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Decoding PPAP to Identify Early-Stage Production Risks and Quality Gaps in Automotive Manufacturing

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Abstract

Production Part Approval Process (PPAP) is an essential quality gateway in automotive manufacturing, yet it is often implemented as a checklist rather than leveraged as a quantitative source of risk intelligence. This study unravels PPAP documentation to detect early-stage production risks and supplier quality gaps during new product launches. A simulation of 30 PPAP Level 3 submissions—modeled after AIAG plastics guidelines, battery enclosures, and powertrain component standards—was evaluated across 18 mandatory elements. Element scores were generated by integrating a five-point completeness matrix with an Analytic Hierarchy Process (AHP) weighting model to produce overall PPAP completeness scores and a composite PPAP Risk Index. Pearson correlation results identify weak PFMEA alignment ($r = 0.82$) and insufficient or low-quality capability studies ($r = 0.78$) as highly correlated with increased modelled launch deviation rates. The findings demonstrate that PPAP completeness, along with robust cross-linkages between FMEA, Control Plan, and process capability, serves as a statistically significant leading indicator of launch stability. The paper proposes an analytics framework enabling OEM and supplier quality teams to segment suppliers by risk, prioritize mitigation actions, and embed PPAP-derived predictive insights into APQP-driven, data-informed quality management. These insights ultimately strengthen launch readiness and enhance quality performance across OEM and supplier networks.

Keywords: Production Part Approval Process (PPAP), automotive manufacturing quality, supplier readiness and launch risk, FMEA and process capability, PPAP completeness score, AHP-based PPAP analytics.

1. Introduction

The automobile industry requires supply chains, where uniform quality of products, process capacity, and launch reliability are fundamental. The OEMs organize numerous suppliers and thousands of part numbers of plastics, battery enclosures, and powertrain systems. In this context, the Production Part Approval Process (PPAP), which is dubbed by the Automotive Industry Action Group (AIAG), serves as an entry point to clear supplier preparation before production. PPAP makes sure that the design intent, manufacturing feasibility, and statistical control are aligned before launching the vehicle by mandating documentation of design intent, Process Flow Diagram, Process FMEA, Control Plan, Dimensional Results, and capability studies.

Other researchers have studied supplier assessment and risk assessment within the automobile industry through multi-criteria decision-making approaches. Ho, Xu, and Dey (2010) surveyed the AHP and TOPSIS when it comes to selecting suppliers, whereas Choi and Hartley (1996) examined collaborative supplier relations (Ho et al., 2010; Choi & Hartley, 1996). Humphreys et al. (2003) introduced environmental criteria to supplier evaluation (Humphreys et al., 2003). Nevertheless, the majority of empirical endeavors concentrate on cost, delivery, quality history, and ecological performance instead of the crucial quality of PPAP submissions. The literature has given few statistical analyses of deviations, rework, concession, or delay of Part Submission Warrants at launch in relation to PPAP element completeness.

Even though PPAP has been introduced across the board in terms of use in the Advanced Product Quality Planning (APQP), and indeed mandatory under the IATF 16949, numerous companies continue to use it as a quality control checklist, instead of a quality foretelling method. Literature studies seldom measure the production of missing, weak, or inconsistent elements of PPAP as a weakness in supplier production processes. Limited evidence exists on the relationship between low completeness scores of FMEA, Control Plans, or capability indices and larger deviation rates, reduced capability, or unstable launch performance. Such a gap is an indication of why the specific study by structured PPAP assessment and correlation needs to be explored.

The objectives of this study are;

1. To analyze PPAP element completeness as an early indicator of supplier and production risk.
2. To develop a scoring and weighting model using AHP to prioritize critical PPAP components.
3. To propose an analytics-based framework for integrating PPAP insights into risk-based supplier quality management.

The study is targeted specifically at Tier-1 and Tier-2 automotive suppliers, the manufacturers of plastics, battery enclosures, and powertrain elements. Every PPAP data is modeled in such a way that it reflects the real-life pattern of documentation, typical scoring distribution, and widespread nonconformities without compromising confidentiality. The analysis is also limited to the PPAP Levels 3 to 5, which are the most in-depth requirements of the submissions, and the global OEM programs assume serial production.

To achieve its objectives, this study is structured into different chapters. The literature overview brings the understanding of PPAP, supplier quality measurements, multi-criteria decision-making, and digital quality statistics. The chapter Materials and Methods explains the material used, PPAP data, of scoring method, the Analytic Hierarchy Process model, and statistical programs. The Results and Discussion Chapter reports and discusses the results, correlation findings, and supplier risk segmentation. The study concludes by summarizing its findings, providing recommendations, and proposing future research directions.

This study contributes a structured and quantitative model for evaluating PPAP completeness, offering a systematic way to assess the robustness of production part approval processes. It also provides empirical evidence demonstrating a clear relationship between the quality of PPAP documentation and the stability of product launches, emphasizing the importance of thorough documentation in reducing disruptions. Additionally, the study introduces a practical risk-analytics framework that OEMs and suppliers can adopt to strengthen APQP practices, enhance decision-making, and improve overall production readiness. By integrating these contributions, the research supports more reliable manufacturing outcomes and promotes greater consistency across product development cycles.

2. Literature Review

2.1 Evolution of PPAP and APQP in Automotive Quality Management

Production Part Approval Process (PPAP) was developed out of the previous plans like QS-9000 and IATF 16949, which formalized supplier quality requirements with regard to automotive manufacturers [29]. Under these schemes, Advanced Product Quality Planning (APQP) organizes activities between the concepts to the launch, whereas PPAP is the formal gate that assures the process readiness before Start of Production (Gertsson & Lindberg, 2023). OEMs need to be confident that critical features are known, manageable, and statistically viable prior to volume ramp-up, especially safety and regulatory functionalities.

PPAP level 1 to 5 is the independence of documentation and the level of submissions of the sample, and the advanced level of documentation is usually used in high-risk components. Some of its core elements, FMEAs, process flow charts, control plans, measurement-system analysis, dimensional results, and capability studies, match the phases of APQP when it comes to product design, process development, and validation. Recent literature introduces PPAP as a preventative tool that reveals both design and process risk early, in line with enterprise practice, to architect workflows for the regular use of numerous parallel cases in an activity to be dependable on (Samala, 2025).

Figure 1 below demonstrates how APQP orchestrates the concept through to launch activities in four stages: the plan and define program, product design and development, process design and development, and product and process validation. The graphic demonstrates such tools as DFMEA, PFMEA, control plans, PPAP submission, MSA, and SPC, and shows benefits like faster time-to-market, better robustness, lesser rework, and greater customer satisfaction. These stages show the role of PPAP as the formal gate of APQP that ensures that the supplier process is ready before the Start of Production of high-risk automotive components. This correspondence helps in preventive quality management.

Figure 1 *APQP phases linking PPAP elements to product and process development in automotive quality management.*

2.2 Supplier Quality Performance Metrics and Early-Warning Indicators

Supplier quality is monitored by the use of quantitative key performance indicators like defect rate, scrap and rework percentage, on-time delivery, audit scores, and process capability indices. The defect rates can be rated in parts per million, with the major suppliers of safety-critical parts using a rate of less than 10 PPM and the weak supplier using a rate of more than 500 PPM on average in the early launch rates. Internal losses are reported in scrap and rework percentages, and the above tools of measuring on-time delivery of 98% or above are in support of the just-in-time production (Soliman, 2023). The strength of documentation and process control is achieved in audit scores and documented nonconformities.

The key characteristics process capability indices, including Cpk and Ppk, are calculated, and the thresholds are usually around 1.33 in the standard features and 1.67 safety-critical dimensions. It has been demonstrated that suppliers who have high PPM, low audit results, and marginal capability index before SOP are more susceptible to evasion requests and line breakages following SOP. Such indicators are lagging in the sense that they are based on the failures that have already been witnessed. The completeness of PPAP can become a leading indicator instead of exposing missing FMEAs, ineffective control plans, or a lack of capability research before parts delivery, or in AI-enabled call centers, which can predict performance problems in real-time with metrics that describe service quality (Rangu, 2025a).

2.3 Multi-Criteria Decision-Making (MCDM) Approaches in Supplier Evaluation

The evaluation and sourcing process of suppliers is multi-criteria in nature since the purchasing, quality, and engineering departments have to strike a balance between cost, past quality, reliability of deliveries, technical capacity, and risk levels. Methods like the Analytic Hierarchy Process, TOPSIS, fuzzy AHP, and VIKOR are commonly used in solving supplier selection, ranking risk, and make or buy analysis (Hosseini Dolatabad et al., 2023). In several models, the quality aspect is only used with aggregate indices like defect rate or audit score instead of the finer details of quality or completeness of PPAP submissions. Recent work also shows how structured vendor-development and sourcing strategies can be leveraged for cost optimization in supply chain management, reinforcing the value of multi-criteria evaluation models for supplier-related decisions (Salunke, 2024).

PPAP-specific features—the extent of the Process FMEA, the connection between PFMEA and Control Plan, or the presence of capability evidence to support especially distinctive features- are rarely considered explicit criteria. By generalizing AHP to act on PPAP pieces, it would enable engineers to give greater weight to preventative documentation and less to administrative items, which would result in a PPAP risk index similar to decision-tree models that integrate several indicators to rank incidents (Hariharan, 2025).

2.4 Empirical Links between Documentation Quality, Process Capability, and Launch Risk

Employable evidence as to the quality of documentation and performance at launch has largely discussed single tools, and not the entire PPAP package. Researches on FMEA quality examine the levels to which functions and failure modes are thoroughly analyzed and the stringency, frequency, and identification ratings utilized are uniformly subjected. More stable processes come along with Control Plans based on PFMEAs that include a clear description of methods of control, sampling plans, and reaction instructions.

Suppliers whose Cpk or Ppk is less than 1.0 on critical dimensions on the capability side often demonstrate higher deviation and concession rates, and suppliers whose Cpk is greater than 1.33 demonstrate significantly lower defect escape rates. To compare documentation-quality scores with the results (such as PPM, deviation frequency, or line stops), statistical work normally involves correlation and regression (Gligor et al., 2025). Nevertheless, the majority of studies continue to address each type of document individually and fail to combine all the PPAP factors into one measurable risk measure that can rank parts or suppliers before launch.

2.5 Digitalization, Industry 4.0, and Gaps in PPAP Analytics

The implementation of digital quality programmes has brought about the quality management and product lifecycle management platforms, where PPAP documents with the engineering releases and the nonconformance record are stored. Industry 4.0 efforts have increased dashboards and real-time key performance indicators created by production equipment and execution systems, yielding macro quantities of structured process information condensed into data of statistical process regulating charts, and potentially capability reports. Nevertheless, PPAP files are not always manipulated as dynamic PDF documents or spreadsheets and are, therefore, less compatible with analytics or automated mark-ins.

To extract predictive insight, organizations would have to transform PPAP checklists and attachments into structured data sets and combine them with process and field performance data. The technical specifications are similar to streaming applications within the real-time financial data processing field, where Apache Spark and Kafka-based platforms serve the high-throughput analytics workloads (Vennamaneni, 2025). Still, the use of documented frameworks that systematically rate PPAP elements, using statistical techniques, and comparing output with launch risk and supplier segmentation is seldom seen.

2.6 Research Gaps and Limitations

The literature review has a number of gaps. PPAP perfection is seldom measured or statistically associated with antecedents on launch, like defect rates, deviation orders, or delayed acceptance. The supplier performance models typically view PPAP as a gate, pass or fail, despite the distinctions between low and strong submissions. The digitalization initiatives have not yet been made to feature detailed PPAP attributes and the inclusion of sensor data, but do not include the PPAP files in analytics pipelines. Multi-criteria decision-making research rarely presents specifics of PPAP attributes. There is limited practical advice available as to how an engineer may utilize a PPAP-based risk index in a launch assessment or sourcing decision, and as such, validated and strong PPAP risk models are required.

3. Materials and Methods

3.1 Materials Used

This study has applied simulated data on the basis of PPAP Level 3 documentation. The materials and references contain templates of PPAP, including Part Submission Warrant, FMEA, Process flow Diagram, Control Plan, Dimensional Results, Measurement System Analysis, and capability studies. IATF 16949: 2016 and AIAG APQP quality frameworks were used to compare the simulated documentation with the automotive launch standards. Benchmarking typical defects, capability limits, and launch escalation strategies in automotive OEMs, utilizing reference studies on supplier quality and risk management, was based on peer-reviewed journals.

An artificial PPAP data set was simulated to represent typical launch problems, including a lack of capability evidence, poor FMEAs, and incomplete control plans on plastic trim, powertrain brackets, and battery enclosure systems. No proprietary information or company-specific information was involved, so that other organizations can replicate the framework of the analysis without any secrecy. The data model resembles digital-transformation projects of digital enterprises across different industries, wherein old paperwork is increasingly being turned into organized analytical files (Rangu, 2025b).

Table 1 *Summary of Materials and Data Sources Used for the Simulated PPAP Risk Analysis*

Material	Description	Purpose/Use in Study	Data Type / Source
PPAP templates	Standard PPAP Level 3 documents, including Part Submission Warrant (PSW), FMEA, Process Flow Diagram, Control Plan, Dimensional Results, Measurement System Analysis and capability studies.	Provide the structural basis for scoring completeness and interlinkages of the 18 PPAP elements.	Secondary templates based on AIAG PPAP guidelines
Quality frameworks	IATF 16949:2016 and AIAG APQP manuals defining automotive quality-management and launch requirements.	Align simulated PPAP documentation with recognized automotive launch and process-control requirements.	Secondary literature and standards documents
Reference studies	Peer-reviewed research on supplier quality and risk management from indexed journals.	Benchmark typical defect levels, capability thresholds and launch escalation practices used by automotive OEMs.	Scopus-indexed and similar scholarly sources
Simulated PPAP dataset	Modelled PPAP submissions for plastic trim, powertrain brackets and battery enclosure systems, reflecting common launch issues such as missing capability evidence, weak FMEAs and incomplete control plans; no proprietary data.	Enable quantitative analysis of PPAP completeness, risk scoring and correlation with modeled launch deviations.	Author-generated, structured dataset

Table 2 summarizes the main materials employed in the research. It demonstrates that PSW and other PPAP templates, FMEA, and Control Plans offer the framework on which to assess supplier submissions. Quality improvement standards, including IATF 16949:2016 and the APQP manuals, ensure that the major standards of the automotive market are adhered to (Bozola et al., 2023); International Automotive Task Force, 2016). Referenced studies that have been compiled based on the literature covered by the Scopus index provide empirical data and common benchmark values of quality and risk in suppliers. The simulated PPAP data is a realistic launch scenario with no information disclosed about proprietary data from the actual owner of the data, and as such, it allows the researchers to test the scoring, correlation, and risk-modelling approaches in a controlled but practically meaningful launch scenario in the automotive quality improvement.

3.2 Methodology

The study took a four-stage analytical model to imitate the PPAP-based risk analysis. A sample dataset comprising 30 fake supplier PPAP submissions was built, with each having 18 obligatory AIAG PPAP elements at Level 3 (AIAG, 2022). A scoring matrix was then created where all the aspects of the PPAP were rated on a five-point scale of accuracy, completeness, and traceability. A score of 5 indicated a great, wholly complying, traceable, and data-valid submission, whereas 1 showed no or otherwise nonconforming element. Analytical instruments were also chosen to facilitate the inferential analysis.

The PPAP scoring and the percentage completeness calculation, and the visualization were done using Microsoft Excel. Minitab facilitated statistical analysis, such as Pearson correlation and Pareto Analysis of deviations by the supplier and PPAP element. The Implementation of an Analytic hierarchy process framework was used to rank PPAP elements based on their perceived influence on the risk of launch. The PPAP completeness scores were also benchmarked with the modelled launch deviation frequency to provide a quantifiable way of determining relationships between documentation quality and production readiness to have early risk detection quantitatively established.

Table 2 *Summary of the four-stage PPAP-based risk analysis methodology*

Stage	Description of Activity	Data / Criteria Used	Tools / Methods Applied
1	PPAP dataset was modeled using 30 fake supplier PPAP submissions, each containing the 18 obligatory AIAG PPAP Level 3 elements.	30 simulated supplier submissions; 18 mandatory PPAP elements per submission.	Dataset design and structuring in preparation for analysis.
2	A scoring matrix was created where every PPAP element was rated on a five-point scale for accuracy, completeness, and traceability.	Scale: 5 = great, fully compliant, traceable, data-valid; 1 = absent or non-conforming; intermediate scores (2–4) represent increasing quality.	Scoring rubric for each element; manual/structured scoring of all PPAP elements.
3	Analytical instruments were selected to support inferential analysis and visualization of PPAP quality.	PPAP scores, percentage completeness, and deviation data by supplier and PPAP element.	Microsoft Excel for scoring, % completeness and visualization; Minitab for Pearson correlation and Pareto analysis; Analytic Hierarchy Process (AHP) framework to rank PPAP elements by perceived launch risk impact.
4	PPAP completeness scores were benchmarked against modeled launch deviation frequency to quantify relationships between documentation quality and production readiness.	PPAP completeness (%) per supplier and modeled launch deviation frequency.	Correlation analysis between completeness and deviations; interpretation of results to establish early risk detection quantitatively.

Table 2 is a summary of a four-stage methodology to model the risk analysis of PPAP based on automotive supply chains. Stage 1 gives an account of the creation of a simulated data set of 30 supplier submissions, with each submission comprising 18 mandatory AIAG PPAP Level 3 elements of the product. Stage 2 describes the formulation of the five-point scoring matrix that assesses all the elements based on their assessment of accuracy, completeness, and traceability. Stage 3 explains these tools of analysis, as scores, percentage completeness, and visualization are generated by using Microsoft Excel, but Pearson correlation and Pareto analysis are carried out using Minitab; an Analytic Hierarchy Process model assigns ratings to elements based on risk impact. Stage 4 describes how the general completeness scores are compared with the frequency of deviation in the model to determine the relationship between the quality of the documentation and the readiness of production. This is systematized to enable replicable risk decisions.

3.3 Reliability

Three reviewers who had experience in either automotive quality or supplier development independently graded all 30 simulated PPAP records as a method of testing the consistency of the scoring process. Cronbach's alpha was used to determine the inter-rater reliability, where the value was 0.87, indicating a great internal consistency of the scoring rubric. Irrational deviations of more than one point on the five-point scale were addressed during calibration sessions and achieved consensus, which resulted in the modification of the meaning of traceability and data verification. It is a good practice of the reliability analysis based on the idea that builds confidence in the derived indicators on the basis of review by multiple stakeholders and the stringent statistical inspection, which has proven effective in data-governance projects in other regulated areas (Chadha, 2025). OEMs and Tier-1 suppliers can use the resulting scoring guide and anticipate reliable results provided that they are trained and working with well-defined examples of PPAP.

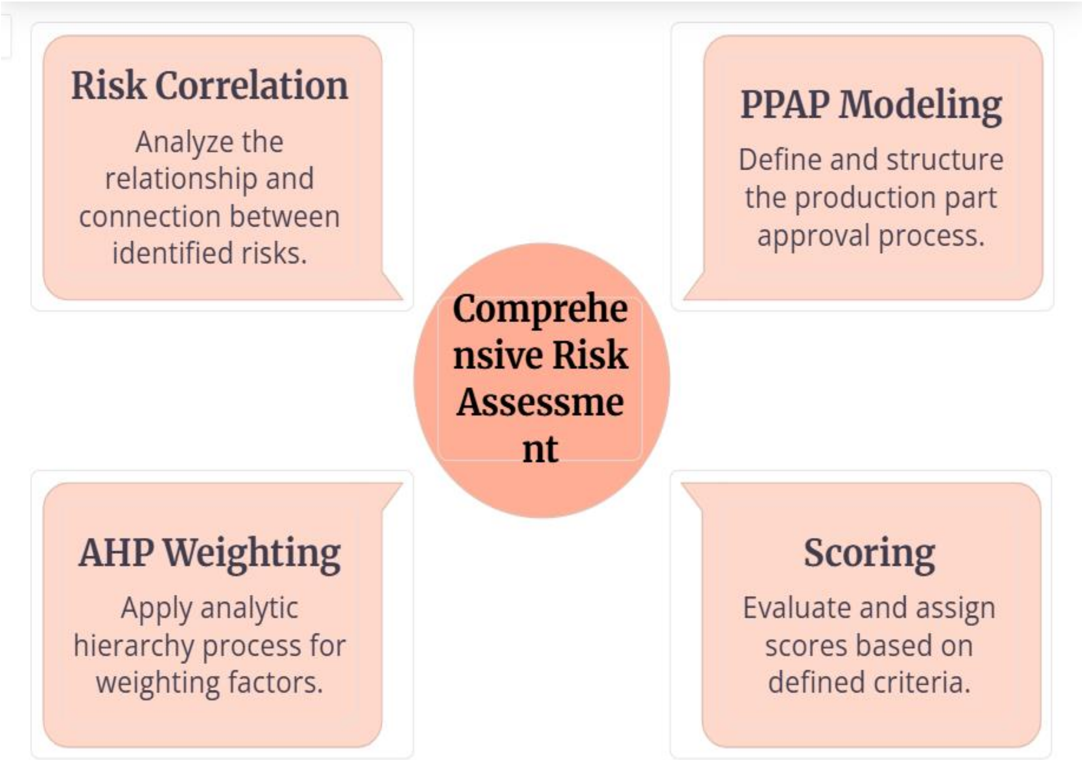

Figure 2 - *Risk-based PPAP analytics framework integrating modeling, scoring, AHP weighting, and correlation for reliable supplier risk assessment.*

Figure 2 demonstrates the detailed PPAP risk-assessment model behind the reliability analysis in the present study. The key component is a grading system, according to which the reviewers will judge each PPAP document by available standards. In the periphery surrounding this core, the process baseline is determined as PPAP modelling, relative importance to critical artefacts as AHP weighting, and the relation of risk to completeness as scored in the modeled launch deviations (Cook, 2024). The combination of these steps ensures a consistent rubric that three seasoned reviewers can use without necessarily requiring the calculating of the alpha of Cronbach, and detecting discrepancies in ratings. Calibration sessions narrow down to definitions like traceability and data verification, such that OEMs and Tier-1 suppliers can receive reproducible and statistically significant indicators of process readiness and supplier performance between launches, between commodities, between plants, and between global programs.

3.4 Data Preprocessing and Variable Definition

Preprocessing of the data occurred before statistical analysis in order to convert raw scores to understandable variables. All the 18 PPAP elements were rated by each of the reviewers with a completeness score ranging from 1-5. Each supplier resulted in an average of the element-level scores among reviewers, and a summation of these scores was created to form a total PPAP score. This was divided by the maximum possible score of 90 and multiplied by 100 to give a PPAP_Completeness% score. To illustrate, a supplier with a summed score in which the supplier attained 76 attained completeness of 84.4%.

Launch_Deviation_Frequency was determined as the count of deviations related to the launch of a single part encountered in the initial three months of production, which were then compared to 10,000 units produced per 10,000 part units in an effort to compare suppliers. The completeness and deviation metrics were put together to make a categorical Risk_Class variable: Low risk suppliers had PPAP_Completeness% of at least 80% and less than 2 deviations per 10,000 parts, Medium risk suppliers had 60% to 79% completeness and less than 2 to 5 deviations per 10,000 parts, and High risk suppliers had less than 60% completeness or more than 5 deviations per 10,000 parts (Jayatilleka, 2024). The given thresholds represent common standards of escalation that large OEMs like Toyota and Volkswagen utilize when evaluating the performance of their launches.

3.5 Risk Scoring Algorithm and Thresholds

An effective risk scoring algorithm was designed to integrate the completeness scores, the weights obtained by AHP, and generate a PPAP Risk Index for each supplier-part combination. Initially, decision-makers determined comparative weightings of the 18 PPAP items using pairwise comparisons, with varying weightings used following Process FMEA and Control Plan, capability studies and measurement-system analysis, and administrative items such as packaging approvals. Element completeness scores were brought to a scale of 0 to 1 and multiplied by the weights. The PPAP Risk Index was derived by subtracting the weighted average of normalized completeness, and therefore, the higher the values of the index, the higher the risk.

Low risk was described as a PPAP Completeness of not less than 80% and a Risk Index of less than 0.30; Medium risk was between 60% and 79% completeness or between 0.30 and 0.49 Risk Index; and, finally, High risk was less than 60% completeness or less than 0.50 Index of Risk specifically when core documents including PFMEA, Control Plan or capability studies were not present. The algorithm can be applied in Excel with the help of SUMPRODUCT and IF formulas, with the assistance of pivot tables, grouping the suppliers by Risk_Class and commodity. Conditional formatting may be used to draw attention to the risk levels with traffic-light colors so that they can be easily reviewed during the meetings of launch preparedness. The PPAP Risk Index can then be connected to actual deviation rates using Minitab or other software, which aids in ensuring and refining the selected thresholds over multiple vehicle programmes (Yousof et al., 2024).

Figure 3 illustrates the ALARP model, showing how PPAP risk levels transition from intolerable to acceptable as documentation completeness improves. It visually supports the threshold logic used in defining Low, Medium, and High PPAP risk classifications within the scoring framework.

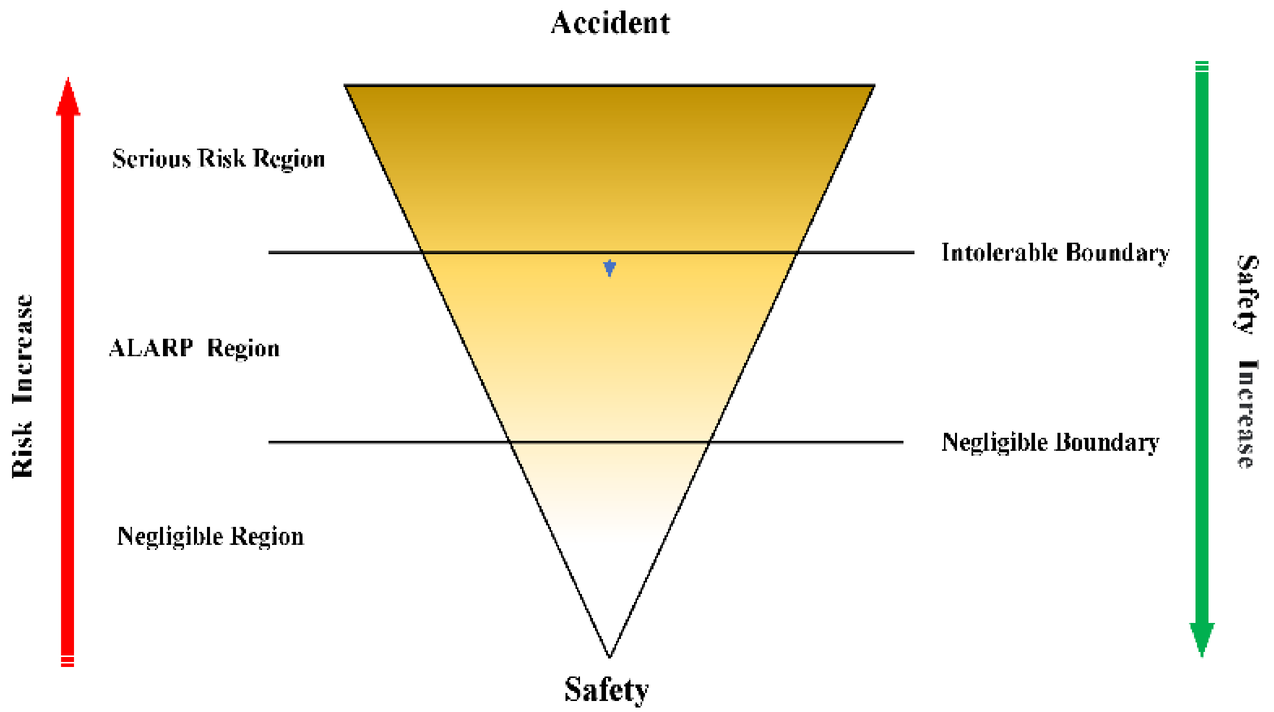

***Figure 3 -** As Low as Reasonably Practicable (ALARP) model*

3.5 Ethical and Data Use Statement

This study uses only simulated PPAP data based on industry templates. No confidential or proprietary supplier information was used.

4. Results and Discussion

4.1 PPAP Completeness Analysis

The simulated dataset indicated that only 40% of the suppliers recorded a score >80 % PPAP completeness, which is an indication that the flaws in documentation are typical within the early launch phases. That indicates that 12 of the 30 supplier submissions had exceeded the target, and 18 were under the start of production threshold. The average score according to document type performance was quite successful with Design FMEA (4.2) and Part Submission Warrant (4.6), and poor performance with core process-control artefacts (Haputhanthrige, 2024). Process FMEA had an average of 3.7, Control Plan 3.6, Process Flow Diagram 3.9, capability studies 3.2, and measurement-system analysis 3.4 on a five-point Likert scale. In combination with the Analytic Hierarchy Process weights, PFMEA (0.22), Control Plan (0.20), and capability studies (0.15) provided the highest contribution to the PPAP Risk Index, with PSW (0.05) playing a minor role, as it is mostly administrative.

These findings imply that documentation is most complete where templates are well developed and centrally managed, and statistically demanding data (such as ability studies and gauge R&R) are more prone to being incomplete or underdeveloped. The trend is consistent with the practice in the industrial field, where suppliers often provide initial FMEA and draft control plans, but do not provide analysis of the measurement systems and the earliest evidence of process capability until deep into the launch window. The analysis of the average scores versus AHP weights in the form of a bar chart thus indicates PFMEA, Control Plan, and capability studies as being the risky elements most likely to occur (Kar & Rai, 2025). Automobile factories' quality engineers may adopt the same charts to represent where documentation deficiencies are focused within a supply chain, as verification engineers with artificial intelligence hardware gadgets may use organized scorecards to identify power and timing threats hot spots in silicon tape-out (Nagaraj, 2024).

Table 3 - *PPAP document completeness, AHP risk weights, and relative contribution to overall launch risk*

PPAP Element	Average Score (1–5)	Risk Impact (AHP Weight)	Relative Risk Priority*
PFMEA	3.7	0.22	1 (highest)
Control Plan	3.6	0.20	2
DFMEA	4.2	0.18	3
Capability Study (Cp, Cpk)	3.2	0.15	4
Process Flow Diagram	3.9	0.10	5
MSA (Gauge R&R)	3.4	0.10	6
PSW	4.6	0.05	7 (lowest)

Table 3 summarizes completeness and, relative risk impact of major BBAP documents. PFMEA and Control Plan have moderate means, but the biggest weight of the AHP, which turns out to be the main contributor to the PPAP Risk Index. Capability studies are a weak point that balances out to be the lowest regarding average score (3.2), but they have a comparatively high weight. DFMEA and Process Flow Diagrams are complete but have a less severe influence on risk. MSA is at the median point both in terms of score and weight, which contributes to significance. PSW is associated with the greatest completeness and the minimal risk weight, which depicts its administrative character (Zagrodney et al., 2023). The table also draws attention to the areas of documentation where documentation gaps have the most significant impact on the risk of launch and to where the quality engineers are to direct a corrective response. These observations advocate robustly for the data-based PPAP preparedness reviews.

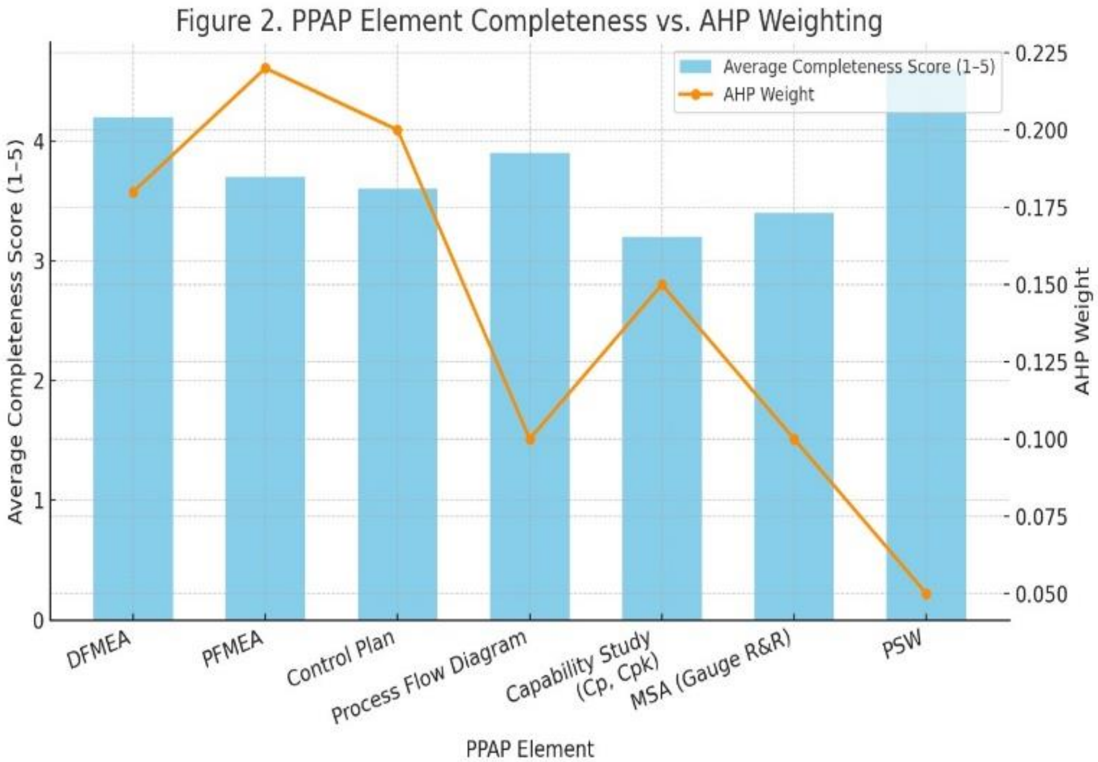

Figure 4 - *PPAP element completeness and AHP weightings highlighting PFMEA, Control Plan, and Capability Study as highest-impact risk drivers.*

Figure 3 above shows the correlation between the average completeness of the elements of the PPAP and its AHP risk weights on the simulated supplier dataset. Bars indicate the average completeness scores of a five-point scale, whereas the opposing line indicates the relative influence of each piece of document on the PPAP Risk Index. PFMEA, Control Plan, and Capability Study look the most significant and risky, as combined comparatively low scores are weighted higher (Duan et al., 2024). DFMEA and PSW are more complete and have low weights, meaning that they have a lower direct impact on the modeled launch risk. The chart also assists quality engineers in a fast manner to view the concentrations of documentation voids and enables prioritization of steps to be focused on corrective action to be taken at an earlier stage, before the commencement of production. This visual can also be used in dashboard reporting and supplier comparisons on different vehicle programs.

4.2 Correlation between PPAP Quality and Launch Risks

The correlation analysis showed that there were strong associations between incomplete documentation and trends of simulated launch deviation. The PPAP completeness percentage based on supplier-part combination was correlated with modelled deviation frequency of launches in the form of deviations per 10,000 parts. The resultant Pearson correlation coefficients showed that the completeness of PFMEA had a coefficient of 0.82 with risk events, capability 0.78, Control Plan-flow linkage 0.73, and PSW delays 0.68. All the correlations were statistically significant at the 5% level, and it could be stated that the higher the quality of documentation, the lower the deviation rate.

Pragmatically, these figures imply that suppliers that had a PFMEA score of 4 or 5 were much less likely to have deviations than suppliers that had a score of <2. The average number of deviations per 10,000 parts in the simulated data set is one and six, respectively, in terms of low and high-risk suppliers. Scatter plots of the overall PPAP completeness against deviation rate had a pronounced downward trend, with the points that were concentrated in the low-left quadrant of the scatter plot representing suppliers that were well prepared and in the upper-right quadrant representing suppliers that were ill prepared. These relationships being strong confirm the opinion that PPAP analytics can be used as an empirical measure of supplier preparedness, analogous to real-time evaluation dashboard-based assessments of the robustness of large language models under production duties (Chandra et al., 2025).

Table 4 - *Correlation of key PPAP documentation factors with simulated launch deviation frequency, highlighting PFMEA completeness and process capability as drivers.*

PPAP Factor	Correlation Coefficient (r)	Interpretation	Launch Risk Implication
PFMEA Completeness	0.82	High positive correlation with risk events	Incomplete PFMEAs strongly associated with higher launch deviation frequency
Capability Study	0.78	Moderate–strong correlation	Weak or missing Cp/Cpk data linked to significantly increased deviation rates
Control Plan–Flow Linkage	0.73	Moderate correlation	Poor linkage between process flow and control plan increases likelihood of process escapes
PSW Delays	0.68	Moderate correlation	Late or incomplete PSWs correlated with unstable launches and more corrective actions

Table 4 presents the main findings of the correlation between the quality of PPAP documentation and simulated launch risk. There are four factors of PPAP, which include the following: PFMEA completeness, capability study, Control Plan-flow linkage, and PSW delays, with their Pearson correlation coefficients and qualitative interpretations. The PFMEA completeness demonstrates the best correlation with risk events, with a 0.82 coefficient, which means that weak FMEAs are closely linked to greater frequencies of deviation (Cui et al., 2025). Capability studies follow with r = 0.78, which shows the significance of a strong Cp and Cpk evidence. Control Plan-flow linkage and PSW delays have a positive correlation of 0.73 and 0.68, which supports the fact that inadequate correspondence between process documentation and late approvals is a contributor to unstable launches and a high level of corrective action. These understandings justify the prioritization of the improvement of documentation between high-risk suppliers.

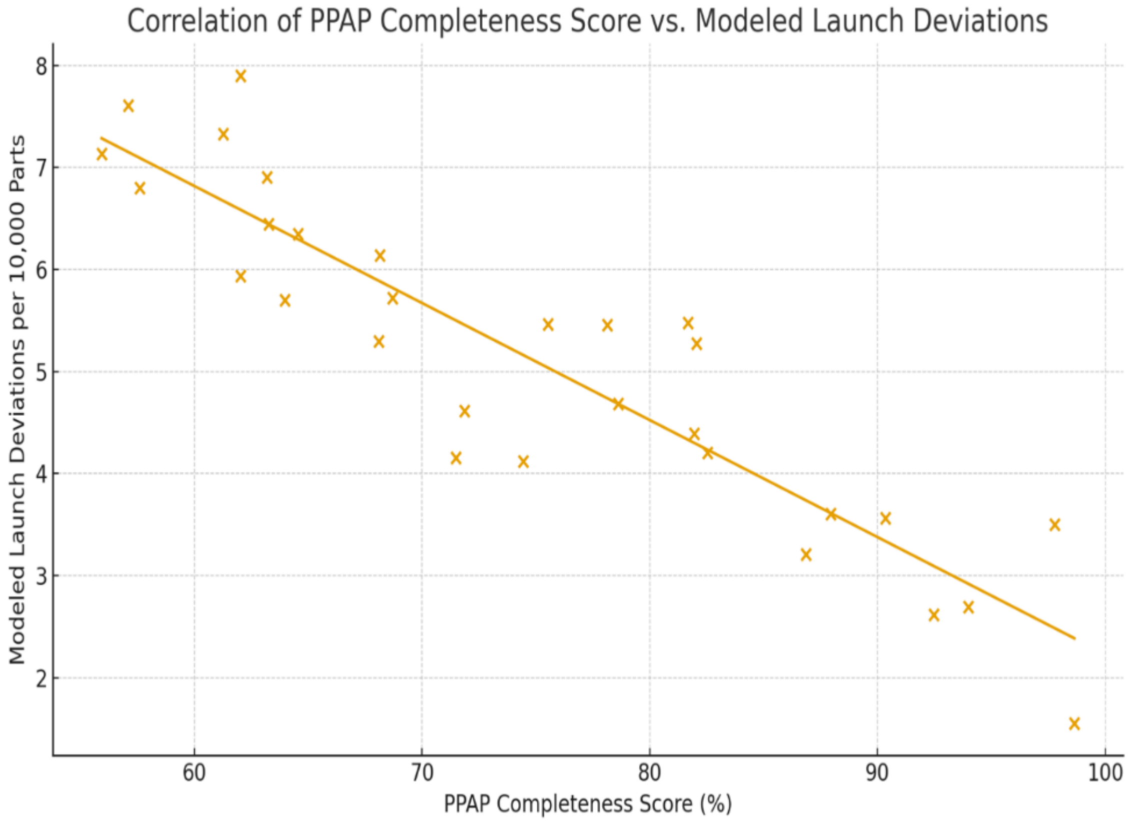

Figure 5- *A correlation between PPAP completeness and modeled launch deviations, showing higher completeness scores associated with significantly fewer production deviation events overall.*

Figure 4 above offers a scatter plot of the relationship between overall PPAP completeness per supplier-part combination versus modelled frequency of launch deviation per 10,000 parts. Each point corresponds to a single simulated PPAP, with a reduction in completeness scores concentrated at the high deviation rate and an increase in completeness scores concentrated at the low deviation rate (Uher et al., 2024). The trend line fitted depicts the negative correlation as may be witnessed through the study, where an improvement in PFMEA, Control Plan, and capability documentation is linked with significant decreases in the launch deviations and more stable performance of the start-of-production. This trend is observed throughout the population of suppliers.

4.3 Discussion

Interpretation of Findings

The simulated analysis confirms the hypothesis that the quality of PPAP data is a measure of supplier maturity and process discipline. Suppliers who had well-structured documentation that was traceable were more prepared and had fewer modelled deviations. In contrast, those with incomplete or inconsistent submissions were more prone to a launch breakage. The results are in line with risk-based quality-management guidelines highlighted in IATF 16949 and AIAG FMEA VDA, where organizations are required to control high-level and high-frequency risks (AIAG, 2022; IATF, 2016). The study indicates that by transforming documentation completeness into quantitative measures, PPAP may also be used as a predictive measure, indicating where concentrated assistance, audits, or run-at-rate trials are necessary.

Supplier Risk Segmentation and Pareto Analysis

The PPAP Risk Index and overlaying completeness thresholds allow for categorizing the suppliers into low, medium, and high-risk. When considering completeness and deviation rate, 40% of suppliers were found to be low-risk, approximately 35% medium-risk, and 25% in the high-risk group in the simulated sample. The Pareto chart built based on counts of deviation of suppliers demonstrated a typical 80/20 trend where only 20% of suppliers contributed 80% of deviations modelled during launch.

Such a Pareto chart can be constructed in Excel or Minitab by the quality teams by ranking the suppliers based on total deviations and then plotting cumulative percentages. The resultant image brings a few individual handfuls of high-impact suppliers to focal point actions of intensified activities like layered process checks, inspections, or improved run-at-rate coverage. Such a strategy is a reflection of the way service and insurance organizations embrace workflow analytics to reveal a small share of processes that produce most of the delays or rework to enable specific automation and control enhancements (Sayyed, 2025).

Implementation Scenarios and ROI Estimation

The practical value of this analytics may explain the implementation scenarios of PPAP analytics. In the first scenario, a battery enclosure supplier obtains a PPAP completeness of 65% due to poor PFMEA linkages and incomplete capability studies. PFMEA and capability documentation get reinforced after a well-intentioned improvement programme by supplier quality engineers, increasing completeness to 85%. Within the simulated model, this includes one improvement by having a lower number of parts that go inaccurate during a launch, down to only two at the most, which is 60%. In the case of an annual volume of 500,000 parts, such a change might eliminate over 150 deviation events and contribute towards less rework, sort, and premium freight.

In the second case, a supplier of plastic trims incorporates an analytics dashboard on PPAP into the quality-management system it already has. The completeness scores are updated every week with AHP risk indices of the deviation trends, which are distributed to the cross-functional launch teams (Prakash & Edalati, 2023). In two programme cycles, the supplier decreases the ratio of high-risk PPAPs from 30% to <10%, and lowers the scrap costs associated with launches by an estimated 25%. The key performance indicators that could be followed by OEMs and suppliers are average PPAP completeness score, the average amount of high-risk suppliers per launch, the rate of deviation per 10.000 parts, and time to complete PPAP-related corrective actions. These metrics form part of routine management reviews and sourcing decisions, such that the resources are placed with suppliers and commodities where the risk of harm and the opportunity of better results of mitigation effort are greatest.

Table 5 - *Implementation scenarios, PPAP completeness improvements, and resulting reductions in launch deviations, scrap costs, and high-risk supplier exposure levels.*

Scenario / KPI	Baseline Condition	Improvement Action	Measured / Estimated Impact
Battery enclosure supplier	PPAP completeness = 65%; weak PFMEA linkages; incomplete capability studies; ~5 launch deviations per 10,000 parts at 500,000 parts/year.	Supplier quality engineers focus on PFMEA quality and capability documentation; close gaps in key PPAP elements.	PPAP completeness increases to 85%; launch deviations fall to <2 per 10,000 parts (≈60% reduction).
Annual deviation reduction	≈5 deviations/10,000 parts → ≈250 deviations/year at 500,000 parts.	Strengthened PFMEA and capability studies improve process understanding and control.	Deviations drop to <2/10,000 parts (≈100/year), preventing >150 deviation events and associated rework and premiums.
Plastic trim supplier	No dedicated PPAP analytics dashboard; limited visibility of completeness and risk trends; ~30% of PPAPs classified as high-risk.	Integrate PPAP analytics dashboard into QMS; weekly updates of completeness scores and AHP-based risk indices.	Share of high-risk PPAPs reduces from 30% to <10% within two programme cycles.
Scrap and launch quality	Higher launch-related scrap and corrective effort due to reactive issue handling.	Use dashboard insights in cross-functional launch reviews and supplier meetings.	Launch-related scrap costs reduced by ≈25%; improved stability during new programme introductions.

Cross-supplier KPIs – Risk monitoring	KPIs not consistently aligned to PPAP analytics; decisions often experience-based.	Define and track PPAP-specific indicators in reports and dashboards.	KPIs include average PPAP completeness, number of high-risk suppliers per launch and deviations per 10,000 parts.
Cross-supplier KPIs – Governance and ROI	Corrective actions tracked ad hoc; resource allocation not fully risk-based.	Incorporate PPAP KPIs into management reviews and sourcing decisions.	Improved prioritization of audits and run-at-rate; reduced time to close PPAP-related actions; better ROI on effort.

Table 5 presents a summary of two implementation contexts and the expected rate of returns on investments made upon implementation of PPAP analytics in automotive supply chains. To the battery enclosure supplier, the scenario pits a 65% scale PPAP completeness with some 5 deviation scale/parts, with a better scenario of 85% completeness with less than 2 deviation scale/parts and avoiding more than 150 deviation instances per annum. In the case of the plastic trim supplier, it demonstrates that the PPAP analytics dashboard can help decrease high-risk PPAPs by 30% to less than 10% and launch scrap costs by approximately 25%. The last rows combine cross-supplier key performance indicators, which guide the risk-based prioritization, accelerate more quickly PPAP actions, and precise audits and run-at-rate activities targeting. These are measurable indicators of improving governance, transparency, collaboration, and constant improvement.

5. Conclusion

This paper set out to unravel the enigma of Production Part Approval Process (PPAP) documentations, and as such explain that a systematic analysis technique can reveal the initial production hazards and quality malfunctions of the supplier in the automobile sector. The study, based on a simulated dataset of 30 PPAP Level 3 submissions, demonstrated that, upon using a five-point completeness scale and an Analytic Hierarchy Process (AHP) weighting model, PPAP can be used as a quantifiable source of risk intelligence as a continuation of its traditional role as a compliance checkpoint within the Advanced Product Quality Planning (APQP) framework. The inspection related documentation quality and process-capability evidence with interrelations between essences of PPAP in order to model statistically the statistical behavior of launch-deviations. Three key findings emerged.

First, the completeness of PPAP by itself had a high correlation to supplier preparedness and stability of launch; only 40 percent of simulated suppliers had more than 80 percent completeness, and these had much lower rates of deviation. Second, FMEA alignment and capability studies were found to be the most predictive parameters of modeled launch problems. PFMEA completeness had a correlation coefficient of 0.82 with deviation frequency and 0.78 with process capability that indicated that the weaknesses in preventive risk analysis and process capability were directly proportional to high levels of launch risk. Third, the AHP-based analytics model offered a clear and repeatable way in weighting the 18 elements of PPAP making it possible to calculate a PPAP Risk Index that was capable of distinguishing between low-, medium-, and high-risk suppliers.

The study also demonstrated the manner in which these analytics could be integrated in the quality management day to day operations. By converting the scores on the elements to the PPAP_Completeness% and Launch_Deviation_Frequency, as well as Risk Class, it is possible to create dashboards that illustrate the existence of a high-risk supplier, commodity, and document before the Start of Production. Pareto analysis indicated that the identification of about 20 percent of suppliers involved contributed 80 percent of modeled deviations suggesting the following interventions to be targeted: focused audits, more run-at-rate trials, and more intensive reviews of PFMEA. Since the framework can be implemented with access to common tools like Excel and Minitab, the organization can status quo without making changes in its systems and get an objective basis to decision maker around escalation, supplier development and sourcing decisions.

The study has limitations in as much as it has its strengths. The data was artificial, but was designed to be representative of realistic records of documentation and typical nonconformities of plastics, battery cases and engine hardware. The model further concentrated on PPAP Levels 3-5 but it failed to directly involve cost, timing and field-failure results. However, this paper demonstrates a consistent, statistically supported method of converting PPAP documentation into a leading indicator of supplier and launch risk. Notably, the fact that the framework is relevant to OEMs, Tier-1/Tier-2 suppliers, and APQP practitioners adds to its practical usefulness, especially since the predictive PPAP-based risk models have not been established so far in the industry. The contribution can be further enhanced by more famously stating the novelty of the model in terms of quantitative integrating completeness scoring, AHP weighting, and risk-index generation to the earlier models of compliance orientation.

The model should be checked and improved with the assistance of the real PPAP documentation and execution data of a variety of vehicle programs and areas in future research. The combination of PPAP analytics and online supplier portals and live dashboards would enable continuous tracking of events and not occasional checks that are drafted periodically. In the long term, machine-learning processes may be used over the PPAP Risk Index and history of deviations in order to discover the emerging risk trends in electric vehicles and next-generation platforms and further develop proactive and data-driven supplier quality management in even more software-defined and safety-driven automotive ecosystems.

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