Journal of Process Management and New Technologies
Vol. 13, Issue 3-4, 2025, pp. 97-106

PRIORITIZATION OF CRITERIA FOR PRODUCTION PLANNING SOFTWARE SELECTION USING PICTURE FUZZY PIPRECIA METHOD: A CASE OF THE ORDU PROVİNCE

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Abstract: *With technological transformation, businesses have begun to carry out more effective production planning and have increasingly needed production planning software programs for short-, medium-, and long-term planning activities. Research shows that production planning software provides significant benefits to businesses in various operational areas such as time management, workforce allocation, production scheduling, overtime control, and inventory management. In addition to enhancing operational efficiency, these software systems also contribute to reducing costs, using resources more effectively, and improving overall organizational performance. However, determining the criteria used in selecting the most suitable production planning software is crucial and requires careful consideration. Within the scope of this study, the criteria used in production planning software selection in manufacturing enterprises were identified and prioritized. For this purpose, the Picture Fuzzy PIPRECIA method was applied. According to the analysis results, among the criteria used in selecting production planning software in manufacturing enterprises, the most important criteria were identified as "Security" and "Reporting and Analysis," while the least important criteria were found to be "Support and Training" and "Updating and Maintenance.*
Keywords: *Production, production planning, MCDM, picture fuzzy PIPRECIA Method.*

Original scientific paper
Received: 10.11.2025
Accepted: 03.12.2025
Available online: 08.12.2025
DOI: 10.5937/jpmnt13-62702

1. Introduction

In production, which constitutes one of the fundamental functions of a business, it has become possible to create value through data analysis, utilizing both machine data and externally collected data sources. The successful management of production is of great significance at the firm, market, and national economy levels. An essential component of production management is production planning and scheduling (Akın & Akın, 2021).

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Production planning represents an economic transformation process. In this transformation, the utilization of resources and quantities, as well as the management of time, constitutes a critical process for both customers and producers (Jacobs & Chase, 2008).

Production planning is a system that determines what, when, and how to produce by utilizing the appropriate amount and quality of raw materials, equipment, labor, and other resources (Sharma, 2019).

It is considered a pre-production activity that involves the prior determination of production requirements such as manpower, materials, machinery, and production processes. Production planning has also been defined as the identification, procurement, and organization of all facilities necessary for the future production of goods (Kumar and Suresh, 2009). With an effective production planning operation, any production process has the ability to utilize its full potential (Telsang, 2018).

Planning and management activities related to production are of critical importance for enterprises. If the developed production plan is not carried out in a coordinated and systematic manner, it may lose its functionality. Deficiencies and disruptions in production activities and planning may lead to delays in achieving the production-related objectives of enterprises. Such delays and disruptions can reduce organizational efficiency and negatively affect the ability to foresee and analyze future conditions. To prevent these adverse outcomes, it is necessary to develop a strategic planning process (Aydın & Dursun, 2022).

According to Kumar and Suresh (2009), production planning not only provides benefits such as efficient utilization of resources, inventory management, and improvement of delivery processes, but also enhances customer satisfaction by ensuring the right products are delivered at the right time to meet customer demands. Timely deliveries increase customer loyalty and create a competitive advantage. In addition to reducing costs, balancing resources, and forecasting future needs, production planning also contributes to monitoring market trends and customer demands, thereby enabling more accurate future predictions. In this regard, production planning supports the strategic planning process of enterprises and assists in sustaining competitive advantage.

In light of the aforementioned points, identifying the criteria that influence production planning software, which provides numerous advantages to enterprises, emerges as a critical issue that requires careful attention. Especially in manufacturing enterprises, the complexity of production processes and increasing competition make it essential to accurately determine and prioritize the criteria used in selecting software. In this context, identifying the criteria and ranking their importance serves as a significant indicator in the strategic decision-making processes of enterprises (Stević et al., 2025).

The identification and prioritization of these factors not only help reduce costs and enhance customer satisfaction but also directly contribute to increasing production efficiency, improving quality standards, and achieving process improvement goals. Moreover, this process enables enterprises to utilize their resources more effectively, thereby gaining a competitive advantage. Therefore, this study serves as an important guide for addressing existing knowledge gaps and developing a more informed and systematic approach to selecting production planning software. The research aims to provide a valuable resource for both academic studies and practice-oriented decision-making processes, contributing to the literature and to industrial applications in the field.

In conclusion, the framework proposed in this study for the addressed decision-making problem makes a significant contribution to filling the theoretical and methodological gaps in the literature. Particularly in complex situations where multiple criteria must be considered in the selection of production planning software and subjective evaluations of decision-makers are involved, the study provides a valuable guide from both theoretical and practical perspectives.

The proposed framework allows researchers to analyze decision-making processes in a more systematic and transparent manner while helping to minimize the effects of uncertainties and subjective judgments.

In this context, the suggested approach for evaluating the criteria used in the selection of production planning software in manufacturing enterprises establishes a reliable and solid theoretical foundation not only for academic studies but also for industrial applications and policy development processes. Moreover, based on the findings obtained, the study offers guiding recommendations to researchers, business managers, and decision-makers, while also providing a methodological reference point for future research. Thus, the study aims to contribute both to the generation of scientific knowledge and to the development of practice-oriented solutions.

Within this framework, the study aims to identify the criteria considered in the selection of production planning software in manufacturing enterprises and to contribute to the process of determining the most appropriate software alternative by revealing the significance levels of these criteria. Accordingly, the Picture Fuzzy Subjective PIPRECIA model is proposed as a solution approach to reduce the impact of uncertainties and subjective judgments in the decision-making process. This model enables decision-makers to express their evaluations more flexibly, thereby ensuring more reliable and realistic results in multi-criteria decision-making problems.

The research consists of four main sections. The second section presents a comprehensive literature review on the importance of production planning in enterprises, the challenges encountered in planning processes, and the factors influencing the selection of production planning software. The third section provides a detailed explanation of the theoretical foundations, implementation stages, and analysis process of the methods employed in the study. This section also describes, step by step, how the Picture Fuzzy Subjective PIPRECIA method was applied within the scope of the research. The final section evaluates the findings obtained from the study, develops recommendations for policymakers, business managers, and academics, highlights the limitations of the current research, and offers suggestions for future studies.

2. Literature review

In this section, national and international studies on production planning and the criteria used in the selection of production planning software are presented:

- Wang et al. (2010) developed an integrated optimization model that incorporates traceability factors related to product safety with operational factors, thereby generating an optimal production plan.
- Feng et al. (2011**)** proposed a production planning optimization method for process industries, focusing on minimizing inventory costs and optimizing production load and load balancing.
- Hadidi et al. (2012) presented an integrated model covering production planning and scheduling, maintenance, and quality, offering various recommendations for future improvements.
- Organ et al. (2013**)** optimized integrated production planning in the manufacturing industry using goal programming.
- Gansterer et al. (2014**)** examined a hierarchical production planning system in a make-to-order production environment.
- Hees and Reinhart (2015) introduced a new approach to production planning in reconfigurable manufacturing systems.

- Buğday (2016) focused on forestry production practices in Turkey, production planning, and the increasingly recognized concept of precision forestry along with its process automation.
- Vogel et al. (2017) aimed to develop a hierarchical and integrated model that considers both aggregate production planning and master production scheduling.
- Akmal et al. (2018) conducted a bibliometric analysis of production planning and control between 1990 and 2016.
- Ellwein et al. (2019) proposed a new software architecture for production planning and control systems to establish a foundation for data exchange among such systems.
- Ediz and Turan (2020) investigated recommendation systems used in production planning and found that although most companies had an ERP system, only about half employed a recommendation system.
- Karabulut and Deste (2021) aimed to implement an integrated production planning application using a goal programming approach.
- Koçak and Yıldız (2022) examined the use of digital twin technology in production planning and control processes within the textile industry.
- Bründl et al. (2023) analyzed the use and implementation of software-based production planning and control systems in variant-rich make-to-order production environments.
- Elyasi et al. (2024) studied production planning under demand uncertainty with flexible manufacturing systems.
- Sheikhkhoshkar et al. (2024) developed an innovative, integrated, and multi-level production planning and control framework aligning various planning methods and control metrics across different planning levels.
- Arab Momeni and Jain (2025) proposed a model integrating production planning with the positioning of products in warehouses.

As a result of this literature review, it is observed that studies focusing specifically on the selection of production planning software are very limited. This indicates a significant gap in both theoretical knowledge and practical applications. The aim of the present study is to contribute to filling this gap by providing new and comprehensive perspectives on the factors influencing production planning software selection, thereby promoting a deeper understanding of the topic.

3. Methodology

In the methodology section of the study, the process of identifying and prioritizing the criteria used in the selection of production planning software in manufacturing enterprises was addressed. In this context, the Picture Fuzzy Sets (PFS) approach was adopted to more accurately reflect the effects of decision-makers' subjective evaluations and uncertainties.

3.1. Picture Fuzzy Sets

Cuong and Kreinovich (2013) introduced Picture Fuzzy Sets (PFSs) as an extension of Intuitionistic Fuzzy Sets. PFSs provide a more realistic depiction of uncertainty by indicating degrees of membership, non-membership, and abstention. This feature allows for more flexible and accurate decision-making procedures. PFSs provide a more thorough approach by generalizing both classical and intuitionistic fuzzy sets.

Let X be a discourse universe. Eq. (1) gives a PFS G, where $\mu_G(x), \eta_G(x), \nu_G(x) \in [0,1]$ (Cuong and Kreinovich, 2013; Korucuk, et al., 2023; Görçün et al., 2024):

$$G = \{\langle x, \mu_G(x), \eta_G(x), \nu_G(x)\rangle | x \in X\}, \quad (1)$$

The positive membership degree is represented as $\mu_G(x)$. $\eta_G(x)$ is the neutral membership degree. The negative membership degree is depicted as $\nu_G(x)$. Furthermore, Eq. (2) should be met (Cuong & Kreinovich, 2013; Görçün et al., 2024):

$$0 \leq \mu_G(x) + \eta_G(x) + \nu_G(x) \leq 1, \forall x \in X. \tag{2}$$

$\pi_G(x) = 1 - (\mu_G(x) + \eta_G(x) + \nu_G(x))$ is the degree of refusal membership of x in G. Assume that g, g_1, and g_2 are three PF numbers (PFNs), where $g = \langle \mu_g, \eta_g, \nu_g \rangle$, $b_1 = \langle \mu_{g_1}, \eta_{g_1}, \nu_{g_1} \rangle$, and $g_2 = \langle \mu_{g_2}, \eta_{g_2}, \nu_{g_2} \rangle$. The basic operations on PFNs are provided in Eq.s (3)-(7) (Cuong & Kreinovich, 2013; Görçün et al., 2024):

$$g_1 \oplus g_2 = \langle 1 - (1 - \mu_{g_1})(1 - \mu_{g_2}), \eta_{g_1}\eta_{g_2}, (\eta_{g_1} + \nu_{g_1})(\eta_{g_2} + \nu_{g_2}) - \eta_{g_1}\eta_{g_2} \rangle, \tag{3}$$

$$g_1 \otimes g_2 = \langle (\mu_{g_1} + \eta_{g_1})(\mu_{g_2} + \eta_{g_2}) - \eta_{g_1}\eta_{g_2}, \eta_{g_1}\eta_{g_2}, 1 - (1 - \nu_{g_1})(1 - \nu_{g_2}) \rangle, \tag{4}$$

$$g_1 \otimes g_2 = \langle (\mu_{g_1} + \eta_{g_1})(\mu_{g_2} + \eta_{g_2}) - \eta_{g_1}\eta_{g_2}, \eta_{g_1}\eta_{g_2}, 1 - (1 - \nu_{g_1})(1 - \nu_{g_2}) \rangle, \tag{5}$$

$$\lambda \cdot g = \langle 1 - (1 - \mu_g)^\lambda, (\eta_g)^\lambda, (\eta_g + \nu_g)^\lambda - (\eta_g)^\lambda \rangle, \tag{6}$$

$$g^\lambda = \langle (\mu_g + \eta_g)^\lambda - (\eta_g)^\lambda, (\eta_g)^\lambda, 1 - (1 - \nu_g)^\lambda \rangle. \tag{7}$$

Assume that g_j is the collection of PFNs, where $j = 1, \dots, n$. The PF weighted arithmetic average (PFWAO) is computed by applying Eq. (8). Moreover, the PF weighted geometric average operator (PFWGO) is calculated using Eq. (9), where $\lambda_i = (\lambda_1, \lambda_2, \dots, \lambda_n)^T$ is the weight vector (Cuong & Kreinovich, 2013; Karamaşa, et al., 2022; Görçün et al., 2024):

$$\begin{gathered} PFWAO_\lambda(g_1, \dots, g_n) = \bigoplus_{j=1}^{n} (\lambda_j, g_j) \\ = \langle 1 - \prod_{j=1}^{n} \left(1 - \mu_{g_j}\right)^{\lambda_j}, \prod_{j=1}^{n} \left(\eta_{g_j}\right)^{\lambda_j}, \prod_{j=1}^{n} \left(\eta_{g_j} + \nu_{g_j}\right)^{\lambda_j} - \prod_{j=1}^{n} \left(\eta_{g_j}\right)^{\lambda_j} \rangle. \end{gathered} \tag{8}$$

$$\begin{gathered} PFWGO_\lambda(g_1, \dots, g_n) = \bigotimes_{j=1}^{n} (g_j)^{\lambda_j} \\ = \langle \prod_{j=1}^{n} \left(\mu_{g_j} + \eta_{g_j}\right)^{\lambda_j} - \prod_{j=1}^{n} \left(\eta_{g_j}\right)^{\lambda_j}, \prod_{j=1}^{n} \left(\eta_{g_j}\right)^{\lambda_j}, 1 - \prod_{j=1}^{n} \left(1 - \nu_{g_j}\right)^{\lambda_j} \rangle. \end{gathered} \tag{9}$$

The defuzzification of a PFN g is carried out via Eq. (10), where $\pi_g = 1 - (\mu_g + \eta_g + \nu_g)$.

$$s(g) = \mu_g + \frac{\eta_g}{2} + \frac{\pi_g(1 + \mu_g - \nu_g)}{2} \tag{10}$$

3.2. Picture Fuzzy PIPRECIA

PF-PIPRECIA is implemented in the following steps.

Step 1. The sets of criteria ($C = \{C_1, \dots, C_n\}$) and the experts ($E = \{E_1, \dots, E_z\}$) are determined.

Step 2. The experts evaluate importance levels of criteria using the linguistic terms listed in Table 1. In this context, the PF importance of j-th criterion identified by k-th expert is represented by $\xi_{jk} = \langle \mu_{jk}, \eta_{jk}, \nu_{jk} \rangle$, where $j = 1, \dots, n$; $k = 1, \dots, z$.

Table 1. Linguistic expressions for evaluating importance of criteria

Codes	*Linguistic expressions*	*Picture fuzzy number*		
		μ	η	ν
VH	Very High	0.90	0.05	0.05
H	High	0.80	0.10	0.10
A	Moderate	0.50	0.20	0.20

L	Low	0.20	0.30	0.50
VL	Very Low	0.10	0.30	0.60

Source: Authors

Step 3. The weight coefficients of experts λ_k are determined, where $\sum_{k=1}^{z} \lambda_k = 1$, $0 \leq \lambda_k \leq 1$.

Step 4. The integrated PF importance of j-th criterion ξ_j is obtained via Eq. (8). After that, $\xi_j = \langle \mu_j, \eta_j, \nu_j \rangle$ is produced (Aytekin and Korucuk, 2024).

Step 5. The crisp importance value of j-th criterion $s(\xi_j)$ is calculated by appliyng Eq. (10).

Step 6. c_j values are determined by comparing the criteria in pairs according to their order in the criteria list. In this framework, Eq. (11) is applied, where $s(\xi_j)$ and $s(\xi_{j-1})$ represent the importance ratings of the j-th criterion and (j-1)-th criterion, respectively.

$$c_j = \begin{cases} 1 + s(\xi_j) - s(\xi_{j-1}), & if\ s(\xi_j) > s(\xi_{j-1}) \\ 1, & if\ s(\xi_j) = s(\xi_{j-1}) \\ 1 + s(\xi_{j-1}) - s(\xi_j), & if\ s(\xi_j) < s(\xi_{j-1}) \end{cases} \tag{11}$$

In these pairwise comparisons, c_j value of the base criterion for comparisons is assumed to be 1. For example, if comparisons are made using the C1 criterion as the base, then $c_1 = 1$.

Step 7. The relative importance values of criteria are determined by applying Eq. (12).

$$\zeta_j = \begin{cases} 1, & if\ j = 1 \\ 2 - c_j, & if\ j > 1 \end{cases} \tag{12}$$

Step 8. The initial weight coefficients of criteria are calculated using Eq. (13).

$$\vartheta_j = \begin{cases} 1, & if\ j = 1 \\ \dfrac{\zeta_{j-1}}{\zeta_j}, & if\ j > 1 \end{cases} \tag{13}$$

Step 9. The weight coefficients of criteria are determined by applying Eq. (14).

$$w_j = \frac{\vartheta_j}{\sum_{j=1}^{n} \vartheta_j} \tag{14}$$

3. Results

This study investigates the factors affecting the cloud computing of businesses. To achieve this purpose, the Picture Fuzzy SWARA method has been employed. The identified factors are presented in Table 2.

Table 2. The list of criteria

Codes	Criteria	Source(s)
C1	Functionality and Ease of Use	Ramayah & Lo (2007)
C2	Integration Capability and Scalability	Oluyisola et al. (2022)
C3	Cost	Caputo et al. (2009)
C4	Support and Training	Chen & Li (2013)
C5	Security	Oluyisola et al. (2022)
C6	Reporting and Analysis	Bartoszewicz & Wdowicz (2019)
C7	Updates and Maintenance	Caputo et al. (2009)
C8	Reviews and References	Junior & Filho (2012)
C9	Flexibility and Customization	Bartoszewicz & Wdowicz (2019)

Source: Authors

Six experts with extensive knowledge and experience on the problem are consulted about the importance of criteria. Table 3 provides the linguistic assessments of experts on criteria.

Table 3. The linguistic evaluations of criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9
E1	H	H	A	H	H	H	A	A	VH
E2	VH	A	H	A	VH	H	A	A	A
E3	H	H	H	L	VH	VH	H	A	A
E4	H	A	A	A	H	VH	L	A	L
E5	H	H	A	L	VH	H	A	H	A
E5	H	H	L	H	H	L	L	L	A

Source: Authors

Table 4 presents the PF- integrated importance of criteria.

Table 4. The results of PF- subjective weighting approach

	C1			***C2***			***C3***		
	μ	η	ν	μ	η	ν	μ	η	ν
ξ_j	0.8218	0.0891	0.0891	0.7286	0.1260	0.1260	0.6016	0.1698	0.1865
$s(\xi_j)$	0.8664			0.8071			0.7163		
	C4			***C5***			***C6***		
	μ	η	ν	μ	η	ν	μ	η	ν
ξ_j	0.5691	0.1817	0.2183	0.8586	0.0707	0.0707	0.8000	0.0953	0.1047
$s(\xi_j)$	0.6808			0.8939			0.8477		
	C7			***C8***			***C9***		
	μ	η	ν	μ	η	ν	μ	η	ν
ξ_j	0.4980	0.2040	0.2450	0.5358	0.1906	0.2094	0.5865	0.1698	0.1865
$s(\xi_j)$	0.6332			0.6737			0.7114		

Source: Authors

The results of PF-PIPRECIA are given in Table 5.

Table 5. The results of PF- PIPRECIA

Criteria	$s(\xi_j)$	c_j	ζ_j	ϑ_j	w_j	**Rank**
C1	0.8664		1.0000	1.0000	0.1200	3
C2	0.8071	0.9408	1.0592	0.9441	0.1133	4
C3	0.7163	0.9091	1.0909	0.8654	0.1038	7
C4	0.6808	0.9646	1.0354	0.8358	0.1003	9
C5	0.8939	1.2131	0.7869	1.0622	0.1274	1
C6	0.8477	0.9537	1.0463	1.0152	0.1218	2
C7	0.6332	0.7855	1.2145	0.8359	0.1003	8
C8	0.6737	1.0405	0.9595	0.8712	0.1045	6
C9	0.7114	1.0377	0.9623	0.9054	0.1086	5

Source: Authors

"C5-Security" is the most important criterion as seen Table 5. The second most important criterion is "C6- Reporting and Analysis."

4. Conclusions

Production planning in manufacturing enterprises is a critical management process that provides a competitive advantage by ensuring that products are manufactured in the desired quantities, at the specified time, and with the required quality. This process is not limited to determining the production volume and timing; it also aims to ensure that the production process is effective, efficient, and cost-sustainable. Achieving this requires accurate cost estimations as a fundamental step. In production planning, all cost components—from raw materials and labor to energy consumption and machine capacity—must be predicted accurately and realistically. Moreover, the enterprise's production policies must be aligned with these plans; strategic decisions such as which products will be prioritized, which production methods will be employed, and how production capacity will be allocated should be integrated into the planning process. For these reasons, production planning software becomes highly significant, with software selection emerging as a particularly critical area.

Within this framework, the study examined the factors determining the criteria used in the selection of production planning software in manufacturing enterprises located in Samsun. According to the study results, the most important criteria in selecting production planning software were identified as "Security" and "Reporting and Analysis". The least significant criteria were found to be "Support and Training"and "Updates and Maintenance".

This study should be evaluated with certain limitations in mind. First, the research was confined to manufacturing enterprises located in Samsun; therefore, the generalizability of the findings to other provinces or different sectors may be limited. Second, the study relies on specific measurement tools and criteria to determine the importance levels of the factors; alternative methodological approaches or data collection techniques might yield different results. Furthermore, the study focuses solely on the current situation, and the temporal changes or long-term effects of the factors have not been comprehensively examined. The findings of this study highlight the criteria relevant to the production planning software selection process in manufacturing enterprises and provide guidance for managers. In addition, future research could extend this work by employing multi-criteria decision-making methods or other parametric and non-parametric approaches for a more comprehensive assessment

Acknowledgment: This study is a revised and expanded version of the study titled "Ranking of Criteria Used in Production Planning Software Selection: The Case of Ordu Province" which was presented as a full-text presentation at the 11th International Scientific Conference Innovation as the Initiator of Development (MEFKON 2025).

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