Development of a Variant Process-Planning Tool: A Case Study

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Paulo Ávila, Bebiana Santos, Alzira Mota, Hélio Castro, Luís Pinto Ferreira, João Bastos, José Carlos Sá, Joaquim Moreira, António Duarte Santos, Gilberto Santos

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ABSTRACT

Purpose: This study addresses the development of a variant process planning tool, following the Knowledge-Based Variant Process Planning methodology, applied in a case study and presents the gains achieved.

Methodology/Approach: Case study supported by six steps: (1) Feature Analysis, (2) Knowledge Retrieval, (3) Inference, (4) Plan Adaptation, (5) Knowledge Update, and (6) Plan Validation/Optimisation.

Findings: The implementation of the Knowledge-Based Variant Process Planning tool led to significant improvements: planner time reduced by 70%, analyst workload by 90%, and process plan errors to 0%. Results show this approach significantly improves process planning in customised production.

Research Limitation/Implication: The limitations are associated with the specificity of the case study problem – the electric engine production systems.

Originality/Value of paper: This study helps fill the gap in case studies on the Variant Process Planning approach, specifically for electric engine production systems, paving the way for similar companies to adopt Knowledge-Based Variant Process Planning.

Category: Case study

Keywords: process planning; variant process planning; knowledge-based variant process planning; case study; continuous improvement

Research Areas: Management of Technology and Innovation; Quality Engineering.

1 INTRODUCTION

Given the recent market trends of short product lifecycles, frequent product design changes, and much more customised products, enterprises are facing the problem of constantly creating new process plans for production, resulting in additional costs, time and effort consumption. Enterprises that want to maintain competitiveness in the market have to improve their process planning (PP) for production and assembly. To ensure rapid implementation and improvement, production and assembly processes for new products should be planned as meticulously as possible before implementation begins, and efficiently designed production and assembly process plans reduce the costs of both their application and improvement (Nyamsuren et al. 2015). Recent studies also highlight the importance of proactive approaches to manufacturing planning as a way to anticipate these challenges, reduce costs and increase process efficiency (Bubeník and Horák, 2014).

PP can be defined as the systematic determination of detailed methods by which parts or components can be manufactured economically and competitively from the initial state (raw material) to the final state (finished product) (Zhang and Alting, 1994). In more detail, Sadaiah et al. (2002) say that PP can be defined in simple terms as converting a given engineering drawing/3D model into manufacturing instructions which give information about operations, machines to be used, tools, cutting parameters, and inspection details. Building upon this definition, Slancová and Plura (2024) emphasise that the digital transformation of quality planning processes is key to ensuring accuracy and traceability of data within PP systems, enabling seamless integration with computer-aided design (CAD) and computer-aided manufacturing (CAM) environments.

PP can be performed manually, based on human knowledge, or semi-automatically/automatically, through the support of Computer-aided process planning (CAPP) systems. CAPP has been seen as a critical link between CAD and CAM. The CAPP systems present great advantages face to the manual process planning, namely: significantly reduces the time required for process planning; consistency and accuracy are improved through automation; and frees up human planners to focus on more complex or strategic tasks. However, as Khayrullina et al. (2015) and Ávila et al. (2025) argue, the full benefits of these systems are realised only when they are embedded in a continuous improvement framework, ensuring that process knowledge evolves with the dynamics of production systems.

With the rapid development of new techniques, many CAPP systems have emerged. In the work of Kumar (2018), most of these CAPP systems are presented and analysed. However, mainly two principal approaches have emerged, the variant approach and the generative one.

The variant approach is based on part similarity within a part family. It follows the mechanism that the equivalent part necessitates the related plan (Xu et al., 2011). It requires an expert to categorise a part, feature information input, recover a comparable plan and make essential alterations. The advantage of this approach is the ease of maintenance, but the shortcoming is the lack of an on-time calculation of the manufacturing process, and the quality of the process plan still depends on the knowledge of a process planner (Santos & Millán, 2013; Zgodavova et al., 2014; Vieira et al., 2019; Silva et al., 2020; Gomes et al., 2022). In the intelligent or generative type, a process plan was developed in accordance with geometry information, decision logic and algorithms. It synthesises a process plan for a new product, based on part shape, material and other variables that affect the manufacturing decision. Geometry description is the prime input to the system. It provides quick advice to the designers and is closely joined with the product-modelling activities.

Complementary, some computer-aided process planning system developers have attempted to combine some features of both approaches, forming another category, which is called semi-generative CAPP.

In the understanding of the authors of this work, the approach of Slicing the model, which is associated with additive manufacturing (AM), one of the pillars of Industry 4.0, should also be considered. In spite of that, additive manufacturing or 3D printing also consists of other critical enabling technologies and principles for promoting collaborative processes and practices between stakeholders in networked manufacturing environments (Santos et al., 2014; Rebelo et al., 2016; Santos et al., 2019; Varela et al., 2022). This technology can fabricate any complex 3D component of any shape by utilising 3D model data, which is impossible to fabricate using traditional manufacturing techniques. In a basic setup, the 3D model data is converted into standard triangulate language format, which is simple to print by additive manufacturing technique (Kumar et al., 2021), promoting innovation (Murmura et al., 2021; Zgodavova et al., 2020; Sun et al., 2023; Santos et al., 2023), to improve the economy (Yülek &Santos, 2022).

The 3D printing process begins with a 3D model of the object, usually designed by CAD software or a scan of an existing artifact; Convert the 3D model to the STL (Stereolithography) format, which is widely accepted in 3D printing; Special software slices this 3D model into cross-sectional layers, creating a digital file that is sent to the 3D printer; The 3D printer produces the object by forming each layer via the selective placement (or forming) of material (Campbell et al., 2011). The generalised steps of AM technologies are shown in Figure 1.

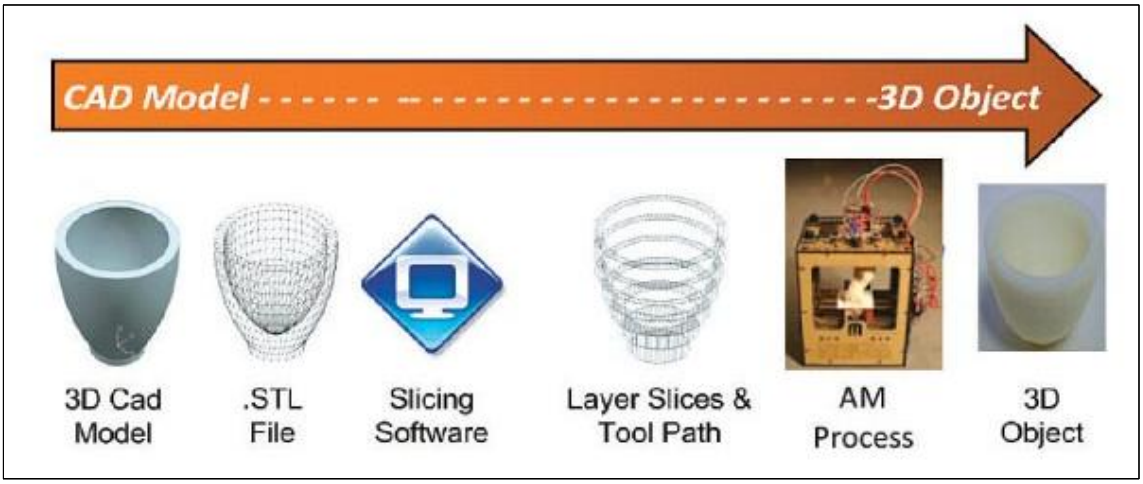


Figure 1 – Generalised steps of the 3D printing process (Campbell et al., 2011)

The characteristics of the AM process itself allow for easy automation of process planning through the slicing of the model step. This phase can be divided into three steps:

1. Importing into a Slicer: Load the STL file into slicing software such as Cura, PrusaSlicer, or Simplify3D.
2. Setting Parameters: Configure printing settings, including layer height, infill density, print speed, and support structures.
3. Generating G-code: The slicer software converts the 3D model into G-code, a set of instructions that the 3D printer can understand and execute.

The authors consider this new process planning approach as slicing the model, as this is the stage of the AM process that allows the development of the process plan.

According to Xu et al. (2011), some of the desirable characteristics of an effective CAPP system are:

- Be interconnected with up- and downstream activities, i.e. design and manufacturing, in such a way that a CAPP system can take design data as it is and generate output that can be fed into a CAM and later a CNC system;
- Be extendible, adaptable and customizable for individual enterprises and to new processes;
- Provide effective knowledge acquisition, representation and manipulation mechanisms as well as the means to check the completeness and consistency of that knowledge;
- Involve users in some parts of the decision-making process, provide heuristics as needed and supplement the system's abilities; and

- Come with a user-friendly interface in support of effective interaction by facilitating inputs, producing outputs and reports, and displaying the results graphically.

The choice of a CAPP system depends on factors such as production volume, product complexity, and the need for flexibility in process planning. Each type has its advantages and disadvantages, making it essential for organisations to carefully evaluate their specific needs and capabilities before implementation.

The objective of this work is to present the development of a variant process planning tool, following the Knowledge-Based Variant Process Planning methodology, applied in a case study of electric motor assembly and to present the gains achieved. The importance of this work is due to the fact that in the bibliography, there are only a few works that address the subject and present the gains achieved in their results. This research aims to show that variant planning can be applied to many companies with characteristics identical to those of our case study, and that the performance gains are effective.

The rest of this paper is organised as follows. Section 2 identifies some research works in the area of variant process planning (VPP), describes the main VPP methodologies and the steps to create a tool based on the Knowledge-Based Variant Process Planning (KBVPP) methodology. Section 3 introduces the case study, covering the topics: the problem, the development process of the KBVPP tool, and the results. To finalise, some conclusions and future works are made in Section 4.

2 THEORETICAL FRAMING FOR THE VARIANT PROCESS PLANNING METHODOLOGIES

The first variant system was developed under the direction and sponsorship of CAM-I (Computer Aided Manufacturing-International) and presented at the 1976 NC Conference. In the same year, MIPLAN was developed by the OIR (Organisation of Industrial Research). Both utilised the variant approach (Cay and Chassapis, 1997).

Since then, several VPP systems have been developed. However, not so many are available in scientific databases, maybe because most of them were created by the companies, but not disseminated in academia. A query was made in three scientific databases (Web of Science, Scopus, and Google Scholar) with the string Variant Process Planning, and the number of papers obtained is low. The summary and the results of the most important works retrieved, in open access mode, are presented below.

A VPP of casting model using an AHP-based nearest neighbour algorithm was developed by Chougule and Ravi (2005) to modify the process parameters, such as size, shape complexity, section thickness, for the geometry and surface finish, tolerance, and maximum void size for quality of produced parts using casting operations.

In the work of Bley and Zenner (2006), a generalised product model was developed and enhanced by self-contained assembly feature objects. With the aid of this product model, the different product views of product design and assembly planning can be combined within one model that allows considering all required product variants even in early planning phases. In order to regard process variants in assembly planning, a decision element is integrated into the process graph. The authors tested the model in a case study from the automotive industry, and the results demonstrated savings in planning time and in the quality of the process plan itself (Azevedo et al., 2019; Craveiro et al., 2023; Talapatra et al., 2022).

Ham et al. (2017) proposed a framework for a VPP system for manned assembly lines. The proposed framework is based on two key templates, which provide process engineers with an efficient mechanism for performing assembly PP for manned assembly lines. This framework has been implemented by Korean assembly-line-based electronic appliances producers and has been seen to have several advantages.

Ali, et al. (2023,) in his research paper, developed a variant process plan tool for the production of a compressor piston. The developed VPP is used as a module of discrete manufacturing in the virtual manufacturing suite of software being developed at the GIK Institute.

VPP is a versatile approach that can be tailored to various manufacturing environments and needs, but is more suited to enterprises involving stable manufacturing processes and manufactured products that vary little (Xu et al. 2011). According to Ham et al. (2017), existing research on VPP can be divided into three methodologies: (1) product design classification or feature-based variant process planning, (2) retrieving techniques for related processes or template-based variant process planning and (3) system designs for developing and modifying a process plan or knowledge-based Variant Process Planning.

(1) Feature-Based Variant Process Planning is an approach in manufacturing that relies on classifying products and their design features to retrieve, adapt, and optimise process plans for similar products. It integrates aspects of Computer-Aided Process Planning (CAPP) and feature-based modelling, utilising existing product features to simplify the creation of new process plans.

(2) Template-Based Variant Process Planning involves retrieving, modifying, and reusing existing process plans for new or similar products. This approach relies on identifying related processes or templates that can be adapted for new parts, rather than creating entirely new plans. Retrieving techniques in VPP are essential for efficiently finding and utilising these related processes or templates from a process database.

(3) Knowledge-Based Variant Process Planning (KBVPP) integrates the principles of VPP with a knowledge-based approach to enhance the retrieval, adaptation, and

optimisation of process plans in manufacturing systems. This method relies on a knowledge base consisting of rules, heuristics, and past experiences to retrieve and modify process plans, making it more flexible and efficient for dealing with a wide range of products.

In this work, our approach to the VPP follows the KBVPP. It will be explained, in the next section, its development related to the case study.

The KBVPP process involves several steps, starting from feature extraction to process plan optimisation:

1. Feature Extraction and Analysis:
    - Extract the features of the new part using CAD models or other data sources. Features may include geometric features (holes, slots) and functional features (locating surfaces, mating features).
    - Analyse the features to determine the similarities with existing parts in the knowledge base.
2. Knowledge-Based Retrieval:
    - Retrieve relevant process plans from the knowledge base using inference mechanisms, such as rule-based reasoning or case-based reasoning (CBR). This involves matching the new part's features against those in the knowledge base.
    - Use similarity measures (e.g., Euclidean distance, cosine similarity) to find the most closely related process plans.
3. Inference Mechanisms:
    - Rule-Based Reasoning (RBR): The system uses a set of predefined rules to match the new part's attributes with existing plans. For example, "IF the part has a cylindrical feature AND material is steel, THEN retrieve a turning process plan."
    - Case-Based Reasoning (CBR): The system retrieves past cases (process plans) that are similar to the new case (part) and adapts them to fit the new requirements.
4. Plan Adaptation and Modification:
    - Modify the retrieved process plans to fit the specific requirements of the new part. This can involve adjusting parameters like machining speed, feed rate, tool selection, or process sequence.
5. Knowledge Update:
    - The knowledge base is continuously updated with new process plans and rules based on the outcomes of the planning process. This ensures that the system improves over time by learning from past experiences.

6. Process Plan Validation and Optimisation:
    - o Validate the adapted process plan against constraints such as machine capabilities, tool availability, and production time.
    - o Optimise the plan using heuristic or metaheuristic optimisation techniques (e.g., genetic algorithms, simulated annealing) to minimise costs, reduce time, or improve quality.

3 CASE STUDY

3.1 The problem

The case study was developed in an electric engine company in Portugal. Its production system is characterised by the production of customised engines, resulting in a high number of different similar products, with similar process plans, prepared for unitary production, in a context of unpredictable demand with a job shop layout.

The final engine assembly process includes assembly activities (where there are several work centres depending on the engine type), painting, final quality control, and packaging and conditioning (depending on the engine and the means of transport to the end customer). In this final assembly process, the company is faced with the daily need to carry out detailed and individual development of each final engine assembly process plan, which, depending on its characteristics, requires a different process plan.

The process of the process plan development is depicted in Figure 2, showing its main activities. This process starts with the development of the process plan by the planner. This manual analysis, based on the planner's knowledge, with an average duration of 10 minutes, is subject to human error and the time spent planning the process. When a process plan is defined incorrectly, it has a negative impact on production, namely, the production of a non-compliant final product and the consequent increase in production costs, the impact on the production flow of other engines, and the possible failure to meet customer delivery deadlines. When the planner is unable to directly define the process plan for the engine, the process plan is handled by an analyst in the area, taking an average of 5 minutes to complement the information in the Process Plan. It is also noted that, on average, each process plan requires the analyst to wait an average of 60 minutes to be handled. In summary, in our case study, we have the following data from the problem:

- 10 minutes spent by the planner to obtain the process plan for all products;
- 5 minutes spent by the analyst for the most complex process plans;
- 15 minutes spent in total when the process plans go through the planner and then through the analyst (10 from the planner plus five from the analyst);

- 31% of the process plans were completed by the analyst (average value obtained between 2021 and 2023);
- 60 minutes of average waiting time for the analyst to complete the plans that come from the planner.

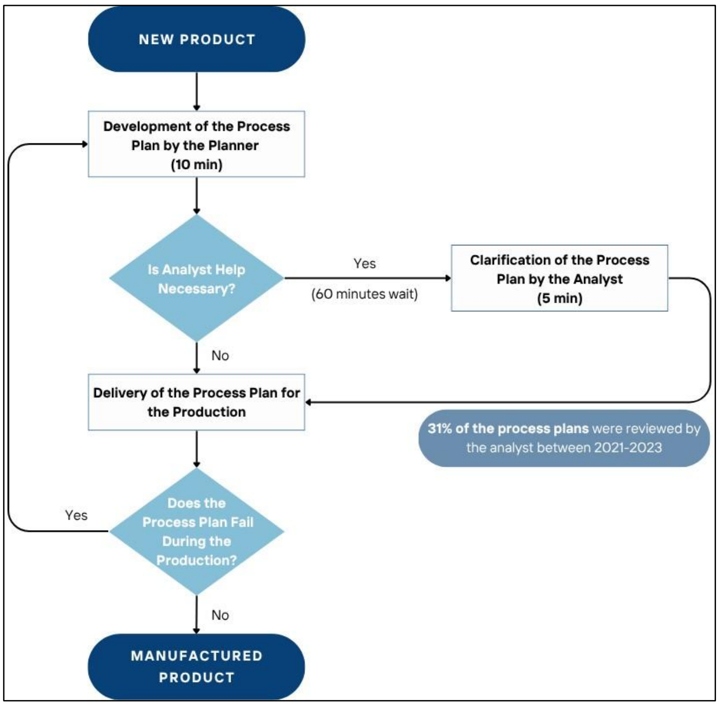


Figure 2 – The process of the process plan development

3.2 Development process of the KBVPP tool

The case study was developed in an electric engine company in Portugal. Its production system is characterised by the production of customised engines, resulting in a high number of different similar products, with similar process plans, prepared for unitary production, in a context of unpredictable demand with a job shop layout. As mentioned in the previous section, the VPP methodology chosen for the case study is KBVPP. This methodology allows not only to recover existing process plans, but also to adapt and/or modify them so that they are more efficient and flexible for a wide range of products. In order to support the KBVPP methodology, a software tool was developed, whose home page is depicted in Figure 3. The way in which the KBVPP methodology was developed and applied is explained below in its six steps.

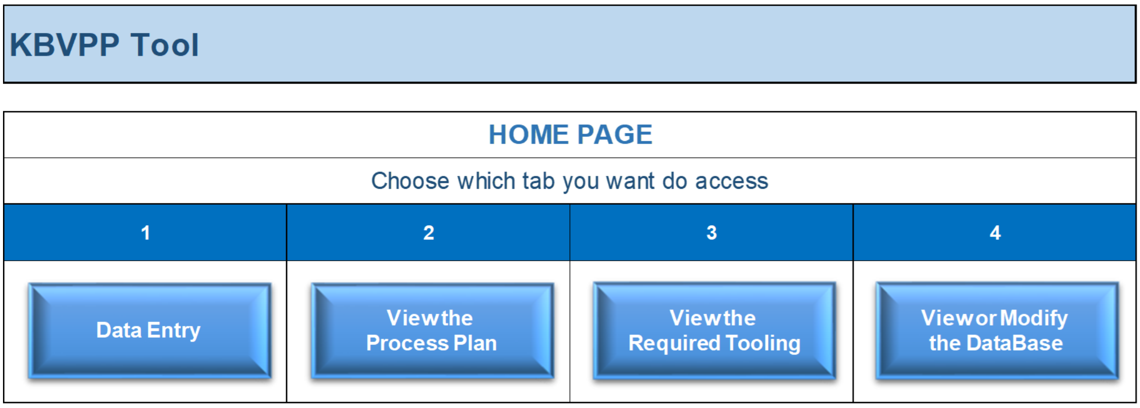


Figure 3 – KBVPP Tool: Home Page

(1) Feature Extraction and Analysis

Product characteristics are extracted by interpreting technical drawings and collecting information from the customer's order stored in the company's ERP software. In this way, the product is characterised into three main groups, each with its respective categories (see Figure 4):

i. General Information (5 categories);

ii. Engine Information (33 categories);

iii. Test Information (6 categories).

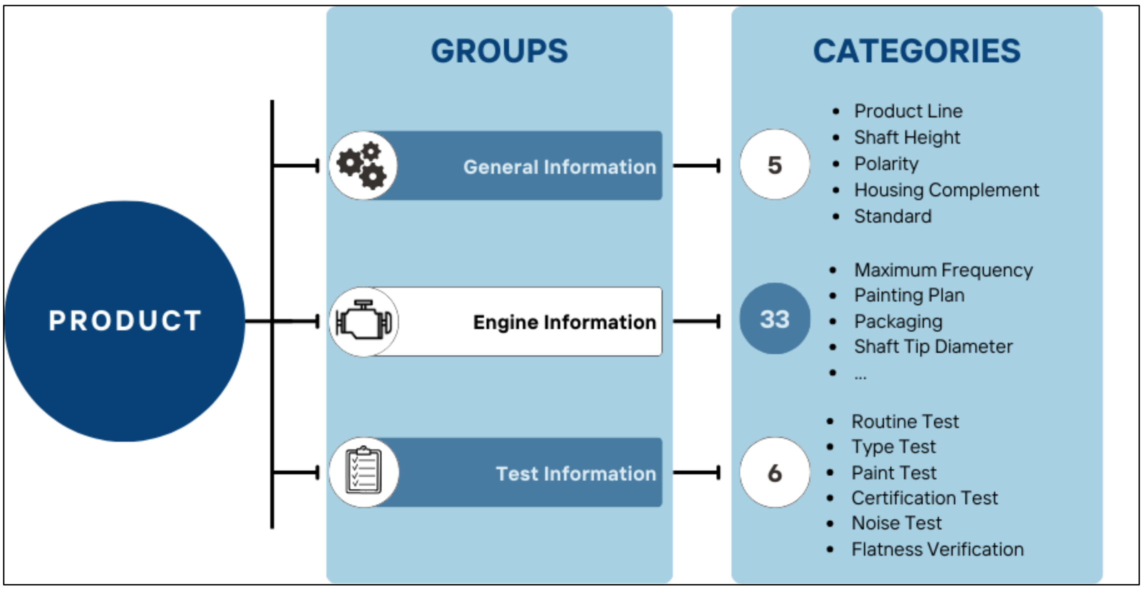


Figure 4 – Product classification structure

In turn, each category has an average of 5 filling options, which generates a high number of data combinations and, consequently, several possibilities to characterise the product. In particular, the total number of product variants (NTv) is given by the principle of multiplying the choices by:

$$NTv = \prod_{categorie\_i=1}^{categorie\_i=44} options\ number_{categorie\_i} \cong 5.3 * 10^{23} \qquad (1)$$

For example, within the “General Information” group, if the engine is “W22” in category 1, with “315 mm” in category 2, category 4 must be filled in. However, if the product is classified with “500 mm” in category 2, category 4 is disabled (see part of the inputs of this example in Figure 5). The combination of the values “W50” in category one and “900 mm” in category two does not exist in the knowledge base, and for this reason, no process plan is returned.

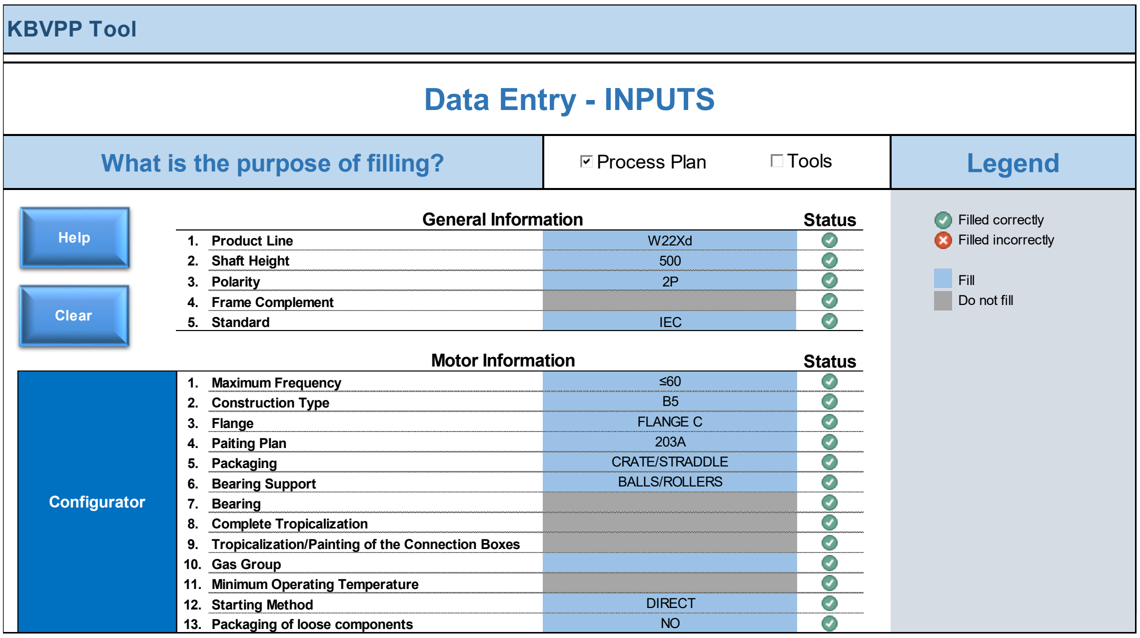


Figure 5 – KBVPP Tool: Window of Data Entry – Inputs

In addition to the numerous possibilities within the same group, there are also several relationships between the categories of different groups, namely between the categories of the “General Information” and “Engine Information” groups.

As the information about the product is extracted and inserted into the file that includes the various combinations of values, it becomes possible to analyse its characteristics and determine the similarity with other parts existing in the knowledge base. It is this similarity that allows the implementation of the second stage of the methodology under study: knowledge-based retrieval of the process plan.

(2) Knowledge-Based Retrieval

Relevant process plans can be retrieved using rules that allow the comparison between the combination of characteristics of the new product and the combinations already existing in the knowledge base. Based on the data entered by the user, the file matches the attributes of the new part to the existing plans. In other words, using the logical function "IF…THEN", each operation that can constitute the process plan is classified as "TRUE" or "FALSE", and those that are classified as true are retrieved. Figure 6 shows an example of the result of the KBVPP Tool for an assembly process plan. Of the 21 possible operations for the assembly, seven will not be part of the process plan because their input criteria returned the result of False. Thus, the route of this process plan is characterised by the remaining operations, fourteen in total.

KBVPP Tool

ASSEMBLY PROCESS PLAN

SAP Operation Number	SAP Work Center	Center	Control Key	Model Key	Operations	Setup time	Operation time	Conditions	Number of employees	Entry criteria in the process plan	Waiting days
0100	3.0	2	ABC1	XYZ001	OPERATION 1	0,001	10	INPUT	1	TRUE	0
0260	5.1	2	ABC1	XYZ005	OPERATION 2			INPUT		FALSE	
0260	3.1	2	ABC2	XYZ002	OPERATION 3	0,001	30	INPUT	1	TRUE	1
0270	1.1	2	ABC2	XYZ003	OPERATION 4	31,5	248	INPUT	1	TRUE	1
0303	4.3	2	ABC1	XYZ004	OPERATION 5	0,001	30	INPUT	1	TRUE	0
0400	3.2	2	ABC1	XYZ005	OPERATION 6	0,001	0	ALWAYS	1	TRUE	0
0450	3.4	2	ABC1	XYZ006	OPERATION 7	0,001	360	ALWAYS	2	TRUE	2
0510	3.3	2	ABC2	XYZ007	OPERATION 8	0,001	360	ALWAYS	2	TRUE	0
0545	5.3	2	ABC1	XYZ004	OPERATION 9			INPUT		FALSE	
0550	5.3	2	ABC1	XYZ028	OPERATION 10			INPUT		FALSE	
0555	5.3	2	ABC1	XYZ007	OPERATION 11			INPUT		FALSE	
0570	4.0	2	ABC2	XYZ008	OPERATION 12	0,001	60	ALWAYS	1	TRUE	0
0575	5.0	2	ABC3	XYZ061	OPERATION 13	0,001	0	INPUT	1	TRUE	5
0600	3.5	2	ABC2	XYZ009	OPERATION 14	0,001	120	ALWAYS	1	TRUE	0
0640	5.5	2	ABC1	XYZ025	OPERATION 15			INPUT		FALSE	
0660	3.5	2	ABC2	XYZ011	OPERATION 16	0,001	90	ALWAYS	1	TRUE	1
0700	5.5	2	ABC1	XYZ014	OPERATION 17			INPUT		FALSE	
0702	4.3	2	ABC1	XYZ013	OPERATION 18	0,001	120	INPUT	1	TRUE	0
0704	4.3	2	ABC1	XYZ014	OPERATION 19	0,001	10	ALWAYS	1	TRUE	0
0710	3.6	2	ABC1	XYZ015	OPERATION 20	0,001	30	INPUT	1	TRUE	0
0710	5.6	2	ABC3	XYZ029	OPERATION 21			INPUT		FALSE	

Figure 6 – KBVPP Tool: Window of Assembly Process Plan

The developed tool returns not only the production plan of the part, with all the information inherent to it, but also displays information about the necessary tools and their availability (see Figure 7).

KBVPP Tool

Tools

Designation	Availability	Observations
Full Key		**Full Key Unavailable:** No Full Key exists for the entered values.
Half Key		**Half Key Available:** 32.9.90.B
Coupling		**Coupling Available:** 87.25.1

Figure 7 – KBVPP Tool: Window of Tools

Analysing Figure 7, when the red icon appears, it means that the tool is essential for the tests required in the "Test Information" group and is not available in the factory. On the other hand, the green icon indicates that the tool is necessary and is in stock, with the file informing the code of the most suitable tool according to the diameter, width, height and shape of the slot - characteristics that define the product.

(3) Inference Mechanisms

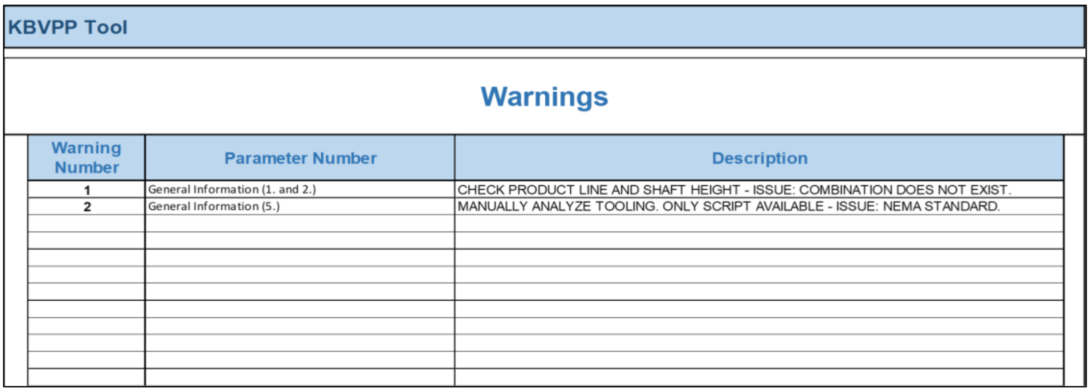
This case study used the inference mechanism of the Rule-Based Reasoning (RBR) type, where the system uses a set of predefined rules to match the new part's attributes with existing plans. The logical conditions created take into account the various fields that define the product. Namely, the range, the shaft height, and other extracted information, which allows the search in the database to be narrowed down to obtain the activities that constitute the final assembly process plan of the new product.

(4) Plan Adaptation and Modification

One of the great advantages of this methodology is the ease of adapting process plans and changing the logical conditions that define them. Based on the information extracted about the new product, the most similar process plan will be retrieved. At this stage, it is possible to modify the production plan in order to meet the specified requirements. For example, it is possible to introduce/remove activities to be performed, change the associated operating and setup times (machine and man), modify the number of employees required to carry out the activity, etc.

(5) Knowledge Update

Although it is possible to modify existing process plans, there are some combinations of product characteristics that may make it impossible to generate a process plan. For example, if the range is "W50" (category 1 – product line) and the shaft height is "500 mm" (category 2 – shaft height), it is not possible to obtain a production route, since this combination of values does not exist in the knowledge base. However, in these cases, the developed file returns a set of alerts to the user, as can be seen in Figure 8.



KBVPP Tool

Warnings

Warning Number	Parameter Number	Description
1	General Information (1. and 2.)	CHECK PRODUCT LINE AND SHAFT HEIGHT - ISSUE: COMBINATION DOES NOT EXIST.
2	General Information (5.)	MANUALLY ANALYZE TOOLING. ONLY SCRIPT AVAILABLE - ISSUE: NEMA STANDARD.

Figure 8 – KBVPP Tool: Window of Warnings

If there are changes in product requirements that affect the automatic generation of the final assembly process plan, it is possible to update the information contained in the knowledge base and the respective logical conditions, and also to expand the knowledge base to new process plans that may arise with the commercialisation of new products. In this way, the knowledge base is continually updated, which ensures that the system is improved over time, becoming more robust and automatic.

(6) Process Plan Validation and Optimisation

The last phase of the KBVPP methodology implementation process consists of validating the recovered process plan. If the recovered process plan corresponds to a product that has already been manufactured in the company, for an identical product, it has already been validated in the past during the production of the product. If the recovered process plan had to undergo adaptations and include new data, then the validation of the new plan is done in two stages. The first validation is done by an analyst in the area before the start of the production of the product, and the second validation, done by the same analyst with the collaboration of the assembly manager, after the manufacture of the product. This last validation is important because it may incorporate some further changes resulting from the production adjustments that were necessary during the assembly of the product.

In addition to the two previous validations, the company practices continuous improvement of its processes, following the principle of Putnik and Ávila (2015), who emphasise in their work that to be competitive in the global market, the practice of a continuous improvement philosophy is an important mechanism to promote it. From this perspective, whenever these improvements are implemented, they are immediately reflected in the update of the tool's knowledge.

3.3 Discussion of the Results

This case study shows that KBVPP relies on a knowledge base to retrieve the most relevant process plan for the new product or part. The tool developed is able to verify the similarities between the characteristics of the new product and the different combinations that already exist in its knowledge base, the automatic selection of the process plan is ensured, and the time required to generate new process plans for each product is reduced.

The development of this tool enabled improved decision-making, since the system uses a structured knowledge base defined according to the restrictions of the product and the process associated with its production. The tool brought qualitative and quantitative gains to the production system of the case study.

Qualitative advantages include consistency of information, consolidation of data in a single knowledge base, greater autonomy for planners in obtaining the process plan adapted to the new product, the analysis of the necessary tooling and the guarantee of its availability for production.

Considering now the quantitative gains achieved and aligned with the problem data, presented in subsection 3.1 – The problem, the following average values were obtained:

- 3 minutes spent by the planner to obtain the process plan, for all products, with the developed tool;

- 5 minutes spent by the analyst to complete the process plans that come out of the developed tool;
- 8 minutes spent in total when the process plans go through the planner and then through the analyst (3 from the planner plus 5 from the analyst);
- 3% of the process plans were completed by the analyst (average value obtained after the implementation of the tool in 2024);
- 60 minutes of average waiting time for the analyst to complete the plans that come out of the developed tool.

Table 1 presents a summary of the quantitative gains achieved and the values that remained unchanged with the implementation of the developed tool.

Table 1 – Summary of the results achieved.

Performance factors	**Initial** (before the developed tool)	**Final** (after the developed tool)	**Percentage change**
Planner time (minutes)	10	3	-70%
Analyst time (minutes)	5	5	0%
Percentage of plans analysed by the analyst	31%	3%	-90%

Although it was not possible to quantify the percentage of process plans with errors before the implementation of the tool, it is recognised by everyone in the company that this percentage has decreased and is now close to 0%.

4 CONCLUSION

After a bibliographic review of developed VPP applications and the three main VPP methodologies recognised by academia, it became clear that VPP has room to be implemented in production systems with customised production and with similarities in the process plans of the products. The works available in the area of VPP are not so many, and consequently, the results obtained do not clearly demonstrate the potentialities of this PP approach.

In order to reinforce the potentialities of the VPP approach, this work developed a tool to support its implementation for an assembly process in a case study. The tool was designed following the KBVPP methodology, and its explanation was presented according to the six steps for the development process of a KBVPP tool. After the implementation of the KBVPP tool, the results obtained in the case study demonstrated several qualitative and quantitative improvements. Namely, quantitative improvements were reflected in: a reduction of 70% for the planner time; a reduction of 90% of the plans analysed by the analyst; a reduction of the process plans with errors, that is now in the order of 0%. The results demonstrated that for customised production with similar process plans, the VPP approach can bring significant benefits for the performance of the PP. More than this, this study, with its results, contributes to minimising the gap of case studies in the literature, opening the door for more similar companies to follow the methodology VPP in the variant of KBVPP.

In the future, it is intended to allocate the knowledge base of the tool with artificial intelligence in order to suggest more accurate process plans for the new products. It means that for new products, the process plans suggested by the tool would be completed, avoiding as much as possible the time consumed by the planner and by the analyst.

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ABOUT AUTHORS

Paulo Ávila ORCID: 0000-0001-8420-0875 (P.A.) – DrS, INESC TEC, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: psa@isep.ipp.pt

Bebiana Santos ORCID: 0009-0001-7164-4183 (B.S.) – BSc, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: 1201130@isep.ipp.pt

Alzira Mota ORCID: 0000-0002-3871-4215 (A.M.) – PhD, INESC TEC, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: atm@isep.ipp.pt

Hélio Castro ORCID: 0000-0001-5712-9954 (H.C.) – PhD, INESC TEC, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: hcc@isep.ipp.pt

Luís Pinto Ferreira ORCID: 0000-0003-4225-6525 (L.F.) – DrS, LAETA-INEGI, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: lpf@isep.ipp.pt

João Bastos ORCID: 0000-0002-9082-3291 (J.B.) – PhD, INESC TEC, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: jab@isep.ipp.pt

José Carlos Sá ORCID: 0000-0002-2228-5348 (J.C.S.) – PhD, LAETA-INEGI, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: cvs@isep.ipp.pt

Joaquim Moreira ORCID: 0000-0002-3220-0678 (J.M.) – MSc, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249- 015 Porto, Portugal, e-mail: jaq@isep.ipp.pt

António Duarte Santos ORCID: 0000-0002-2773-1829 (A.S.) – PhD, Department of Economic and Business Sciences, Autonomous University of Lisbon and CARS—Centre for Economic Analysis of Social Regulation, Rua de Santa Marta, n° 47, 6° Andar, 1150-293 Lisboa, Portugal, e-mail: ajsantos@autonoma.pt

Gilberto Santos ORCID: 0000-0001-9268-3272 (G.S.) – DrS, INEGI- LAETA - Institute of Science and Innovation in Mechanical and Industrial Engineering, Campus da FEUP, 4200-465 Porto, Portugal.

AUTHOR CONTRIBUTIONS

Conceptualisation, A.M., B.S. and P.A.; Methodology, H.C., L.F., B.S. and P.A.; Validation, L.F., A.M., J.B., J.C.S., B.S. and P.A.; Formal analysis, H.C., A.S., J.C.S. and G.S.; Investigation, B.S., A.M. and P.A.; Resources, B.S., J.B. and P.A.; Data curation, B.S., J.M., and P.A.; Original draft preparation, J.C.S. and L.F.; Review and editing, H.C., A.M., J.C.S. and G.S.; Visualization, A.S., J.M. and J.B.; Supervision, P.A. and G.S.; Project administration, B.S., J.B., A.S. and J.C.S.

CONFLICTS OF INTEREST

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