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Research Arcticle

Warehouse Manager Selection by CRITIC-MULTIMOORA Hybrid Method based on Single-Valued Neutrosophic Sets

Karahan Kara [1], Galip Cihan Yalçın[2] Sercan Edinsel[3]*

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Abstract

Warehouses are junction points in the supply chain. To avoid disruptions in the supply chain flow, the materials stored in the warehouse must be safely protected and made available for the next transportation activity. Warehouse personnel are critical in ensuring full-time material flow. For the administrative dimension, warehouse managers are the leaders responsible for the successful execution of all warehouse input-output processes. Therefore, a successful warehouse manager is needed for successful warehouse operations. The purpose of this research is to determine the warehouse manager selection criteria for general warehouses and to select the best warehouse manager among the candidate with using multi-criteria decision making (MCDM) methods as a hybrid. In the literature, it is seen that the manager selection problem is overseen with various MCDM methods. In this study, eight warehouse manager selection criteria were determined and their weights were calculated by the criteria importance through inter-criteria correlation based on single-valued neutrosophic set method (SVNS-CRITIC) method. Four alternatives were ranked with the multi-objective optimization by ratio analysis based on single-valued neutrosophic sets (SVNS-MULTIMOORA) method. The manager selection was made for the general warehouse owned by a company operating in Turkey. A team consisting of two experts and a proficient manager was established to evaluate the candidates. As a result of the application, the most important warehouse manager selection criterion is determined as the skills of managers to manage warehouse input-output and storage activities. In addition, the best manager candidate was determined for the general warehouse. According to the results of the research, suggestions were developed for warehouse manager candidates and researchers. With this research, it has been brought to the literature that warehouse manager selection criteria and SVNS-CRITIC-MULTIMOORA hybrid method can be used in manager selection problems.

1. Introduction

In highly competitive international business contexts, warehouses play a vital role in supply chains, making proper management of them even more crucial as consumers' requirements change. Any warehouse's quality depends on its staff and warehouse management (Keller and Keller, 2014). Because of its expansion, the job of warehouse manager today has the largest list of knowledge requirements among all positions in the logistics industry. The crucial connection between the warehouse and the rest of the logistics chain is now represented by the warehouse manager. It may be devastating for the organization's short-term efficacy and long-term viability to manage the optimization of the performance of persons in this position without having a thorough grasp of how to do so (LeMay et.al., 2018).

Warehouse management is important in delivering orders to customers and successfully ensuring material flow. Meeting the demands of daily operations is the significance of warehouse management. This management strategy prevents waste by reducing redoing work, misplacing resources, obtaining the best inventory, and other issues. This organizational method of approach enables activities to be conducted within the boundaries of a regulated scale, which ultimately helps to preserve quality criteria (Shashidharan and Anwar, 2021). Any manager should have the trust of both the staff and the business's owners. Additionally, the business owner should have faith in the manager's capacity to manage the company's finances, inventories, and decision-making as needed. The ability to solve issues and make judgments is necessary for the warehouse

[1] Logistics Program, Department of Administration and Organization, Hopa Vocational School, Artvin Çoruh University, Artvin, Turkey.
(*) Corresponding Author: Karahan Kara, karahan.kara@artvin.edu.tr

[2] Institute of Science and Technology, Kırıkkale University, Kırıkkale, Turkey.

[3] Deparment of Administration and Organization - OSTIM Technical University, Ankara, Turkey.

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manager. Because of demeanor and interactions with staff, the warehouse manager should be a natural leader who demands respect. Due to budget cuts, warehouse managers frequently must make difficult choices like terminating staff or reducing hours. So having a competent warehouse manager is crucial for logistic organizations.

The main purpose of this research is to determine the warehouse manager selection criteria for the general warehouse and to determine the best manager candidate. In the study, the criteria importance through inter-criteria correlation based on single-valued neutrosophic set method (SVNS-CRITIC) has been preferred for weighting the criteria. The multi-objective optimization by ratio analysis based on single-valued neutrosophic sets method (SVNS-MULTIMOORA) has been selected for ranking the alternatives. The main goal of the research is to guide researchers and practitioners in selecting a warehouse manager by applying the CRITIC-MULTIMOORA hybrid method based on SVN sets. In this direction, three research questions are formed. The research questions (RQ) are:

- RQ 1: Is the SVNS-CRITIC method a viable method for weighting warehouse manager criteria?
- RQ 2: Is the SVNS-MULTIMOORA method a viable method for ranking warehouse manager alternatives?
- RQ 3: Is the SVNS-CRITIC-MULTIMOORA hybrid method a viable method for solving the warehouse manager selection problem?

In the second part of the study, literature review and the criteria are presented. In the third part, the steps of the SVNS-CRITIC and SVNS-MULTIMOORA methods are shown. In the fourth part, the application results of the warehouse manager selection problem are presented. In the fifth part, the results are illustrated. In the sixth part, suggestions and limitations are depicted.

2. Literature Review and Criteria Selection

In this research, the warehouse manager selection problem is discussed. The SVNS-CRITIC method is used to determine the criteria importance levels. The SVNS-MULTIMOORA method is used to rank the alternatives. The literature review for the conduct of this research was carried out in three steps. In the first step, a literature review of the CRITIC method used for criterion weighting was made. It also has been revealed in which selection problems are handled. In the second step, a literature review of the MULTIMOORA method was made. In addition, it is explained how often the CRITIC-MULTIMOORA hybrid method is discussed in the literature. In the third step, a literature review was conducted for the manager selection criteria in the literature to determine the warehouse manager selection criteria.

In the literature, it is seen that the CRITIC method is widely used in criterion weighting of selection and evaluation problems. In addition, CRITIC method is carried out based on various sets. There are CRITIC (Adalı and Işık, 2017; Tuş and Adalı, 2019; Tabak et al., 2019), based on fuzzy sets (F-CRITIC) (Trivedi et al., 2022), based on interval type-2 fuzzy sets (IT2FS- CRITIC) (Ghorabaee et al., 2017; Mohamadghasemi et al., 2020), based on fermatean fuzzy set (FFS-CRITIC) (Mishra et al., 2022), based on probabilistic uncertain linguistic term sets (PULTS-CRITIC) (Wang et al., 2021), based on bipolar complex fuzzy sets (BCF-CRITIC) (Baidya et al., 2021; Liu et al., 2022), based on pythagorean fuzzy sets (PF-CRITIC) (Peng et al., 2020; Mishra et al., 2021), based on spherical fuzzy sets (SF-CRITIC) (Ali, 2021), based on type-2 neutrosophic numbers (T2NN-CRITIC) (Simic et al., 2022), based on linguistic D numbers (LDN-CRITIC) (Lai and Liao, 2021), based on intuitionistic fuzzy soft set (IFSS-CRITIC) (Peng and Garg, 2021), based on interval-valued intuitionistic fuzzy sets (IVIF-CRITIC) (Li and Wang, 2020), based on SVNS-CRITIC (Rani et al., 2021). In this study, the SVNS-CRITIC method was chosen for criterion weighting for the warehouse manager selection problem. The applications of the CRITIC method in the literature are shown in Table 1.

In the literature, it is seen that the MULTIMOORA method is used for selection problems. MULTIMOORA method are also carried out based on various sets. There are MULTIMOORA (Adalı and Işık, 2017), based on fuzzy sets (F-MULTIMOORA) (Baležentis et al., 2012; Deliktas and Ustun, 2017; Alkan and Albayrak, 2020), based on interval-valued grey numbers (IVGN-MULTIMOORA) (Datta et al., 2013), based onhesitant fuzzy linguistic term sets (HFL-MULTIMOORA) (Liu et al., 2018), based on picture fuzzy numbers (PFN-MULTIMOORA) (Lin et al., 2020; Tian et al., 2022), based on Z-numbers (ZN-MULTIMOORA) (Peng et al., 2022), based on neutrosophic numbers (NN-MULTIMOORA) (Zavadskas et al., 2017; Aydin, 2018), based on stochastic multi-criteria acceptability analysis (SMAA-MULTIMOORA) (Mi et al., 2020), SF-MULTIMOORA(Kutlu Gündoğdu, 2020), based on probabilistic linguistic term sets (PLTS-MULTIMOORA) (Chen et al., 2019), based on bipolar complex fuzzy sets (BCF-MULTIMOORA) (Baidya et al., 2021), IVIF-MULTIMOORA (Aydin and Seker, 2020), FFS-MULTIMOORA (Rani and Mishra, 2021), SVNS-

MULTIMOORA (Rani et al., 2021). The SVN-MULTIMOORA method has been preferred for warehouse manager selection problem. The literature review of the MULTIMOORA method is shown in Table 2.

Table 1. Literature review of the CRITIC method

Authors	Method	Selection Problem
Ghorabaee et al. (2017)	IT2FS-CRITIC	"Third-party logistics providers assessments"
Adalı and Işık (2017)	CRITIC	"Contract manufacturer selection"
Tabak et al. (2019)	CRITIC	"Logistics location selection"
Tuş and Adalı (2019)	CRITIC	"Software selection"
Li and Wang (2020)	IVIF-CRITIC	"Service quality of wireless sensor networks evaluation"
Peng et al. (2020)	PF-CRITIC	"5G industry evaluation"
Mohamadghasemi et al. (2020)	IT2FS-CRITIC	"Crane selection"
Wang et al. (2021)	PULTS-CRITIC	"Site selection"
Baidya et al. (2021)	BFC-CRITIC	"Third-party reverse logistics providers selection"
Rani et al. (2021)	SVNS-CRITIC	"Food waste treatment method selection"
Mishra et al. (2021)	PF-CRITIC	"Agriculture crop selection"
Ali (2021)	SF-CRITIC	"Smartphone selection"
Lai and Liao (2021)	LDN-CRITIC	"Blockchain platform evaluation"
Peng and Garg (2021)	IFSS	"Cache placement strategy selection"
Mishra et al. (2022)	FFS-CRITIC	"Sustainable third-party reverse logistics providers selection"
Simic et al., (2022)	T2NN	"Public transportation pricing system selection"
Liu et al. (2022)	BFC-CRITIC	"Green supplier selection"
Trivedi et al. (2022)	F-CRITIC	"Wire arc additive manufacturing technique selection"

Table 2. Literature review of the MULTIMOORA method

Authors	Method	Selection Problem
Baležentis et al. (2012)	F-MULTIMOORA	"Personnel selection"
Datta et al. (2013)	IVGN-MULTIMOORA	"Robot selection"
Adalı and Işık (2017)	MULTIMOORA	"Laptop selection"
Deliktas and Ustun (2017)	F-MULTIMOORA	"Personnel selection"
Zavadskas et al. (2017)	NN-MULTIMOORA	"Material selection"
Liu et al. (2018)	HFL-MULTIMOORA	"Robot evaluation and selection"
Aydin (2018)	NS-MULTIMOORA	"AR goggles selection"
Lin et al. (2019)	PFN-MULTIMOORA	"Site selection of car sharing station"
Chen et al. (2019)	PLTS-MULTIMOORA	"Cloud-based ERP system selection"
Aydin and Seker (2020)	IVIF-MULTIMOORA	"Hub location selection"
Mi et al. (2020)	SMAA-MULTIMOORA	"Green supplier selection"
Alkan and Albayrak (2020)	F-MULTIMOORA	"Ranking of renewable energy sources"
Kutlu Gündoğdu (2020)	SF-MULTIMOORA	"Personnel selection"
Rani and Mishra (2021)	FFS-MULTIMOORA	"Electric vehicle charging station selection"
Rani et al. (2021)	SVNS-MULTIMOORA	"Food waste treatment method selection"
Baidya et al. (2021)	BFC- MULTIMOORA	"Third-party reverse logistics providers selection"
Peng et al. (2022)	ZN-MULTIMOORA	"Hotel selection"
Tian et al. (2022)	PFN-MULTIMOORA	"Medical institution selection"

Although CRITIC and MULTIMOORA methods are widely used, it has been observed that they are used as hybrids in limited number of selection and performance determination problems. Işık (2019) applied the CRITIC-MULTIMOORA hybrid method to determine the financial performance rankings of insurance companies operating in Turkey. Baidya et al. (2021) used this hybrid method based on BCF in the third-party reverse logistics providers selection problem. Rani et al. (2021) applied this hybrid method based on SVNS in the problem of food waste treatment method selection. The warehouse manager selection problem is handled by using the SVN-CRITIC-MULTIMOORA method.

Manager selection is among the main research topics of the human resource management process. It is seen that the manager selection problem is investigated with MCDM methods. The literature review for the determination of the warehouse manager selection problem criteria is presented in Table 3. Zavadskas et al. (2008) used the complex proportional assessment of alternatives to grey relations (COPRAS-G) method in the selection of the construction project manager. Six criteria were used in the study. Kelemenis et al. (2011) preferred the fuzzy based technique for order of preference by similarity to ideal solution (F-TOPSIS) method in the middle level manager selection problem. Twelve criteria were used in the study. For the quality control manager selection problem, Zolfani et al (2012) used the analytic hierarchy process (AHP) and COPRAS-G method. Seven criteria were also used in the study. For project manager selection problem, Sadeghi et al (2014) performed F-TOPSIS and goal programming (GP) methods. Three criteria were used in the study. Mohammadi et al. (2014) selected the project manager with the cybernetic analytic network process (CANP) method. Eighteen criteria were used in the study. Dodangeh et al. (2014) applied the F-MCDM method using four criteria in the project manager selection problem. Kusumawardani and Agintiara (2015) selected human resources managers with the F-AHP-TOPSIS hybrid method. Chaghooshi et al. (2016) solved the project manager selection problem by combining fuzzy decision-making trial and evaluation laboratory (F-DEMATEL) and fuzzy visekriterijumsa optimizacija i kompromisno resenje (F-VIKOR) methods. Five criteria were used in the study. Çelikbilek (2018) discussed the hospital manager selection problem with the grey-based AHP-MOORA hybrid method. Sharma and Kumar (2018) applied the AHP method to the facilitating quality project manager selection problem. Baharin et al. (2021) carried out the middle level manager selection problem with the F-TOPSIS method using twelve criteria. Acar and Enücük (2022) applied the AHP technique to the store manager selection problem. Altuntas and Yildirim (2022) used the IF-TOPSIS method in the logistics specialist selection problem.

Table 3. Literature review of manager selection criteria

Authors	Method	Criteria
Zavadskas et al. (2008)	COPRAS-G	"Personal skills, project management skills, business skills, technical skills, quality skills, time of decision-making (6 criteria)"
Kelemenis et al. (2011)	F-TOPSIS	"Creativity/Innovation, problem solving/decision making, conflict management/negotiation, empowerment/delegation, strategic planning, specific presentation skills, communication skills, team management, diversity management, self-management, professional experience, educational background (12 criteria)"
Zolfani et al. (2012)	AHP, COPRAS-G	"Knowledge of product and raw material, experience and educational background, administrative orientation, behavioral flexibility, risk evaluation ability, payment, teamwork (7 criteria)"
Dodangeh et al. (2014)	F-MCDM	"Basic requirements, project management skills, management skills, interpersonal skills (4 criteria)"
Mohammadi et al. (2014)	CANP	"Job experience, academic achievement, communication skills, Microsoft project software, planning skill, organizing skill, directing/ leading, controlling/ monitoring, conducting meetings, record keeping, time management, property management, worker welfare management, rules and regulation, problem solving skills, decision making, multi-tasking, correspondence (18 criteria)"
Sadeghi et al. (2014)	F-TOPSIS, GP	"Knowledge Competencies, Performance Competencies, Behavioral Competencies (3 criteria)"
Kusumawardani and Agintiara (2015)	F-AHP, F-TOPSIS	"Assessment center score, level of education, major at school/university, stream match, length of time on stream, talent cluster index, performance index, competence index, length of time on position band, disciplinary sanction (10 criteria)"
Chaghooshi et al. (2016)	F-DEMATEL, F-VIKOR	"Site management capacity, technical level, level of leadership, personal qualities, contextual competences (5 criteria)"
Çelikbilek (2018)	Grey based AHP-MOORA	"General criteria, character criteria, sectoral criteria, emergency criteria (4 criteria and 20 sub-criteria)"
Sharma and Kumar (2018)	AHP	"Human skill, conceptual and organizational skill, technical skill (3 main criteria and 18 sub-criteria)"
Baharin et al. (2021)	F-TOPSIS	"Creativity/Innovation, problem solving/decision making, conflict management/negotiation, empowerment/delegation, strategic planning, specific presentation skills, communication skills, team management, diversity management, self-management, professional experience, educational background (12 criteria)"

Altuntas and Yildirim (2022)	IF-TOPSIS	"Graduation, professional experience, computer literacy, fluency in foreign language(s), communication/negotiation skills, analytical thinking, teamwork (7 criteria)"
Acar and Enücük (2022)	AHP	"Personal qualities, communication and leadership skills, experience, consistency with the company's vision (4 criteria)"

In warehouse manager selection processes, companies tend to select managers who have the ability to successfully run warehouse operations. There are five basic storage operations in storage processes. These are receiving/shipping, storage, order-picking, distributed process, dispatching/routing (Chen et al., 2017). In addition, eight "Key Performance Indicators (KPIs)" draw attention in the evaluation of the performance success of storage operations. These are "Good quality, delivery accuracy, on-time delivery, short time delivery, security of delivered goods, top-quality service, acceptable price, latent needs satisfied" (Chen et al., 2017). Faber et al. (2012) define warehouse management as "the combination of planning and control systems". It is planned at the tactical level and implemented at the operation level. The right tactical planning system is needed for successful storage management. Also, for successful storage process management, "Inbound, storage and outbound" decisions must be successful. On the other hand, to determine the success of storage planning, a successful "Control system" must be established. The storage manager must be qualified to meet these expectations. With the manager selection criteria in the literature, the warehouse manager selection criteria were created by considering the abilities and skills expected from the warehouse manager. These criteria are presented in Table 4.

Table 4. Selected criteria for warehouse manager selection problem

Criteria	Explanation
Warehouse management experience (C1)	It refers to the warehouse management experience of the candidate warehouse manager
Skills in setting up a control system (C2)	It indicates the success of establishing and executing a control system to determine whether the warehouse management processes are conducted in accordance with the plans.
Analytical thinking skills (C3)	It refers to the skills necessary to strengthen the relations between the staff and lead the staff in warehouse management.
Tactical planning skills (C4)	It refers to the ability to plan warehouse operations.
Communication and leadership skills (C5)	It refers to the skills necessary to strengthen the relations between the staff and lead the staff in warehouse management.
Inbound, storage and outbound process management skills (C6)	It refers to the success of managing the inbound, storage and outbound processes in the warehouse.
Educational background (C7)	It refers to the highest level of education of the candidate warehouse manager.
Skills in using warehouse management software programs (C8)	It refers to the ability to use software programs used in warehouse management.

3. Methodology

3.1. The Criteria Importance Through Inter-Criteria Correlation based on Single-Valued Neutrosophic Numbers (SVNS-CRITIC) Method

SVNS is recommended for decision making in an environment of uncertainty. Let U be a space of objects, U denoted by u. A SVN set $\widetilde{N}$ is characterized by truth-membership function ($T_{\widetilde{N}}$), indeterminacy-membership function ($I_{\widetilde{N}}$), falsity-membership function ($F_{\widetilde{N}}$). For each object, u in U, $t_N(u), i_N(u), f_N(u): U \to [0,1]$ and $0 \leq t_N(u) + i_N(u) + f_N(u) \leq 3$ (Wang et al., 2010). For SVNS-CRITIC, which will be used to calculate criterion weights, alternatives are defined as $\{F_1, F_2, \dots, F_m\}$, criteria as $P = \{P_1, P_2, \dots, P_n\}$ and decision makers as $E = \{E_1, E_2, \dots, E_l\}$. The evaluation of the i^{th} alternative according to the j^{th} criterion by the k^{th} decision maker is defined as $\xi_{ij}^{(k)}$. SVNS-CRITIC occurs in eight steps. These steps are as follows (Baidya et al., 2021, Rani et al., 2021):

Step 1-1: The weights of the decision makers ($\overline{\omega}_k$) are calculated with Eq. (1). Decision makers are evaluated according to Table 5 (Haq et al., 2022).

$$\bar{\omega}_k = \frac{3+t_k-2i_k-f_k}{\sum_{k=1}^{l}(3+t_k-2i_k-f_k)}, \sum_{k=1}^{l}\bar{\omega}_k = 1 \quad (1)$$

Step 1-2: With Table 6, the decision makers evaluate alternatives according to the criteria. The data obtained from the decision makers are combined with Eq. (2) (Ye, 2014).

$$\xi_{ij} = (t_{ij}, i_{ij}, f_{ij}) = SVNWA_{\bar{\omega}}\left(\xi_{ij}^{(1)}, \xi_{ij}^{(2)}, \dots, \xi_{ij}^{(l)}\right) = \left(1-\prod_{k=1}^{l}\left(1-t_{ij}^{(k)}\right)^{\bar{\omega}_k}, \prod_{k=1}^{l}\left(i_{ij}^{(k)}\right)^{\bar{\omega}_k}, \prod_{k=1}^{l}\left(f_{ij}^{(k)}\right)^{\bar{\omega}_k}\right) \quad (2)$$

Step 1-3: The score matrix ($\mathbb{S}(\xi_{ij})$) is created with Eq. (3).

$$\mathbb{S}(\xi_{ij}) = \frac{3+t_{ij}-2i_{ij}-f_{ij}}{4} \quad (3)$$

Table 5. The importance of decision-makers

Linguistic Variables	SVNSs
Expert	(0.90; 0.10; 0.10)
Proficient	(0.80; 0.25; 0.20)
Competent	(0.60; 0.35; 0.40)
Advanced Beginner	(0.40; 0.55; 0.55)
Novice	(0.20; 0.75; 0.80)

Table 6. SVNS numbers

Linguistic Variables	SVNNs	Linguistic Variables	SVNNs
Extremely high (EH)	(1.00; 0.00; 0.00)	Moderately low (ML)	(0.40; 0.65; 0.60)
Very very high (VVH)	(0.90; 0.10; 0.10)	Low (L)	(0.30; 0.75; 0.70)
Very high (VH)	(0.80; 0.15; 0.20)	Very low (VL)	(0.20; 0.85; 0.80)
High (H)	(0.70; 0.25; 0.30)	Very very low (VVL)	(0.10; 0.90; 0.90)
Moderately high (MH)	(0.60; 0.35; 0.40)	Extremely low (EL)	(0.00; 1.00; 1.00)
Fair (F)	(0.50; 0.50; 0.50)		

Step 1-4: Benefit criteria (P_b) and non-beneficial criteria (P_n) are standardized with Eq. (4). For Eq. (4), $\xi_j^+ = \max_i \xi_{ij}$ and $\xi_j^- = \min_i \xi_{ij}$.

$$\tilde{\xi}_{ij} = \begin{cases} \frac{\xi_{ij}-\xi_j^-}{\xi_j^+-\xi_j^-}, & j \in P_b \\ \frac{\xi_j^- - \xi_{ij}}{\xi_j^+-\xi_j^-}, & j \in P_n \end{cases} \quad (4)$$

Step 1-5: The standard deviation values (σ_j) of the criteria are calculated with Eq. (5).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(\tilde{\xi}_{ij}-\bar{\xi}_j)^2}{m}}, \bar{\xi}_j = \sum_{i=1}^{m}\frac{\tilde{\xi}_{ij}}{m} \quad (5)$$

Step 1-6: The correlation coefficient values (r_{jt}) of the criteria are calculated with Eq. (6).

$$r_{jt} = \frac{\sum_{i=1}^{m}(\tilde{\xi}_{ij}-\bar{\xi}_j)(\tilde{\xi}_{ij}-\bar{\xi}_t)}{\sqrt{\sum_{i=1}^{m}(\tilde{\xi}_{ij}-\bar{\xi}_j)^2(\tilde{\xi}_{ij}-\bar{\xi}_t)^2}}, \ t = 1,2,\dots,j \quad (6)$$

Step 1-7: c_j values of the criteria are calculated with Eq. (7).

$$c_j = \sigma_j \sum_{t=1}^{n}(1-r_{jt}) \quad (7)$$

Step 1-8: The weights of the criteria (w_j) are calculated with Eq. (8).

$$w_j = \frac{c_j}{\sum_{j=1}^{n} c_j} \tag{8}$$

3.2. The Multi-Objective Optimization By Ratio Analysis based on Single-Valued Neutrosophic Sets (SVNS-MULTIMOORA) Method

While the MOORA model comprises ratio system (RS) and reference point (RP) models (Brauers and Zavadskas, 2006), the MULTIMOORA model RS, RP and full multiplicative form (FMF) models (Brauers and Zavadskas, 2010). The procedure of SVNS-MULTIMOORA procedure is described with ten steps. These steps are (Rani et al., 2021):

Step 2-1: For the RS model, the SVNWAO values of the benefit criteria (Y_i^+) and non-beneficial criteria (Y_i^-) are calculated with Eq. (9) and Eq. (10), respectively.

$$Y_i^+ = \left(1 - \prod_{j\in P_b}\left(1 - t_{ij}\right)^{w_j},\ \prod_{j\in P_b}\left(i_{ij}\right)^{w_j}, \prod_{j\in P_b}(f_{ij})^{w_j}\right) \tag{9}$$
$$Y_i^- = \left(1 - \prod_{j\in P_n}\left(1 - t_{ij}\right)^{w_j},\ \prod_{j\in P_n}\left(i_{ij}\right)^{w_j}, \prod_{j\in P_n}(f_{ij})^{w_j}\right) \tag{10}$$

Step 2-2: The values y_i^+ and y_i^- are calculated by Eq. (11).

$$y_i^+ = \mathbb{S}(Y_i^+) \text{ and } y_i^- = \mathbb{S}(Y_i^-) \tag{11}$$

Step 2-3: The y_i value is calculated by Eq. (12). These values determine the order of alternatives.

$$y_i = y_i^+ - y_i^- \tag{12}$$

Step 2-4: For the RP model, the $p^* = \{p_1^*, p_2^*, \dots, p_n^*\}$ values are calculated with Eq. (13).

$$p_j^* = \begin{cases} \left(\max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij}\right), for\ beneficial\ criteria\ P_b \\ \left(\min_i t_{ij}, \max_i i_{ij}, \max_i f_{ij}\right), for\ non-beneficial\ criteria\ P_n \end{cases} \tag{13}$$

Step 2-5: For $\delta_1, \delta_2 \in SVNN(U)$, the distance measure ($D_{ij}$) values to be used determining the ranking of the alternatives are calculated by Eq. (14) and Eq. (15).

$$D_h(\delta_1, \delta_2) = \frac{1}{3}\left(\left|t_{\delta_1}(u_i) - t_{\delta_2}(u_i)\right| + \left|i_{\delta_1}(u_i) - i_{\delta_2}(u_i)\right| + \left|f_{\delta_1}(u_i) - f_{\delta_2}(u_i)\right|\right) \tag{14}$$
$$D_{ij} = w_j\left(D_h\left(\xi_{ij}, p_j^*\right)\right) \tag{15}$$

Step 2-6: The d_i value is calculated by Eq. (16). These values determine the order of alternatives.

$$d_i = \max_j D_{ij} \tag{16}$$

Step 2-7: For the FMF model, SVNWGO values are calculated by Eq. (17) and Eq. (18).

$$A_i = \left(\prod_{j\in P_b}\left(t_{ij}\right)^{w_j},\ \prod_{j\in P_b}\left(1 - i_{ij}\right)^{w_j}, \prod_{j\in P_b}(1 - f_{ij})^{w_j}\right) \tag{17}$$
$$B_i = \left(\prod_{j\in P_n}\left(t_{ij}\right)^{w_j},\ \prod_{j\in P_n}\left(1 - i_{ij}\right)^{w_j}, \prod_{j\in P_n}(1 - f_{ij})^{w_j}\right) \tag{18}$$

Step 2-8: The α_i and β_i values are calculated by Eq. (19).

$$\alpha_i = \mathbb{S}(A_i)\ and\ \beta_i = \mathbb{S}(B_i) \tag{19}$$

Step 2-9: The u_i values are calculated by Eq. (20). These values determine the order of alternatives.

$$u_i = \frac{\alpha_i}{\beta_i} \tag{20}$$

Step 2-10: The values for the final alternative ranking are obtained by Eq. (21) (Wu et al., 2018). Eq. (22) is used while performing these operations.

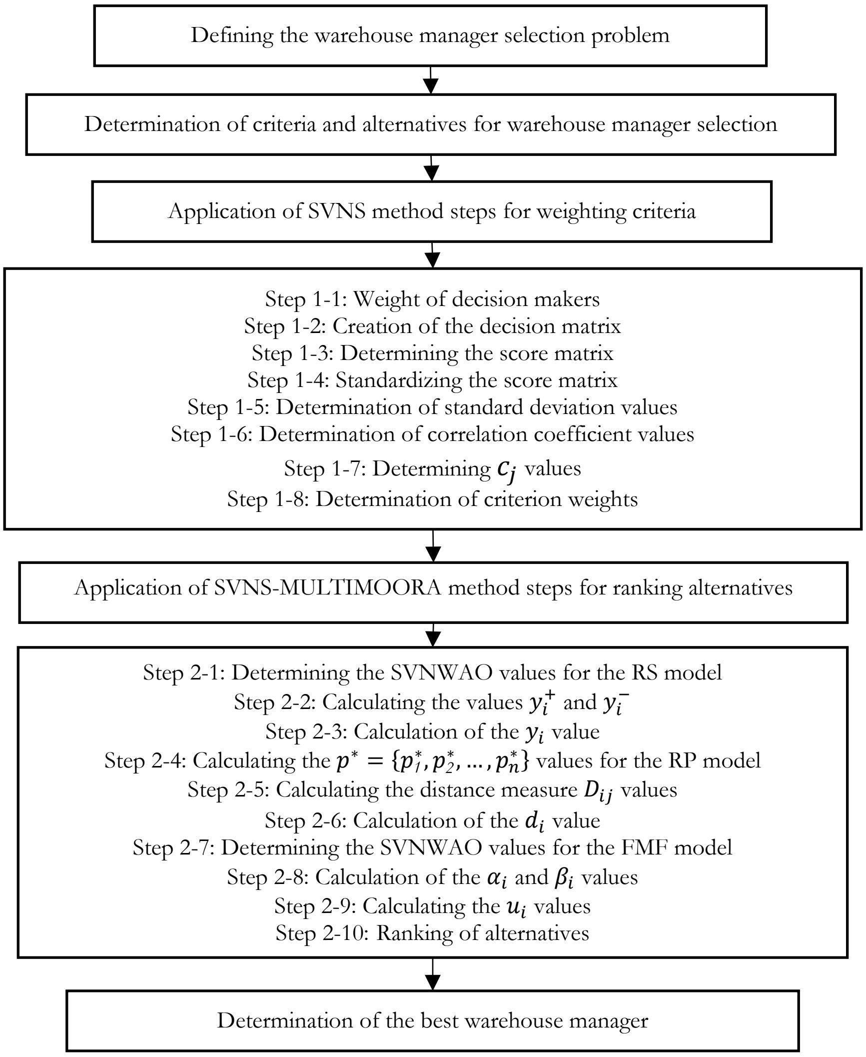
$$I_B(F_i) = y_i^* \frac{m-\rho(y_i^*)+1}{(m(m+1)/2)} - d_i^* \frac{\rho(d_i^*)}{(m(m+1)/2)} + u_i^* \frac{m-\rho(u_i^*)+1}{(m(m+1)/2)} \tag{21}$$

$$y_i^* = \frac{y_i}{\sqrt{\sum_{i=1}^{m}(y_i)^2}}, d_i^* = \frac{d_i}{\sqrt{\sum_{i=1}^{m}(d_i)^2}}, u_i^* = \frac{u_i}{\sqrt{\sum_{i=1}^{m}(u_i)^2}} \tag{22}$$

4. Application

In this research, the warehouse manager selection problem is discussed for a company operating in Turkey. Three decision makers (k=1, 2, 3), eight criteria (j=1, 2, …, 8) and four alternative manager candidates (i=1, 2, 3, 4) were used in the study. The SVNS-CRITIC method was used to weight the criteria, and the SVNS-MULTIMOORA method was used to rank the alternatives. The application flow is shown in Figure 1. The application was carried out according to the process steps presented in the methodology section. The application steps are as follows:

Figure 1. Application flow chart



Step 1-1: Decision makers and SVNS numbers are presented in Table 7. Decision maker weights were calculated by Eq. (1). It is shown in Table 8.

Table 7. The decision makers and SVNS numbers

DM-1	DM-2	DM-3
Expert	Expert	Proficient

(0.90; 0.10; 0.10)	(0.90; 0.10; 0.10)	(0.80; 0.25; 0.20)

Table 8. The decision maker weights

	DM-1	DM-2	DM-3
$\overline{\omega}_k$	0.3495	0.3495	0.3010

Step 1-2: According to Table 6, the decision makers evaluated alternatives for each criterion. Linguistic expressions are shown in Table 9 and SVNS numbers in Table 10. The evaluations of the decision makers were combined with Eq. (2). They are shown in Table 11.

Table 9. The decision maker weights (linguistics)

		A1	A2	A3	A4
DM-1	C1	VVH	VH	VH	H
	C2	VVH	VH	H	H
	C3	VH	MH	F	F
	C4	VH	VH	VH	H
	C5	H	VH	H	H
	C6	MH	H	H	VH
	C7	VVH	VH	VH	VH
	C8	VH	VH	H	VH
DM-2	C1	VVH	VH	H	H
	C2	VH	VH	VH	MH
	C3	VH	VH	H	H
	C4	VVH	VVH	H	MH
	C5	VH	VH	VH	VH
	C6	VH	F	MH	H
	C7	VVH	VVH	VH	H
	C8	VVH	VVH	VH	VH
DM-3	C1	VVH	VVH	VH	H
	C2	VVH	VVH	VVH	H
	C3	H	H	H	H
	C4	VH	VH	VH	H
	C5	VVH	H	VH	H
	C6	VH	VH	H	VH
	C7	VVH	VH	VH	VH
	C8	VVH	VH	VH	H

Table 10. The decision maker weights (SVNS numbers)

		A1			A2			A3			A4		
		t	*i*	*f*	*t*	*i*	*f*	*t*	*i*	*f*	*t*	*i*	*f*
DM-1	C1	0.90	0.10	0.10	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30
	C2	0.90	0.10	0.10	0.80	0.15	0.20	0.70	0.25	0.30	0.70	0.25	0.30
	C3	0.80	0.15	0.20	0.60	0.35	0.40	0.50	0.50	0.50	0.50	0.50	0.50
	C4	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30
	C5	0.70	0.25	0.30	0.80	0.15	0.20	0.70	0.25	0.30	0.70	0.25	0.30
	C6	0.60	0.35	0.40	0.70	0.25	0.30	0.70	0.25	0.30	0.80	0.15	0.20
	C7	0.90	0.10	0.10	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20
	C8	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30	0.80	0.15	0.20
DM-2	C1	0.90	0.10	0.10	0.80	0.15	0.20	0.70	0.25	0.30	0.70	0.25	0.30
	C2	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20	0.60	0.35	0.40
	C3	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30	0.70	0.25	0.30
	C4	0.90	0.10	0.10	0.90	0.10	0.10	0.70	0.25	0.30	0.60	0.35	0.40
	C5	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20
	C6	0.80	0.15	0.20	0.50	0.50	0.50	0.60	0.35	0.40	0.70	0.25	0.30

	C7	0.90	0.10	0.10	0.90	0.10	0.10	0.80	0.15	0.20	0.70	0.25	0.30
	C8	0.90	0.10	0.10	0.90	0.10	0.10	0.80	0.15	0.20	0.80	0.15	0.20
DM-3	C1	0.90	0.10	0.10	0.90	0.10	0.10	0.80	0.15	0.20	0.70	0.25	0.30
	C2	0.90	0.10	0.10	0.90	0.10	0.10	0.90	0.10	0.10	0.70	0.25	0.30
	C3	0.70	0.25	0.30	0.70	0.25	0.30	0.70	0.25	0.30	0.70	0.25	0.30
	C4	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30
	C5	0.90	0.10	0.10	0.70	0.25	0.30	0.80	0.15	0.20	0.70	0.25	0.30
	C6	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30	0.80	0.15	0.20
	C7	0.90	0.10	0.10	0.80	0.15	0.20	0.80	0.15	0.20	0.80	0.15	0.20
	C8	0.90	0.10	0.10	0.80	0.15	0.20	0.80	0.15	0.20	0.70	0.25	0.30

Table 11. The combined decision matrix

	A1			**A2**			**A3**			**A4**		
	t	*i*	*f*	*t*	*i*	*f*	*t*	*i*	*f*	*t*	*i*	*f*
C1	0.900	0.100	0.100	0.838	0.133	0.162	0.770	0.179	0.230	0.700	0.250	0.300
C2	0.873	0.115	0.127	0.838	0.133	0.162	0.813	0.159	0.187	0.668	0.281	0.332
C3	0.774	0.175	0.226	0.712	0.235	0.288	0.641	0.319	0.359	0.641	0.319	0.359
C4	0.843	0.130	0.157	0.843	0.130	0.157	0.770	0.179	0.230	0.668	0.281	0.332
C5	0.813	0.159	0.187	0.774	0.175	0.226	0.770	0.179	0.230	0.740	0.209	0.260
C6	0.745	0.202	0.255	0.683	0.273	0.317	0.668	0.281	0.332	0.770	0.179	0.230
C7	0.900	0.100	0.100	0.843	0.130	0.157	0.800	0.150	0.200	0.770	0.179	0.230
C8	0.873	0.115	0.127	0.843	0.130	0.157	0.770	0.179	0.230	0.774	0.175	0.226

Step 1-3: The score matrix $\mathbb{S}(\xi_{ij})$ was calculated by Eq. (3). It is shown in Table 12.

Table 12. The score matrix ($\mathbb{S}(\xi_{ij})$)

	A1	**A2**	**A3**	**A4**
C1	0.900	0.852	0.795	0.725
C2	0.879	0.852	0.827	0.694
C3	0.800	0.738	0.661	0.661
C4	0.856	0.856	0.795	0.694
C5	0.827	0.800	0.795	0.765
C6	0.772	0.705	0.694	0.795
C7	0.900	0.856	0.825	0.795
C8	0.879	0.856	0.795	0.800

Step 1-4: All criteria are benefit criteria. The criteria are standardized by Eq. (4). It is shown in Table 13.

Table 13. The standardized SVNS-matrix ($\tilde{\xi}_{ij}$)

	A1	**A2**	**A3**	**A4**
C1	1.000	0.728	0.401	0.000
C2	1.000	0.858	0.721	0.000
C3	1.000	0.558	0.000	0.000
C4	1.000	1.000	0.624	0.000
C5	1.000	0.555	0.483	0.000
C6	0.770	0.110	0.000	1.000
C7	1.000	0.585	0.285	0.000
C8	1.000	0.734	0.000	0.053

Step 1-5: The standard deviation values of the criteria were calculated by Eq. (5). They are shown in Table 14.

Table 14. The standard deviation values of the criteria (σ_j)

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**

σ_j	0.373	0.385	0.420	0.409	0.355	0.425	0.371	0.431

Step 1-6: The correlation coefficient values (r_{jt}) values of the criteria were calculated by Eq. (6). It is shown in Table 15.

Table 15. The correlation coefficient values of the criterion (r_{jt})

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	1.0000	0.9405	0.9206	0.9530	0.9685	-0.2373	0.9845	0.9061
C2	0.9405	1.0000	0.7332	0.9786	0.9341	-0.5321	0.8787	0.7189
C3	0.9206	0.7332	1.0000	0.7813	0.8668	0.1392	0.9615	0.9861
C4	0.9530	0.9786	0.7813	1.0000	0.8959	-0.5087	0.8850	0.7973
C5	0.9685	0.9341	0.8668	0.8959	1.0000	-0.2101	0.9696	0.8127
C6	-0.2373	-0.5321	0.1392	-0.5087	-0.2101	1.0000	-0.0706	0.0874
C7	0.9845	0.8787	0.9615	0.8850	0.9696	-0.0706	1.0000	0.9296
C8	0.9061	0.7189	0.9861	0.7973	0.8127	0.0874	0.9296	1.0000

Step 1-7: c_j values of the criteria were calculated by Eq. (7). It is shown in Table 16.

Step 1-8: The weights of the criteria (w_j) were calculated by Eq. (8). It is shown in Table 17.

Table 16. The c_j values of the criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
c_j	0.584	0.904	0.676	0.906	0.625	3.538	0.542	0.759

Table 17. The criterion weights (w_j)

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
w_j	0.0684	0.1060	0.0792	0.1062	0.0732	0.4146	0.0635	0.0890
Ranking	7	3	5	2	6	1	8	4

Step 2-1: Since all the criteria for the RS procedures are benefits, only the Y_i^+ values of the criteria calculated by Eq. (9) are shown in Table 18.

Table 18. The Y_i^+ values

		Y_i^+	
	t	i	f
A1	0.819	0.153	0.181
A2	0.772	0.190	0.228
A3	0.731	0.221	0.269
A4	0.736	0.213	0.264

Step 2-2: The y_i^+ and y_i^- values are calculated by Eq. (11). It is shown in Table 19. Since there are no non-beneficial criteria, t_{ij}, i_{ij} *and* f_{ij}values were taken as 0 in the calculation of β_i values.

Table 19. The y_i^+ and y_i^- Values

	A1	**A2**	**A3**	**A4**
y_i^+	0.833	0.791	0.755	0.761
y_i^-	0.750	0.750	0.750	0.750

Step 2-3: The y_i values are calculated by Eq. (12). It is shown in Table 20.

Table 20. The y_i values and alternative rankings

	A1	**A2**	**A3**	**A4**
y_i	0.0831	0.0410	0.0051	0.0112
Ranking	1	2	4	3

Step 2-4: The p^* values for the RP model were calculated by Eq. (13). It is shown in Table 21.

Table 21. The p^* Values

	p^*		
	t	i	f
C1	0.900	0.100	0.100
C2	0.873	0.115	0.127
C3	0.774	0.175	0.226
C4	0.843	0.130	0.157
C5	0.813	0.159	0.187
C6	0.770	0.179	0.230
C7	0.900	0.100	0.100
C8	0.873	0.115	0.127

Step 2-5: D_{ij} values were calculated by Eq. (15). It is shown in Table 22.

Table 22. The D_{ij} Values

	A1	A2	A3	A4
C1	0.0000	0.0036	0.0078	0.0125
C2	0.0000	0.0031	0.0057	0.0203
C3	0.0000	0.0049	0.0108	0.0108
C4	0.0000	0.0000	0.0069	0.0177
C5	0.0000	0.0023	0.0026	0.0048
C6	0.0098	0.0370	0.0421	0.0000
C7	0.0000	0.0030	0.0053	0.0072
C8	0.0000	0.0022	0.0080	0.0076

Step 2-6: d_i values were calculated by Eq. (16). It is shown in Table 23.

Table 23. The d_i values and ranking the alternatives

	A1	A2	A3	A4
d_i	0.0098	0.0370	0.0421	0.0203
Ranking	1	3	4	2

Step 2-7: The $A_i$values for the FMF model were calculated by only Eq. (17) because all criteria are benefit criteria. It is shown in Table 24.

Table 24. The A_i values

	A_i		
	t	i	f
A1	0.806	0.160	0.194
A2	0.757	0.204	0.243
A3	0.721	0.231	0.279
A4	0.730	0.220	0.270

Step 2-8: α_i and β_i values were calculated by Eq. (19). It is shown in Table 25. Since there are no non-beneficial criteria, t_{ij}, i_{ij} *and* f_{ij}values were taken as 0 in the calculation of β_i values.

Table 25. The α_i and β_i Values

	A1	A2	A3	A4
α_i	0.823	0.776	0.745	0.755
β_i	0.750	0.750	0.750	0.750

Step 2-9: The u_i values calculated by Eq. (20) and the alternative ordering is shown in Table 26.

Table 26. The u_i values and ranking alternatives

	A1	A2	A3	A4
u_i	1.097	1.035	0.994	1.006
Ranking	1	2	4	3

Step 2-10: $I_B(F_i)$ values were calculated by Eq. (21). The final alternative ranking is shown in Table 27.

Table 27. The $I_B(F_i)$ values and ranking alternatives

	A1	A2	A3	A4
$I_B(F_i)$	0.5516	0.0979	-0.2251	0.0541
Ranking	1	2	4	3

5. Results and Discussion

Warehouses are the junction points where materials are not in motion in supply chain processes. Materials are stored safely and securely at these points. Warehouse management is the management of all processes between recording the materials and bringing them to the warehouse, and recording and sending them from the warehouse. In this research, the warehouse manager selection problem that a company operating in Turkey needs to improve the management processes of its distribution warehouse is discussed. To determine the best warehouse manager candidate, MCDM methods were used in a hybrid way. The research was carried out in two stages. In the first stage, the importance levels of the criteria were determined by the SVVN-CRITIC method. In the second stage, four manager candidates were ranked using the SVVN-MULTIMOORA method.

According to the findings of the SVVN-CRITIC method, the importance levels of the criteria are as follows: Inbound, storage and outbound process management skills ($w_6 = 0{,}4146$), tactical planning skills ($w_4 = 0{,}1062$), skills in setting up a control system ($w_2 = 0{,}1060$), skills in using warehouse management software programs ($w_8 = 0{,}0890$), analytical thinking skills ($w_3 = 0{,}0792$), communication and leadership skills ($w_5 = 0{,}0732$), warehouse management experience ($w_1 = 0{,}0684$), educational background ($w_7 = 0{,}0635$). The highest criterion weight is the sixth criterion. This criterion is explained as the skills of warehouse managers to manage warehouse processes. The processes of taking the materials to the warehouse, storing, and sending them from the warehouse are important in order not to disrupt the supply chain. For this reason, the warehouse manager is expected to successfully manage all these processes. In addition, this criterion has a remarkably prominent level of importance when compared with other criteria. At this point, it can be said that process management is indispensable for warehouse management (Faber et al., 2012). The importance levels of tactical planning and control system development criteria are close to each other. For the success of warehouse management operations, tactical plans should be made by the managers and control mechanisms for the applications should be developed. Warehouse managers also could set up and manage planning and control mechanisms. Today, warehouse management is conducted with warehouse management software programs, not manual records. Warehouse managers should be able to use these software programs to control warehouse flow processes simultaneously with material movement. In addition, the warehouse manager should have analytical thinking skills, effective communication skills, advanced team leadership skills, high educational level and experienced. In the literature, the personality traits, education levels and work experience of managers are cited as high-importance criteria (Zavadskas et al., 2008; Dodangeh et al., 2014; Çelikbilek, 2018). However, in this research, rather than the typical characteristics of the manager, the importance levels of the skills required for warehouse management come to the fore.

In the second stage, the alternatives were ranked. Among the four alternative warehouse managers, the best alternative was determined as the first alternative candidate. In fact, the preference level of the first candidate is extremely high compared to other alternative manager candidates. Ultimately, the first alternative candidate was identified as the best warehouse manager for the company.

6. Suggestions and Limitations

According to the literature review, no research on the warehouse manager selection problem has been found. Warehouse managers are considered mid-level managers. Tactical level suggestions should be developed for middle managers. The suggestions of warehouse manager candidates who are accepted as middle level managers within the scope of this research are as follows: (i) The management of inbound, storage and outbound activities, which are the three basic stages of the warehouse management process, is the most important criterion in warehouse management. For this reason, warehouse manager candidates should develop their skills in the management of warehouse management processes. (ii) Warehouse manager candidates should develop the skills to combine warehouse planning and control processes. (iii) Warehouse manager candidates should have knowledge about and be able to use software programs for warehouse management. (iv) Warehouse manager candidates should develop their general managerial skills. (v) Warehouse manager candidates should have effective communication skills with personnel. They should also be able to lead personnel. Suggestions for researchers are as follows: (i) In this research, warehouse manager criteria for the general warehouse based on material distribution and ranking among alternative candidates according to these criteria. Researchers can revisit the research by specifying warehouse manager criteria for other types of warehouses. (ii) Various MCDM methods can be used in warehouse manager selection. The obtained results can be compared with the findings of this research. (iii) In this research, three decision makers, four alternative manager candidates and eight criteria were used in the selection of warehouse managers. Warehouse manager candidate selection can be made in different sample areas and considering the number of different criteria. (iv) SVNS-CRITIC-MULTIMOORA method was used in warehouse manager selection. This method can be applied in the selection of managers for different logistics activities.

The limitations of the research are: (i) This research was based on SVNS sets. Different results can be obtained if different fuzzy-based MCDM techniques are applied. (ii) This research was conducted based on eight criteria. Different results can be obtained if the number of criteria and criteria weights change. (iii) This research was conducted with three decision makers. Decision makers consist of experts and proficient. If there are differences in the number of decision makers and the level of expertise of the decision makers, different results can be obtained in the criteria weights and alternative rankings. (iv) In this study, the manager selection problem for the general warehouse is discussed. Cold storage warehouses, solid bulk warehouses, liquid bulk warehouses, warehouses etc. Differences can be observed in the warehouse manager criteria of warehouse types. Finally, with this research, warehouse manager selection criteria were developed and applied to the manager selection process. With this research, it has been determined that a manager selection application can be made with the SVNS-CRITIC-MULTIMOORA hybrid method. In addition, it has been evaluated that it will guide companies in the execution of the warehouse manager selection process.

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