the search engine returned 195 articles (gross hits). The analysis continued in the same way as in the previous round. No further relevant article matching the research needs was however found.

Since the papers of the WoS database fundamentally did not meet the needs of the research, the authors decided to focus on literature dealing with the issue of project management with the stress on automotive industry standards.

2.2 Industry Standards of Project Management

The research of industry standards of PM in automotive industry revealed that they are created by automotive industry trade groups. These groups unite car makers and key suppliers with the aim of exploring shared interests, exchanging practical knowledge, and establishing guidelines to streamline collaboration across all tiers of the industry's supply chains. American Automotive Industry Action Group (AIAG) and German Verband der Automobilindustire (VDA) proved to be the most popular and active worldwide in terms of standardization of PM procedures.

There were 80+ titles discovered in the databases of the AIAG group. The following titles conformed to the research limitations (see chapter 7.2 - categories "Application Sector" and "Scope") and were subjected to closer examination [35]:

- Advanced Product Quality Planning [5;6],
- AIAG & VDA FMEA [7],
- Costs of Poor Quality Guide [8],
- Effective Problem Solving Guide [9],
- Layered Process Audit Guideline [10],
- Measurement System Analysis [11],
- Production Part Approval Process [12], and
- Statistical Process Control [13].

There were 40+ titles discovered in the databases of the VDA group. The following titles conformed to the research limitations and were subjected to closer examination:

- VDA Minimizing risks in the supply chain [14],
- VDA Maturity level assurance for new parts [15],
- VDA2 Quality assurance prior to serial production [16],
- VDA4 Quality assurance in the process landscape [17],
- VDA Customer specific requirements [18],
- VDA 6.3 Process audit [19], and
- VDA 14 Preventive quality management methods in the process landscape [20].

A detailed analysis showed that the only publication with the character of a complex methodology dealing with the quality assurance of manufacturing systems is APQP.

2.2.1 APQP

According to the publication [5], APQP is a standard designed to product and production system quality planning in the early stages of car development, focusing on planning and preparation before serial production. The standard is made in the form of a graphic model, expanding plain text in the scope of 45 pages and appendices. The graphical model consists of phases, quality checks and activities. Horizontally, the model is divided into two levels. The higher of both levels (level N) consists of five overlapping phases. The mentioned stages align with the conventional steps of the Product Creation Process. Throughout these stages, the methodology suggests employing 11 auxiliary tools and techniques (listed in one of the appendices), such as CP, MSA, PFMEA, or PPAP that enhance the likelihood of success in development endeavors. For practicality, the five phases are condensed into five primary activities comprising the N-1 level. The content of each phase is outlined in the methodology through suggested crucial inputs and outputs (49x), where the output of one phase seamlessly feeds into the input of the next phase. Each input and output is subsequently described briefly in plain text. Validation of the procedure's accuracy is facilitated by predefined questionnaires provided in the methodology's appendix. There are 15 checklists in total and they are tied to various key activities such as Control Plan, D-FMEA, Floor Plan, New Equipment, Process Flowchart, P-FMEA, and Product/Process Quality [35].

2.2.2 Remaining AIAG and VDA Publications

The remaining AIAG and VDA publications are recognized as established tools and techniques for ensuring product and production system quality, which can be effectively implemented within the automotive sector [35]. No other truly relevant sources were discovered.

2.3 Research Design and Hypotheses

The results of the SLR showed that the current state of knowledge encompasses various information sources that are highly relevant to crafting a methodology aimed at guaranteeing the quality of production systems developed by suppliers in the automotive industry. These sources differ not only in the time and place of creation and the purpose for which they were created, but above all in their scope and method of processing. The research however confirmed that the current state of knowledge does not offer a comprehensive industry methodology for the development of production systems, which would guide the user through all the important steps of the development stage (= Production System Creation Process = PSCP) and minimize the related project risks. Based on the results of the theoretical part of the research and confirmation of the gap in world knowledge, the objectives of the practical part of the research, the research question and hypotheses were determined.

The main research objectives were defined as:

1) Creation of a methodology for the development of production systems of automotive industry suppliers, and
2) Validation of the methodology in practice on authentic projects of the application sector.

The research question based on the main objectives is: "Will automotive industry suppliers that deploy the proposed methodology for the development of production systems, achieve higher project performance than suppliers that do not deploy the methodology?"

2.3.1 Research Hypotheses

In order to evaluate the impact of the applied methodology on project performance and to answer the research question, the research hypotheses were deliberately formulated to verify or disprove the impact of the methodology on the three main objectives of the project, which are:

1) <u>Time</u> required to achieve the project results,
2) <u>Quality</u> of the project product (main output), and
3) <u>Costs</u> required to achieve the project results.

The research hypotheses are:

H1: Automotive industry suppliers that deploy the proposed methodology for the development of production systems, <u>will achieve a lower number of delayed activities</u> than suppliers that do not deploy the methodology.

H2: Automotive industry suppliers that deploy the proposed methodology for the development of production systems, <u>will achieve a lower number of non-conformities</u> than suppliers that do not deploy the methodology.

H3: Automotive industry suppliers that deploy the proposed methodology for the development of production systems, <u>will achieve lower costs for resolving non-conformities</u> than suppliers that do not deploy the methodology.

The defined hypotheses were supportively related to the proposed methodology and its verification in practice. The following chapter describes the steps that led to the fulfillment of the main research objective #1.

3 PROPOSAL OF CONSTRUCTION OF THE METHODOLOGY

Based on the knowledge gained in the theoretical part of the research, it was decided that the methodology will be processed in the form of a complex model of the Production System Creation Process consisting of two basic forms of notation – PROCESS MAP and PROCESS CARDS. The model will be divided into 4 levels (N - N-3) depending on the purpose and detail they are supposed to treat [35].

The PROCESS MAP was determined as the basis of the model. The process map was inspired by the graphic model of Product Creation Process of the VW concern (including the brands such as Audi, Porsche, Seat, Škoda, or VW), which the authors analyzed in detail within the framework of the SLR [2, 5]. This model visualizes on a single page in a natural way the most important process steps of the car development stage and their interrelationships. Stages, quality gates and milestones play a key role in this model. By way of visualization and the symbols used, this form corresponds to general models of the project life cycle (PJLC) - see, for example, Jan Doležal - Project management [23], or PMI - PMBOK [3]. Such a form of notation is compatible with all key world standards and concepts of project management and at the same time corresponds to the habits of the application sector.

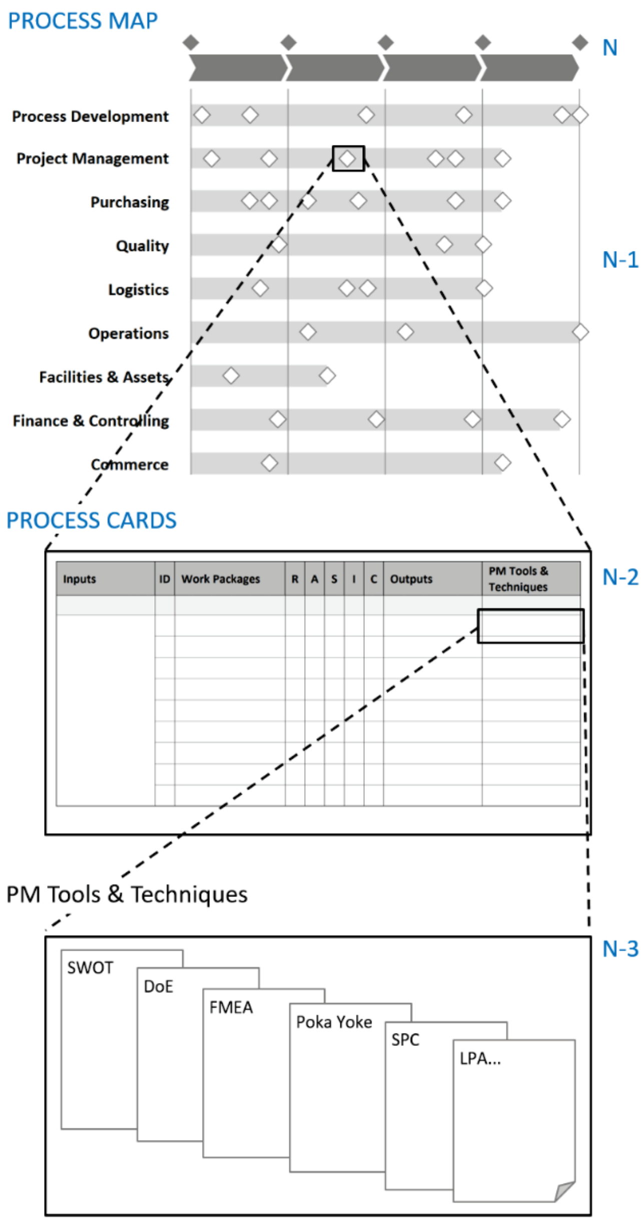

Figure 1 Proposed Model of Production System Creation Process [35]

The proposed process map consists of two levels:

- **N** level forms the main axis of the model divided into the basic stages. The boundaries between the individual stages form quality gates, following the model of the Maturity Level Assurance publication by VDA. The main supplier milestones will come to the axis, which follow on the main milestones of the OEM. These form the basic interface of mutual cooperation.
- **N-1** level makes up the PM success factors of the Production System Creation Process. PM success factors are defined by professional literature as circumstances and influences that lead directly or indirectly to ensuring the quality of the project's product (here production systems), while the correct identification and treatment of these factors will help the success of the project and the achievement of project goals (Doležal, 2016) [23]. Success factors take the form of milestones placed in a matrix according to responsibilities and the required date of fulfillment in the so-called "swimlanes".

The task of the process map is to clearly visualize WHAT is to be done by WHO and WHEN.

In order for the methodology to serve its purpose well, the process map is further complemented by PROCESS CARDS clearly characterizing the individual process steps.

The process cards also consist of two levels:

- **N-2** level consists of the A4 landscape format process cards themselves, which characterize the individual process steps in detail by describing their:
  - Inputs,
  - Process Steps,
  - Responsibilities,
  - Outputs, and
  - PM Tools & Techniques forming N-3 level.
- **N-3** level provides a reference to general PM tools and techniques well applicable to the quality management of automotive supplier production systems. However, the methodology will only refer to these techniques as proven solutions described in detail in separate books, which do not need to be invented or repeated again.

Process Cards are intended to correct deficiencies in the current state of knowledge and show users HOW. See Chapter 6 for a better understanding of the differences in a traditional approach and the proposed methodology.

4 CREATION OF THE METHODOLOGY

The standardization of the methodology consisted of two steps in terms of time and according to the nature of the activities performed. These were the mapping of the business process designated as the PSCP and its subsequent modeling.

4.1 Mapping

Mapping began in the initial phase of the research with the analysis and synthesis of the current state of knowledge.

Scientific method: Analysis and synthesis of the current state of knowledge through systematic literature review

Systematic literature review, also referred to as content analysis of documents, is characterized by experts as a systematic, explicit, and repeatable procedure designed for the identification, evaluation, and synthesis of results created by researchers, academics, and practitioners (Fink, 2014) [24]. Unlike observation or questioning, it does not collect data in the field (field research), but directly evaluates data that is already collected and available (Jesson, 2011) [25].

Selection of resources:

- Selection criteria: content conforms to the research limitations - categories "Application Sector" and "Scope"
- Area: WoS scientific database, literature, database of OEMs organized in VDA (BMW, Daimler, Porsche, VW), database of AIAG and VDA trade groups.

Procedure: The purpose of the review is already described in the introduction of Chapter 2, it was planned for 1 year and was conducted through ICT. Among others, the following sources were analyzed: the three most popular general PM standards - PMBOK Guide [3], IPMA ICB4 [26] and PRINCE2 [27], the Product Creation Process (PCP) of the VW Group [2, 5], or specific requirements of the VW group for its suppliers [18, 28]. Due to a very limited formal scope of this article, the sources are not described in more detail.

Benefit to the research:

- Inspiration for the form and content of the Process map
- Source of 9 key N level milestones
- Source of 30 N-1 level success factors
- Inspiration for the form and content of Process cards
- Source of 200+ level N-3 tools and techniques of PM.

Since the available literary sources did not offer the comprehensive information needed to develop the methodology, especially the success factors of the N-1 level, the authors decided on additional mapping in the field based on cooperation with experts from the application sector who best understand the needs of the industry. Due to the nature and objectives of the research, a Delphi method was chosen as the appropriate method.

Scientific method: Delphi method with a panel of experts.

In a broader sense, the Delphi method can be defined as a process of structuring group communication, in a narrower sense then, as a method of collecting expert opinions through multi-round questioning with controlled feedback between individual rounds. Among the basic features of the method are the anonymity of experts, controlled feedback and statistical determination of the consensus of experts' opinions. The Delphi method can be advantageously applied in areas in which it is necessary to obtain expert opinions on issues that are more difficult to ascertain through statistical analysis or other standard methods. The method is suitable for data collection in the field (field research) [31, 29, 30].

Selection of experts:

- Selection criteria:
  - Has ≥ 8 years of experience in project management in the field of production system development in Tier1/2 supplier companies,
  - Holds a professional certificate in project management,
  - Works in middle or senior management.
- Final number: 25 (the number recommended by the methodology is 15-35).

Procedure: The research was aimed at identifying the success factors of the PSCP (see Chapter 3), it was attended by 25 experts selected in accordance with the research limitations and the author of the research in the role of moderator, the research was determined to be three-round, planned for 5 months and conducted via e-mail.

Benefit to the research: Source of 48 N-1 level success factors.

4.2 Modeling

4.2.1 Process Map Modeling

The modeling started with the modeling of the Process Map, which forms the basis of the PSCP model. Due to the nature and objectives of the research, it was determined that the modeling will take place through a group interview with a panel of experts.

Scientific method: Guided semi-structured group interview with a panel of experts.

Group interviews belong to questioning. As the name implies, it is an activity connected with interpersonal contact of the researcher with a selected panel of respondents. On the basis of the discussion, under the guidance of an expert moderator, information is obtained about the opinions of the panelists on the chosen topic - issue. The advantage of the method is not only the ability to capture data, but also to penetrate deeper into the motives and attitudes of the respondents and obtain deeper information about the topic [31]. The method also allows participants to search for majority agreement (consensus) on the issue being addressed, which increases the validity of the outputs [32].

Selection of experts:

- Selection criteria:
  - Comes from a panel of 25 experts who participated in the Delphi survey (conforms to the same criteria),
  - Comes from a different enterprise than the other candidates (to ensure diversity).
- Final number: 7 (the number recommended by the methodology is 6-9).

Procedure:

The research investigation was focused on the modeling of the process map according to the construction design presented in Chapter 3, the interview was attended by 7 experts selected in accordance with the research limitations and the author of the research in the role of moderator, the investigation was determined to be two-round, it was planned for one day and it was placed in the production plant of the author of the research. The participation of 7 selected experts enabled majority agreement of respondents on a solution (= consensus).

Benefit to the research: Creation of a process map.

- **N** level is made up of:
  - the basic axis of the model divided into 4 stages,
  - 5 quality gates RG0-RG4,
  - 9 strategic milestones of the company, largely following on from the main milestones of the OEM.

- **N-1** level is made up of 78 milestones (key success factors) located in swimlanes. Each process step is provided with a unique identifier paired with a corresponding descriptive process card.

4.2.2 Process Cards Modeling

The second modeling step was the modeling of process cards. The processing of process cards was left to the individual enterprises participating in testing the methodology in practice. The reason is simple. As stated by IPMA [26], each organization is original and what works in one may not suit another. However, the authors standardized the process card template and provided specific examples for the initial (#0 - "PJ PRESETS") and final process step (#77 - "HOP") of the PSCP model. In addition, they provided the enterprises with more than 200 project management tools and methods discovered during SLR, which were sufficient to cover the needs of the enterprises

Selection of industrial enterprises: see Chapter 5

Benefit to the research: Creation of 78 process cards.

All the planned steps of the practical part of the research designed to fulfill the main research objective #1 were completed by modeling the PSCP model. The following chapter describes the steps that led to the verification of the validity of the proposed methodology in practice and to the fulfillment of the main research objective #2.

5 VERIFICATION OF THE METHODOLOGY IN PRACTICE

The chapter describes the confrontation of the proposed solution with reality (practice). This took place by testing the methodology on authentic projects of the application sector. Due to the nature and objectives of the research, it was determined that the testing of the methodology will take place through Case Studies.

Scientific method: Case Studies on authentic projects of application sector.

A case study is one of the qualitative research approaches. Unlike a statistical survey, in which a limited amount of data is collected from many individuals (cases), a case study collects a large amount of data from one or a few cases. The method thus enables capturing the complexity, details, relationships and processes taking place in a given microenvironment [33]. It is essential to select the case that will be examined in such a way that it represents a certain type or group of similar cases. Research using case studies takes place in the field (field research) [34].

Selection of industrial enterprises:

- Selection criteria:
- Conforms to the research limitations - category "Application Sector",
- Represents a global enterprise,
- Operates in the Czech Republic,
- Reaches the required maturity of the project management system.

Note: Maturity was tested according to the methodology "Analysis and assessment of project management in organizations" by IPMA. The criteria were set at ≥ 80%.

- Final number: 5

Selection of KPIs:

For monitoring and evaluating the performance of the projects, traditional project indexes evaluating the fulfillment of the scope over time were chosen. The indexes compare the scope that should have been achieved by the evaluation date and the scope that was actually achieved. Performance Index = 1 (equivalent to 100 percentage points) means that the project is running according to plan, $PI > 1$ signals the achievement of a higher scope than originally planned, and $PI < 1$ signals the achievement of a lower scope than originally planned. The nature of the indexes enables mutual comparison of performance of different projects regardless of their scope or character.

Re H1: As stated in Chapter 2.3, the purpose of H1 was to verify or disprove the positive influence of the proposed methodology on **Time**. The selected KPI suitable for verifying or disproving the H1 was Schedule Performance Index, refered to as **SPI**. The source of input data for evaluating project performance through SPI is the Project Master Plan. The project master plan contains all the significant activities of the cross-sectional project team that need to be carried out within the project from its initiation to completion in order to achieve the desired project results. The SPI was calculated according to the following formula:

SPI = actual number of completed activities / planned number of completed activities

Re H2: H2 was intended to verify or disprove the positive influence of the proposed methodology on the **Quality** of the project product (= production system). The selected indicator suitable for verifying or disproving the second hypothesis was the Quality Performance Index, referred to as **QPI**. This indicator expresses the degree of maturity of the production system reflected in the quality of its main output - the product. For this purpose, a key characteristic of the product is systematically monitored, which is directly influenced by the maturity (capability) of the production system from which the product originates. The QPI was calculated according to the following formula:

QPI = actual number of characteristics conforming to requirements / planned number of conforming characteristics

Re H3: H3 was intended to verify or disprove the positive influence of the proposed methodology on **Costs.** The appropriate indicator chosen to verify or disprove the third hypothesis was the Costs Performance Index, referred to as **CPI**. For the purposes of practical testing and verification of the validity of the proposed methodology, the consumption of External Failure Costs was specifically monitored and evaluated. External Failure Costs represent the costs incurred to resolve failures after delivery to the customer. In a narrower sense, the costs indicate, whether the production system has reached the required level of maturity in time and is able to produce the product in accordance with the customer's requirements. In a broader sense, they indicate the state of maturity of the entire project and how well the control mechanisms across the value stream are set to prevent the delivery of non-conforming products to the customer. The source of input data for evaluating project performance through the CPI is the Project Budget, or its sub-item called the External Failure Costs Plan. The CPI was calculated according to the following formula:

CPI = planned cost of external nonconformities / actual cost of external nonconformities

Procedure: The purpose of confronting the proposed solution with reality was to confirm or refute the research hypotheses and answer the research question. Testing took place simultaneously in all 5 companies selected according to the selection criteria. In each company, 2 projects were managed in a traditional way and 2 according to the proposed methodology (20 projects in total). For the sake of mutual comparability, projects of an appropriate scale intended for OEMs organized in the VDA business group with identical customer requirements were selected for testing. The testing was planned for a total of 3 years and was managed through regular meetings of steering committee. By applying the methodology in practice, real data were obtained and the outputs were compared with the assumptions that were considered during the design of the methodology. After the tests were completed, the results of both approaches were averaged and compared to each other.

5.1 Re H1: Verification of the Impact on Time

SPI - E #1: Ø Projects before (0.83) × after (0.93) = Δ +0.10
SPI - E #2: Ø Projects before (0.87) × after (0.93) = Δ +0.06
SPI - E #3: Ø Projects before (0.93) × after (0.94) = Δ +0.01
SPI - E #4: Ø Projects before (0.85) × after (0.91) = Δ +0.07
SPI - E #5: Ø Projects before (0.79) × after (0.90) = Δ +0.11

In terms of verifying or disproving the positive impact on **Time**, the results showed the following:

- For all projects managed with the help of the proposed methodology, there was an improvement in performance compared to projects managed in a traditional way,
- The smallest improvement occurred in Enterprise #3, by an average of 0.01 points (1%),
- The biggest improvement occurred in Enterprise #5, by an average of 0.11 points (11%),
- The overall average improvement was 0.07 points (7%).

Based on the practical testing conducted and based on a comparison of the performance of projects managed in the traditional way and projects managed with the help the proposed methodology, it is possible to state that **hypothesis H1 was CONFIRMED**.

5.2 Re H2: Verification of the Impact on Quality

QPI - E #1: Ø Projects before (0.80) × after (0.93) = Δ +0.13
QPI - E #2: Ø Projects before (0.77) × after (0.94) = Δ +0.17
QPI - E #3: Ø Projects before (0.92) × after (0.96) = Δ +0.04
QPI - E #4: Ø Projects before (0.77) × after (0.94) = Δ +0.17
QPI - E #5: Ø Projects before (0.82) × after (0.90) = Δ +0.08

In terms of verifying or disproving the positive impact on **Quality**, the results showed the following:

- For all projects managed with the help of the proposed methodology, there was an improvement in Performance,
- The smallest improvement occurred in Enterprise #3, by an average of 0.04 points (4%),
- The biggest improvement occurred in Enterprise #2 and Enterprise #4, by an average of 0.17 points (17%),
- The overall average improvement was 0.12 points (12%).

Based on the results of practical testing, it is possible to state the **hypothesis H2 was CONFIRMED**.

5.3 Re H3: Verification of the Impact on Costs

CPI - E #1: Ø Projects before (0.33) × after (0.76) = Δ +0.43
CPI - E #2: Ø Projects before (0.71) × after (0.95) = Δ +0.24
CPI - E #3: Ø Projects before (1.04) × after (1.12) = Δ +0.08
CPI - E #4: Ø Projects before (0.86) × after (1.38) = Δ +0.53
CPI - E #5: Ø Projects before (1.05) × after (3.07) = Δ +2.02

In terms of verifying or disproving the positive effect on **Costs**, the results showed the following:

- For all projects managed with the help of the proposed methodology, there was an improvement in performance,
- The smallest improvement occurred in Enterprise #3, by an average of 0.08 points (8%),
- The biggest improvement occurred in Enterprise #5, by an average of 2.02 points (202%),
- The overall average improvement was 0.66 points (66%),
- Cost experienced more dramatic fluctuations in performance over time than Quality and Time.

Based on the results of practical testing, it is possible to state that the **hypothesis H3 was CONFIRMED**.

The results of testing the methodology in practice showed that all research hypotheses were confirmed and the answer to the research question is YES. The proposed methodology can thus be **declared valid**, despite pseudo-verification on a relatively small sample of Case Studies.

By verifying the validity of the proposed methodology in practice, the main goal of research #2 was fulfilled. A successful confrontation with reality was followed by a confrontation with world knowledge (theory).

6 DISCUSSION

The chapter confronts the proposed solution with the current state of knowledge analyzed in the theoretical part of the research. In order to make the comparison objective, only resources intended primarily to ensure the quality of production systems in the automotive sector are compared.

6.1 Reference Model by Baraldi and Kaminski (2018)

Analysis of the paper showed that the methodology was designed for the purpose of implementation of new production processes in the automotive sector, it is a simple guide through the entire Production System Creation Process (PSCP), it defines responsibilities of participants and it can be tailored to a specific project. It is processed in the form of a simple graphic model providing a very rough instructions on WHAT to do, WHO should do it and WHEN to do it. What cannot be found in the model, is the answer to the question HOW to do it. The model generally exhibits an excesive generalization of content and a significantly narrower scope compared to the sources from which it originates. For comparison, while the APQP methodology describes the process of product and process quality planning on 108 pages, the model by Baraldi and Kaminski fits on 3 pages. Among the auxiliary tools and techniques used in the planning and development of production systems, it mentions two, namely the PFMEA and the Control Plan. These tools are however not elaborated or analyzed in any further way. For the reasons stated above, it can be stated that the paper represents more of a schematic model than a full-fledged methodology, with the help of which it would be possible to effectively manage complex development projects. The publication can from the point of view of fulfilment of the goals of this research be marked with the label "BASIC".

6.2 APQP by AIAG (2008)

A detailed analysis of APQP showed that the methodology was designed to product quality planning in the early stages of car development, it guides the user through the entire Product Creation Process (PCP) and it can be tailored to the needs of a specific project. It is processed in the form of a simple graphic model supplemented by a modest explanatory text, validation of the accuracy of the process is facilitated through predetermined sets of questions provided in the methodology's appendix. The methodology provides the user a basic instructions on WHAT to do, WHEN to do it and WHY. This publication however does not provide information on WHO should perform the task and HOW to do it. Product and process quality assurance is thus looked at more from the point of view of a customer interested in the result, than from the point of view of a supplier who must achieve the result. Additionally, as the name suggests, APQP is a methodology designed primarily for product quality planning. Process quality planning is therefore partially addressed. The methodology also advises utilization of 11 supplementary analytical methods, like CP, FMEA, MSA, PPAP, or SPC, which enhance the likelihood of success of the development activities, but only the Control Plan is further elaborated from these techniques [35]. Based on the above information, it can be concluded that the methodology is intended for more experienced users, who will serve as a basis for standardizing their own PM procedures. The publication can be marked with the label "ADVANCED" from the point of view of fulfilling the research objectives.

6.3 PSCP by Knapp and Šimon (2023)

As can be seen from the paper, PSCP is a full-fledged methodology designed to plan and manage activities associated with the development of production systems in the automotive sector, it is a complex guide in the entire Production System Creation Process (PSCP), it defines the responsibilities of its participants and it can be tailored to the needs of a specific project. It is processed in the form of a clear but detailed PROCESS MAP supported by explanatory PROCESS CARDS providing the users not only instructions on WHAT to do, WHO should do it and WHEN to do it, but also HOW to do it. Process quality assurance is thus not looked at from the point of view of customer interested "just" in the result, but from the point of view of a supplier, who must achieve the results. The methodology also advises utilization of 200+ auxiliary analytical methods, such as DoE, FMEA, LPA, MSA, SPC, or SWOT, which enhance the likelihood of success of the development activities. However, it only refers to these as established tools that are described in separate literature and need not be described again [35]. The methodology is developed in such a way that it can be used even without previous expert experience in the field of PM and is therefore intended not only for experienced users, but also for beginners. The publication can be marked with the label "PROFESSIONAL" from the point of view of fulfilling the research objectives.

A brief description of individual solutions is complemented by a comparison of their scope.

Table 1 Comparison of the scope of individual solutions

		Solution		
Level	Subject	RM	APQP	PSCP
N	Stages	5	5	4
	Milestones	6	5	9
N-1	Process steps	52	49	78
N-2	Process cards	0	0	78
N-3	Tools and techniques of PM	2	11	200+

A comparison of the proposed methodology with the current state of knowledge showed that all three standards are intended to treat the quality of production systems, are based on a similar philosophy and show common features. Nevertheless, they differ significantly from each other, not only in terms of the time and place of creation and the environment from which they originate, but above all in the way of processing, formal complexity, scope and demands on the professional competence of users.

7 CONCLUSION

The final chapter summarizes the research results, states how the results could be applied in theory and practice, what are its limits and where the research could go next.

7.1 Research Results and Contribution to World Knowledge

The main objectives of the research were: creation of a methodology for the development of production systems of automotive industry suppliers and its validation in practice. The methodology was created through the structured scientific procedure described in the previous text, and the obtained materials were carefully assembled so that the proposed solution corrected the shortcomings of world knowledge and well fulfilled the purpose for which it was created. The proposed solution was tested in practice through case studies. The results of the testing showed that in all projects managed using the proposed methodology there was an increase in performance compared to projects managed in a traditional way. The successful confrontation of the solution with reality (practice) was then underlined by a successful confrontation with world knowledge (theory). The mutual comparison showed that the proposed methodology can be described as evolutionary, not only due to a significantly greater scope and level of detail, but also because it does not demand professional competence of the users, and contains elements that none of the available world knowledge solutions offers. The way of using the created and tested standard depends on the motives and needs of individual users. The following can be cited as an example:

- Training material: "Theory of project management within the automotive industry" intended for training workplaces,
- Methodology applicable in engineering practice in application sector enterprises for managing new projects,
- PM guideline of automotive industry suppliers meeting the requirements of ISO 9001 and IATF 16949 standards.

7.2 Research Limitations

Application sector:

- Automotive industry
- Tier1/Tier2 suppliers
- Serial suppliers (build-to-print).

Scope of the methodology:

- Project management (not program/portfolio)
- Development stage of the car life cycle.

Validity of the methodology:

- Pseudo-verification of the validity of the methodology through Case Studies on a relatively small sample: 5 enterprises, 20 projects.

7.3 Direction of Further Research

The recommendation for the direction of further research smoothly follows on from the results of the current work, which was artificially limited, mainly due to the formal limitation of the scope of the work.

- **Increasing the validity of the methodology**. For the reasons stated in Chapter 5, the validity of the methodology was tested on a relatively small sample of Case Studies (5 enterprises, 20 projects). The authors thus recommend a gradual controlled iteration through the DBR (Design Based Research) methodology based on new ideas, lessons learned (LL) and best practices (BP) obtained during the controlled deployment of the methodology on other projects of the application sector.
- **Increasing the horizontal scope of the methodology**. In its current state, the methodology covers the period of Production System Development. In the case of additional treatment of the period of Product Development (+ 0.8yr), the applicability of the standard can be extended to the entire Development stage of the car's life cycle.
- **Extending the scope of the methodology to program/portfolio management**.

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