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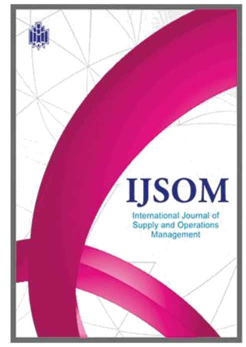

Performance Measurement with Lean, Agile and Green Considerations: An Interval-Valued Fuzzy TOPSIS Approach in Healthcare Industry

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Abstract

This study develops an integrated classic-interval-valued fuzzy TOPSIS approach to assess performance of different departments of a hospital. Although the concept of performance measurement has been discussed in previous studies, its concurrent integration with lean, agile, and green strategies is less investigated. Therefore, this research has been completed in three linked phases as follows. Firstly, the critical metrics of lean, agile, and green strategies are extracted from previous literature. Secondly, a fuzzy TOPSIS approach is developed to compare three departments of a hospital using the investigated metrics of previous phase. According to the obtained results of this phase, the eye, and emergency departments are the best and worst departments, respectively. Next, the obtained results are checked by an interval-valued fuzzy TOPSIS approach for further investigation in the third phase. Similarly, approving the previous results, eye department provides the best performance according to the second approach. As a contribution, this research showed that different MCDM techniques might provide a same result. Furthermore, the developed methodology can be applied to assess and compare the performance of different departments.

Keywords: Performance Measurement; Lean Manufacturing; Agile Manufacturing; Green Manufacturing; Fuzzy Logic.

1. Introduction

There are numerous issues forcing organizations to focus on performance measurement. Among these issues, there are many circumstances where organizations should consider more than one strategy to survive in today's competitive markets. In other words, companies, factories, hospitals, and other manufacturing and service organizations approve the necessity of considering more than one strategy to deal with different sources of uncertainties (Shaw et al. 2022). Traditionally, the early Performance Measurement Systems (PMSs) focused on cost and accounting. Therefore, Lean Manufacturing (LM) concept could be a proper alternative to focus on cost saving, waste elimination and customer satisfaction. With the advent of manufacturing systems and market growth, Agile Manufacturing (AM) was suggested as an alternative of LM. In other words, once the leanness was achieved by companies, it was suggested to focus on AM requirements. Although both paradigms have been initially developed for manufacturing companies, their concept, tools and techniques are applicable for any organization seeking for less cost, waste, and more customers' satisfaction.

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Recently, environmental considerations have forced companies, hospitals, banks and other manufacturing and service providers to consider these issues in operating processes. In this regard, many studies suggest different strategies to improve green performance. Although the concept of LM, AM and Green Manufacturing (GM) have been vastly investigated in previous literature, less attempt has been made for their concurrent assessment in healthcare industry. In this regard, recognizing the specific measures of each strategy, developing appropriate assessment methods, and unifying the obtained results can be beneficial for managers, practitioners and scholars. In other words, as different criteria should be applied to assess different alternatives, it is classified as a Multiple-Criteria Decision Making (MCDM) problem. While healthcare performance measurement has been addressed in previous literature, there is no study to compare different departments of a hospital using lean, agile and green strategies. This ignorance is due to intrinsic complexity of developing specific measures of these strategies in hospitals, linking them to MCDM problems, and finally providing a proper approach to solve them. In addition, decision making outputs are commonly made in uncertain and ambiguous environments which is hard to be measured. In other words, similar to other organizations, the decision makers of healthcare industry prefer to apply linguistic terms instead of exact scalar values. Therefore, concurrent consideration of these issues to investigate the performance of healthcare industry is beneficial. Following research questions are addressed in this study:

- What are the main metrics of LM, AM and GM to assess the performance of hospitals?
- How different departments of a hospital can be prioritized using the developed metrics?

This study has been completed in a hospital located in Kermanshah, Iran. However, the research methodology, applied framework, obtained results, and recommendations can be applicable for other scholars, practitioners and managers to assess the performance of hospitals from different perspectives. Regarding the novelty, this research contributes in identifying the main metrics of leanness, agility and greenness to be applied in hospitals, developing fuzzy approaches to consider inherent uncertainties of decision makers' judgments, and finally comparing the obtained results of two fuzzy approaches. From the research and practical perspectives, contributions of this research are novel, since, to the best of authors' knowledge, no comparable study has been conducted before. The remainder of this research is arranged as follows. Second section discusses the previous conducted studies on LM, AM and GM. In addition, a summary of previous studies, and identification of gaps are provided in this section. Following, Section 3 discusses the research methodology. This section is followed by results and discussion in Section 4, concluding remarks in Section 5 and list of the references in Section 6.

2. Literature Review

This section discusses the previous literature on LM, AM, and GM. Furthermore, a summary of preceding literature, and identification of research gaps are provided.

2.1. Performance Measurement

There are many studies on performance measurement (Aazami and Saidi-Mehrabad, 2021; Kaviyani-Charati et al. (2022)). Though, the exact definition of this topic is not clear enough. There are different definition varying from strategic to operational issues of companies, businesses, and supply chains. However, the majority of previous studies define it as the process of quantifying an action to be measured. In addition, it has been defined from customers' viewpoint. According to Kotler (1984) and Neely (1995), performance measurement should assess customers' satisfaction level. The topic has been investigated by practitioners, managers and scholars since 1970s (Neely, 1999). Literally, performance measurement problem initiated from simple cost and accounting based systems (Bourne et al. 2000). Following, different topics such as lean, agility, sustainability and other strategies were added to enrich the problem (Galankashi et al. 2018; Rahiminezhad Galankashi and Helmi, 2016). According to previous literature, Performance Measurement System (PMS) of companies should be aligned with their applied strategies. Following discusses different strategies linked with PMS.

2.2. Lean Manufacturing (LM)

LM is a production philosophy focused on waste elimination and continuous improvement. More related to healthcare industry, LM philosophy can be applied to improve the performance of hospitals from both organizational and patients' perspectives. This philosophy has been practiced in different companies, businesses, service providers, and many other organizations. There are different tools developed by LM to achieve its objectives. These tools include Just in Time (JIT), five S, and Total Productive Maintenance (TPM) (Zarei et al. 2011; Galankashi Helmi, 2017). The concept is originated from Japan. However, it has been extended to other countries and their industries (Herron and Hicks, 2008; Cooney, 2002; Piercy & Rich 2009; Stone, 2012).

2.3. Agile Manufacturing (AM)

AM can be considered as the next step of LM implementation. In other words, once an organization successfully implemented LM, it should try for agility. The AM philosophy aims to maintain quality, cost and other important issues of production while focusing on fast response to customers' requirements and market changes (Vinodh et al. 2012). There are many issues to be considered by managers namely price, cost, service, speed delivery and market changes. In this context, AM is suggested to be an appropriate approach to deal with these issues (Yang and Li, 2002; Kaviyani-Charati et al. 2022). As an important topic of LM, agility concept is defined as the process of implementing and assessing different practices of LM in companies (Vinodh et al. 2012). In other words, AM satisfies customers' necessities in fast changing markets with shortest time (Prince and Kay, 2003; Bottani, 2009). There are many studies on agility measures (Tsourveloudis and Valavanis, 2002).

2.4. Green Manufacturing (GM)

With the advent of technology, it is critical for managers, practitioners and scholars to focus on environmental concerns (Yang et al. 2003). These concerns should be addressed by manufacturers, hospitals, banks, etc. As a potential solution, GM has been practiced by many studies in previous literature (Barber, 2007; Salem and Deif, 2017). The major concerns of GM include waste elimination, pollution mitigation, and other environmental concerns (Testa and Iraldo, 2010; Vachon, 2007). GM can be implemented or assessed by different measures. However, these measures are not easy to be generalized. In other words, each company, business, and service provider need its specific measures of GM. Therefore, as it has been approved in previous literature, fit measures of each strategy should be developed. Although GM has been discussed in previous literature, it is less investigated in healthcare industries. Furthermore, specific measures of GM should be more investigated in hospitals.

2.5. Related Works

This section investigates previous literature by focusing on performance assessment of hospitals. The topic has been discussed from different perspectives. These perspectives include cost based approaches, risk based methodologies, etc. For example, DesHarnais et al. (1990) developed risk-adjusted readmissions index, risk-adjusted complications index, and risk-adjusted mortality index for hospitals' performance measurement. As an example of cost based approaches, according to Mark et al. (1998), financial performance of hospitals can be enhanced by integrating them with employed physicians. Other concerns of managers to improve performance of hospitals include production efficiency and resource utilization (Athanassopoulos et al. 1999). Hibbard et al. (2005) highlighted the importance of information sharing and its impact on performance of hospitals. According to this study, long term performance of hospitals is improved by information sharing. There are different perspectives to assess the performance of hospitals. For example, safety, clinical effectiveness, production efficiency, staff orientation, patient centeredness, and responsive governance should be considered in performance assessment of hospitals (Veillard et al. 2005). There are different levels of decisions to assess the performance of hospitals. As an example of operational decision making, according to Ramanathan (2005), operational assessment of hospitals can lead to a better performance. As an application of Balanced Scorecard (BSC), Chen et al. (2006) developed a BSC to assess the performance of hospitals. In another study focusing on different perspectives of performance measurement, according to Minvielle et al. (2008), quality of work life, and human relations dimension are two important scopes of performance measurement. Different sets of performance measures can be developed to assess hospitals. In a study conducted by Groene et al. (2008), different culture and resource availability were considered in the process of performance measures development. As another example of BSC application in performance assessment of hospitals, Davis et al. (2013) provided a feasibility study to apply common measures of BSC in performance measurement of hospitals. As hospitals are dynamic and operate in fast changing environments, Poulos et al. (2015) investigated emergency rooms in disaster situations.

According to Weintraub and Garratt (2017), medical regulatory policies should be questioned and more investigated to find its faults. Performance of hospitals has been more investigated in recent literature. There are different performance measurement frameworks applied to assess hospitals. For example, Rouis et al. (2018) applied a Balanced Scorecard (BSC) to assess hospitals. Zare (2019) applied a hybrid Data Envelopment Analysis (DEA) to investigate hospitals. In addition to overall performance, logistics performance of hospital supply chain has been investigated in previous literature (Moons et al., 2019). In a similar study, Jiang et al. (2020) applied MCDM approaches to determine the most important metrics of hospital selection. In another application of DEA, Yang et al. (2020) applied this approach to assess the performance of hospitals. In another similar study, Kutlu Gündoğdu and Kahraman (2021) applied an interval-valued spherical fuzzy Analytic Hierarchy Process (AHP) to assess hospitals. Ayyildiz (2021) applied interval valued intuitionistic fuzzy AHP to investigate supply chains in post COVID-19 era. Mondal and Roy (2021) investigated a supply chain during COVID-19 pandemic situation. This research developed a multi-objective sustainable opened-and closed-loop supply chain under mixed uncertainty. Zarrin et al. (2022) developed a framework to assess hospitals. In another application of BSC, Ghifari et al. (2022) applied a BSC to assess hospitals in Covid 19 pandemic. Table 1 tabulates a comparative study to show the difference of current research and other reviewed paper discussed in this section.

Table 1. Comparative Study

Study	**Application of Fuzzy Logic**	**Green Strategy**	**Lean Strategy**	**Agile Strategy**	**Developing Country**
DesHarnais et al. (1990)	×	×	×	×	×
Mark et al. (1998)	×	×	×	×	×
Athanassopoulos et al. 1999	×	×	×	×	×
Hibbard et al. (2005)	×	×	×	×	×
Veillard et al. 2005	×	×	×	×	×
Ramanathan (2005)	×	×	×	×	√
Minvielle et al. (2008)	×	×	×	×	×
Groene et al. (2008)	×	×	×	×	×
Davis et al. (2013)	×	×	×	×	×
Poulos et al. (2015)	×	×	×	×	×
Weintraub and Garratt (2017)	×	×	×	×	×
Rouis et al. (2018)	×	×	×	×	√
Zare (2019)	×	×	×	×	×
Moons et al., 2019	×	×	×	×	×
Jiang et al. (2020)	√	×	×	×	×
Yang et al. (2020)	√	×	×	×	×
Kutlu Gündoğdu and Kahraman (2021)	√	×	×	×	×
Ayyildiz (2021)	√	√	×	×	×
Zarrin et al. (2022)	√	×	×	×	×
Ghifari et al. (2022)	√	×	×	×	×
This Research	√	√	√	√	√

2.6. Summary and Identification of Research Gaps

This section discusses the summary of previous studies, research gaps and novelties of this research. In summary, according to the discussed literature review, concurrent investigation of hospitals' performance with lean, agile and green strategies is not investigated yet. Additionally, as there are different measures to be applied in performance assessment of hospitals by different strategies, it is critical to develop their specific measures to save time and cost. Furthermore, with regard to MCDM nature of problem, application of mathematical techniques is necessary. As an important issue, decision makers prefer to make their judgments by linguistic expressions. In other words, with regard to fuzzy nature of decision making process, decision makers prefer fuzzy environments to express their judgments. In this regard, it is critical to consider fuzzy logic and its related tools and techniques in the problem. Furthermore, as this research considers lean, agile, and green strategies concurrently, the developed model provides an integrated score of hospital's performance. Finally, lean, agile, and green-based hospital investigation is beneficial as these issues are less investigated in developing countries. So, to fill the gap of literature, this research develops an integrated classic-Interval-valued fuzzy TOPSIS approach to compare different departments of a hospital. Table 2 tabulates performance measures of lean, agile, and green strategies. The strategies, measures and sub-measures are essential to be applied in lean, agile, and green assessment of hospitals. In other words, different metrics of each strategy are developed according to previous literature.

Table 2. Performance measures of lean, agile and green strategies

Strategy	Measure & Sample Reference	Sub-measures
Lean strategy	Waste Elimination Schonberger (2018)	Extra inventory
		Extra movement
		Waiting
		Over processing
		Transportation
		Over production
		Faults
		Human resources
	Added-value Nabelsi and Gagnon (2017)	Capacity
		On time response
		Quality
		Customer satisfaction
		Staff satisfaction
		Supplier relationship
		Total Productive Maintenance (TPM)
		Outsourcing
	Operation Flow Smoothness Militello et al. (2007)	Staff cooperation
		Top management support
		Human resource education
		Information Technology (IT)
		Equipment renewal
	Continuous Improvement Ulhassan et al. (2015)	Management and staff relationship
		Treatment process reengineering
		Performance based payment
		Total Quality Management (TQM)
Agile strategy	Responsiveness Awoke et al. (2017)	Balance of demand and supply
		Requirement forecasting ability
		Supplier selection
		Staff job satisfaction
	Competency Truong et al. (2014)	Information accuracy
		Uncertainty minimization
		Investigating the advantages and disadvantages of the hospital
		Teaching the human resource
		Service innovation
	Flexibility Truong et al. (2014)	Organization culture
		Staff flexibility
		Design flexibility
		Service flexibility
	Speed	Decreasing waiting time
		Decreasing the development time of new department

	Kessler and Glasgow (2011)	Increasing improvement of customer service
	IT	IT application for activities integration
	Gardner et al. (2019)	IT application for medicine supply integration
Green strategy	Green process	Medical wastes management
		Non-medical wastes management
		Green transportation
		Less application of hazardous materials
	Chías and Abad (2017)	Reverse logistics
		Green purchase
		Green research and development
		ISO 14001 certificate
	Green design	Energy saving buildings
		Daylight usage
	Stichler (2009)	Solar energy usage
		Healing garden
		Green design certificate

3. Research methodology

This section discusses the research methodology of this study by enlightening different steps to achieve its objectives. This research is completed in three linked phases as follows. Firstly, the critical measures of lean, agile and green strategies are investigated. To do so, a comprehensive literature review is conducted to extract the specific metrics of lean, agile and green from previous literature. Different keywords such lean, agile, green, lean manufacturing, green manufacturing, agile manufacturing, leanness, greenness, agility, and their combination with healthcare industry were applied to search related papers. Secondly, a fuzzy TOPSIS approach is developed to compare three departments of a hospital with lean, agile and green strategies. An overall overview on different departments of hospital is expected in this phase. In other words, this phase compares different departments of hospital from lean, agile and green overview. Following, the obtained results are checked by an interval-valued fuzzy TOPSIS model for further investigation. As a justification for this phase, as there are different MCDM techniques, many researchers are interested in comparing the results of these techniques for a same problem. In other words, as these approaches are completed according to the comments of experts, it is proper to reinvestigate the result to show its consistency. Therefore, this phase has applied an interval-valued fuzzy TOPSIS model to reinvestigate the results of previous phase. The required steps of each phase are discussed as follows.

Phase 1: Developing the critical measures of lean, agile and green strategies

There are different metrics to assess the performance of companies and hospitals with regard to different strategies. In this context, it is critical to develop the specific metrics of each strategy. However, as there might be many metrics, it is recommended to apply less but fit metrics to assess these strategies. In other words, using more appropriate and fit metrics is strongly preferred in comparison with a lot of unrelated metrics. Therefore, a literature review was conducted to determine the applied metrics of LM, AM, and GM to assess the performance of hospitals.

Phase 2: Developing a fuzzy TOPSIS approach to compare three departments of a hospital

Decision making models are applied to choose the best alternative amongst different choices (Mondal et al. 2022). Fuzzy logic can be applied to enrich the process of decision making (Mondal et al. 2021). This study applies TOPSIS method developed by Yoon and Hwang (1981) to compare three departments of a hospital with lean, agile and green strategies. According to Yoon and Hwang (1981), the best alternative should have the least distance from ideal solution. The linguistic values tabulated in Table 3 are applied in pairwise judgments. According to Sadollah (2018), The Membership Functions (MFs) can be of any form and shape as long as they address the applied data with required degree of memberships. Regarding the MFs selection process, it varies in different problems. In other words, with experience, it is possible to understand which shape of MF is appropriate for the problem. However, overall, Triangular MF (TMF) is one of the most encountered and practical MF. Among different MFs, the TMFs are shaped by straight lines. Hence, these straight line MFs have the benefit of straightforwardness.

Table 3. Fuzzy numbers applied for linguistic variables

Fuzzy Number	Linguistic Terms for rating of alternatives	Fuzzy Number	Linguistic Terms for weighting of alternatives
(0,0.5,1.5)	Worst (W)	(0,0.05,0.15)	Very Low (VL)
(1,2,3)	Very Poor (VP)	(0.1,0.2,0.3)	Low (L)
(2,3.5,5)	Poor (P)	(0.2,0.35,0.5)	Fairly Low (FL)
(3,5,7)	Fair (F)	(0.3,0.5,0.7)	Medium (M)
(5,6.5,8)	Good (G)	(0.5,0.65,0.8)	Fairly High (FH)
(7,8,9)	Very Good (VG)	(0.7,0.8,0.9)	High (H)
(8.5,9.5,10)	Excellent (E)	(0.85,0.95,0.1)	Very High (VH)

Hospitals are the most important section of healthcare industry. This section should be carefully investigated as many patients assess overall performance of healthcare industry according to their experience in hospitals. Among different hospitals operating in healthcare industry, many of them include numerous specialized departments such as eye, injuries, etc. In this regard, the overall performance of hospitals is directly related to its departments. In other words, different departments of a hospital contribute in its overall performance. Hence, hospitals need to develop and apply systematic approaches in their performance assessment. Additionally, as there are numerous strategies and their requirements, it is appropriate to investigate and develop appropriate metrics of each strategy to be applied in hospitals. A real world case study has been selected to show the proficiency and practicality of the model. The case study is a reputable and large hospital located in Iran. The hospital's managers were interested in considering different strategies to be applied in performance measurement process of the hospital. Initially, managers of the hospital decided to focus on famous and well-known strategies discussed in previous literature. In other words, they were interested in assessing and comparing different departments of the case study. The investigated departments are different with regard to size, functions and their other characteristics.

Assume an MCDM problem includes n alternatives of $A_1, A_2, ..., A_n$ and m criteria of $C_1, C_2, ..., C_m$. Each alternative is assessed by m criteria. Furthermore, the rankings and weights are assigned with regard to decision making matrix shown by $X(x_{ij})_{n.m}$. The $W=(w_1 , w_2 , ... , w_m)$ is the weight vectors where $\sum_{j=1}^{m} w_j = 1$. Following discusses different steps of applying TOPSIS method:

Step 1: Normalizing the decision matrix

The normalization process of decision matrix is conducted by Equation (1) as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}} \qquad i = 1 , ... , n \qquad j = 1 , ... , m \tag{1}$$

Step 2: Weighting the normalized decision matrix

The weighted normalized matrix is obtained by multiplying each column of normalized matrix with its related weights. This process is mathematically expressed in Equation (2).

$$v_{ij} = w_j \times r_{ij} \qquad i = 1 , ... , n \qquad j = 1 , ... , m \tag{2}$$

Where w_j is the weight of jth criteria.

Step 3: Ideal and non-ideal alternative

The ideal and non-ideal alternatives are defined as follows:

$$A^* = \{v_1^*, v_2^*, \dots, v_m^*\} = \left\{\left(\max_j v_{ij} \middle| j \in \Omega_b\right), \left(\min_j v_{ij} \middle| j \in \Omega_c\right)\right\} \quad (3)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_m^-\} = \left\{\left(\min_j v_{ij} \middle| j \in \Omega_b\right), \left(\max_j v_{ij} \middle| j \in \Omega_c\right)\right\} \quad (4)$$

Where Ω_b and Ω_c show the sets of benefit and cost criteria, respectively.

Step 4: Distance to ideal and non-ideal solutions

The Euclidean distance is applied to calculate the distance of each alternative from ideal and non-ideal solution. The calculation process is conducted by Equation (5) and (6).

$$S_i^+ = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^*)^2} \qquad i = 1, \dots, n \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2} \qquad i = 1, \dots, n \quad (6)$$

Step 5: Relative Closeness (RC)

The RC to the ideal solution is defined as:

$$RC_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad i = 1, 2, \dots, m \qquad 0 \le RC_i \le 1 \quad (7)$$

Step 6: Ranking the alternatives

Ranking process of alternatives is conducted based on descending order of their RC. As results are expert based, sensitivity analysis is not applicable in this research. In other words, using the comments of different experts or applying the equivalent weights follow the same steps and do not add value to the results.

Phase 3: Developing an interval-valued fuzzy TOPSIS approach

The relative weights and ranking of decision making problems are determined by fuzzy numbers. However, linguistic variables can be converted to triangular interval-value fuzzy numbers as shown in Table 4. The multiplication, addition, distance, determination of maximum and minimum of fuzzy numbers are completed using the extension of fuzzy TOPSIS method based on interval-valued fuzzy sets (Ashtiani et al. 2009).

Table 4. triangular interval-valued fuzzy numbers (Ashtiani et al. 2009)

Importance of each criterion		**Linguistic variables for the ratings**	
Very Low (VL)	[(0,0);0;(0.1,0.15)]	Very Poor (VP)	[(0,0);0;(1,1.5)]
Low (L)	[(0,0.05);0.1;(0.25,0.35)]	Poor (P)	[(0,0.5);1;(2.5,3.5)]
Medium Low (ML)	[(0,0.15);0.3;(0.45,0.55)]	Moderately Poor (MP)	[(0,1.5);3;(4.5,5.5)]
Medium (M)	[(0.25,0.35),0.5,(0.65,0.75)]	Fair	[(2.5,3.5),5,(6.5,7.5)]
Medium High (MH)	[(0.45,0.55),0.7,(0.8,0.95)]	Moderately Good (MG)	[(4.5,5.5),7,(8,9.5)]
High (H)	[(0.55,0.75),0.9,(0.95,1)]	Good	[(5.5,7.5),9,(9.5,10)]
Very High	[(0.85,0.95),1,(1,1)]	Very Good (VG)	[(8.5,9.5),10,(10,10)]

Let $\tilde{x}$ be a fuzzy decision matrix for a MCDM problem where $A_1, A_2, ..., A_n$ are n possible alternatives and $C_1, C_2, ..., C_m$ are m criteria of the problem. Therefore, the performance of A_i with regard to C_j criteria is shown by $\tilde{x}_{ij}$ as follows. Furthermore, the triangular interval-valued fuzzy numbers are shown in Figure 2.

$$\tilde{x} = \begin{cases}(x_1, x_2, x_3) \\ (\acute{x}_1, x_2, \acute{x}_3)\end{cases} \tag{8}$$

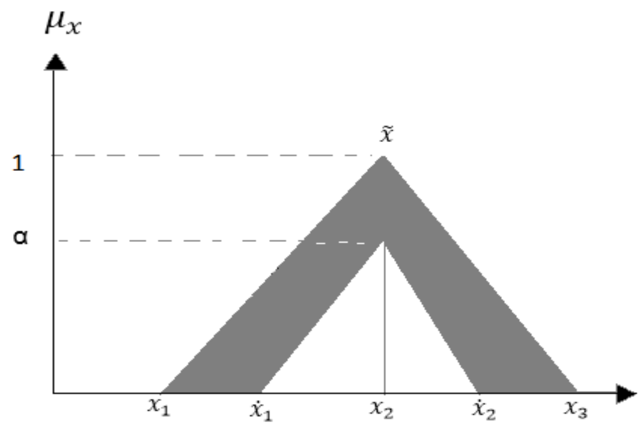

Figure 2. Triangular interval-value fuzzy numbers (Ashtiani et al. 2009)

It is also possible to show $\tilde{x}$ as $\tilde{x} = [(x_1, \acute{x}_1); x_2; (\acute{x}_3, x_3)]$. It is worthy to note that using interval-valued numbers let the experts to use lower and upper bound values as an interval for weights of criteria and the elements of decision making matrix. Furthermore, in case of group decision making circumstances with k experts, ranking of alternatives and importance of each criteria can be calculated as follows:

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots + \tilde{x}_{ij}^k\right] \tag{9}$$

$$\widetilde{w}_{ij} = \frac{1}{k}\left[\widetilde{w}_{ij}^1 + \widetilde{w}_{ij}^2 + \cdots + \widetilde{w}_{ij}^k\right] \tag{10}$$

So, with regard to this introduction on triangular interval-value fuzzy numbers, following steps are conducted for Interval Valued Fuzzy TOPSIS (IVFT) calculations:

Step 1: Normalizing the decision making matrix

For $\tilde{x}_{ij} = \left[\left(a_{ij}, \acute{a}_{ij}\right); b_{ij}; \left(\acute{c}_{ij}, c_{ij}\right)\right]$, the normalization process developed by Chen and Tzeng (2004) is applied as follows:

$$\tilde{r}_{ij} = \left[\left(\frac{a_{ij}}{c_j^+}, \frac{\acute{a}_{ij}}{c_j^+}\right); \frac{b_{ij}}{c_j^+}; \left(\frac{\acute{c}_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)\right] \qquad i = 1, \dots, n \qquad j \in \Omega_b \tag{11}$$

$$\tilde{r}_{ij} = \left[\left(\frac{a_j^-}{\acute{a}_{ij}}, \frac{a_j^-}{a_{ij}}\right); \frac{a_j^-}{b_{ij}}; \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{\acute{c}_{ij}}\right)\right] \qquad i = 1, \dots, n \qquad j \in \Omega_c \tag{12}$$

$$c_j^+ = \max_i c_{ij}, \qquad j \in \Omega_b$$

$$a_j^- = \min_i \acute{a}_{ij}, \qquad j \in \Omega_c$$

Where the normalization procedure of this approach is same as what is applied in deterministic TOPSIS method. Therefore, the normalized matrix of $\tilde{R} = \left[\tilde{r}_{ij}\right]_{n \times m}$ is the main ouptput of this step.

Step 2: Weighted normalized matrix

Considering the importance of each criteria, the weighted normalized matrix of $\widetilde{V}$ is constructed as $\widetilde{V} = [\tilde{v}_{ij}]_{n\times m}$. The $\tilde{v}_{ij} = \tilde{r}_{ij} \times \widetilde{w}_j$ is calculated by Equation (13) as follows:

$$\tilde{v}_{ij} = \left[\left(\tilde{r}_{1_{ij}} \times \widetilde{w}_{1_j}, \acute{\tilde{r}}_{1_{ij}} \times \acute{\tilde{w}}_{1_j}\right); \tilde{r}_{2_{ij}} \times \widetilde{w}_{2_j}; \left(\acute{\tilde{r}}_{3_{ij}} \times \acute{\tilde{w}}_{3_j}, \tilde{r}_{3_{ij}} \times \widetilde{w}_{3_j}\right)\right] = \left[\left(g_{ij}, \acute{g}_{ij}\right); h_{ij}; \left(l_{ij}, \acute{l}_{ij}\right)\right] \tag{13}$$

Step 3: Ideal and non-ideal solutions

The ideal and non-ideal solutions are defined as follows:

$$A^{+} = [(1,1); 1; (1,1)], \qquad j \in \Omega_b \tag{14}$$

$$A^{-} = [(0,0); 0; (0,0)], \qquad j \in \Omega_C \tag{15}$$

Step 4: The distance from ideal and non-ideal solutions

The distance from ideal and non-ideal solutions is calculated by Euclidean formula as follows:

$$D^{-}(\widetilde{N}, \widetilde{M}) = \sqrt{1/3 \sum_{i=1}^{3} \left[\left(N_{x_i}^{-} - M_{y_i}^{-}\right)^2\right]} \tag{16}$$

$$D^{+}(\widetilde{N}, \widetilde{M}) = \sqrt{1/3 \sum_{i=1}^{3} \left[\left(N_{x_i}^{+} - M_{y_i}^{+}\right)^2\right]} \tag{17}$$

Where, $\widetilde{N}$ *and* $\widetilde{M}$, are interval-valued fuzzy numbers. Furthermore, $D^{-}(\widetilde{N}, \widetilde{M})$ and $D^{+}(\widetilde{N}, \widetilde{M})$ are primary and secondary distant measures, respectively. Therefore, the distance of each alternative from ideal alternative ($[D_{i1}^{+}, D_{i2}^{+}]$) can be calculated as follows:

$$D_{i1}^{+} = \sum_{j=1}^{m} \sqrt{1/3 \left[\left(g_{ij} - 1\right)^2 + \left(h_{ij} - 1\right)^2 + \left(l_{ij} - 1\right)^2\right]} \tag{18}$$

$$D_{i2}^{+} = \sum_{j=1}^{m} \sqrt{1/3 \left[\left(\acute{g}_{ij} - 1\right)^2 + \left(h_{ij} - 1\right)^2 + \left(\acute{l}_{ij} - 1\right)^2\right]} \tag{19}$$

Similarly, the separation from non-ideal alternative is calculated by Equation (20) as follows:

$$D_{i1}^{-} = \sum_{j=1}^{m} \sqrt{1/3 \left[\left(g_{ij} - 0\right)^2 + \left(h_{ij} - 0\right)^2 + \left(l_{ij} - 0\right)^2\right]} \tag{20}$$

$$D_{i2}^{-} = \sum_{j=1}^{m} \sqrt{1/3 \left[\left(\acute{g}_{ij} - 0\right)^2 + \left(h_{ij} - 0\right)^2 + \left(\acute{l}_{ij} - 0\right)^2\right]} \tag{21}$$

Step 5: The RC

Similar to what discussed, next step of IVFT approach determines the RC by following equations:

$$RC_1 = \frac{D_{i2}^{-}}{D_{i2}^{+} + D_{i2}^{-}} \tag{22}$$

$$RC_2 = \frac{D_{i1}^{-}}{D_{i1}^{+} + D_{i1}^{-}} \tag{23}$$

Step 6: Ranking the alternatives

Final ranking of alternatives is conducted by Equation (24) as follows:

$$RC_i^* = \frac{RC_1 + RC_2}{2} \tag{24}$$

4. Results and Discussion

According to research methodology section, three linked phases are required to address different objectives of this research. The first phase of the research methodology has been addressed in Section 2. In other words, the critical metrics of lean, agile, and green strategies are extracted and presented in the literature section. Following, as discussed in research methodology section, the developed metrics of first phase should be applied to investigate the performance of a hospital. In other words, a fuzzy TOPSIS approach is developed to compare three departments of a hospital using the developed metrics. The potential results of this phase determine the best and worst departments of hospital, respectively. Finally, the obtained results are checked by an interval-valued fuzzy TOPSIS approach for further investigation in the third phase. According to the majority of previous studies, it is common to apply two or more MCDM techniques to enrich the obtained results. In other words, applying two or more MCDM techniques assists scholars to provide more generalizable results to be applied in other industries, countries, and case studies. Although the majority of previous literature apply different MCDM techniques, the third phase of this research aims to investigate the outputs of each technique. In other words, this phase aims to approve the obtained results of the second phase. Furthermore, this study investigates the potential differences of applying two MCDM approaches for a same problem. Therefore, this section has been separated based on each method.

4.1. Fuzzy TOPSIS Results

This section applies the steps of research methodology to finalize the objectives. Table 5 displays fuzzy decision matrix and weights. The simple average of fuzzy pairwise comparison matrices provided by the experts have been applied to fill this table. In other words, the values tabulated in Table 4 are calculated based on arithmetic mean of experts' judgments. The decision makers include ten experts counting doctors, nurses, staffs, workers, and other personnel that are completely familiar with different processes of the hospitals.

Table 5. Fuzzy decision matrix and weights

Department	Green			Agile			Lean		
Emergency Department	(2.4	4.1	5.8)	(3	4.7	6.4)	(2.8	4.4	6)
Burns Department	(2.8	4.4	6)	(3.4	5	6.6)	(3.8	5.6	7.4)
Eye Department	(3	4.7	6.4)	(3.6	5.3	7)	(4.2	5.9	7.6)
Weight	(0.63	0.72	0.48)	(0.62	0.72	0.57)	(0.51	0.64	0.61)

Following, this matrix is defuzzified as shown in Table 6. As a common and well-known approach, the Center Area Method (COA) which is also recognized as centroid method (Chu et al. 2002) has been applied for the defuzzification process. Next, according to research methodology, normalized matrix is displayed in Table 7.

Table 6. Defuzzified Matrix

Departments	Lean	Agile	Green
Emergency Department	4.1	4.7	4.4
Burns Department	4.4	5	5.6
Eye Department	4.7	5.3	5.9
Weight	0.34	0.35	0.31

Table 7. Normalized Matrix

Department	Lean	Agile	Green
Emergency Department	0.537	0.542	0.476
Burns Department	0.577	0.577	0.605
Eye Department	0.616	0.611	0.638
Weight	0.34	0.35	0.31

In second step, by multiplying the columns in their related weights, the weighted matrix is constructed as displayed in Table 8.

Table 8. Weighted matrix

Department	Lean	Agile	Green
Emergency Department	0.183	0.190	0.147
Burns Department	0.196	0.202	0.188
Eye Department	0.209	0.214	0.198

Following, in the third step, the ideal and non-ideal alternative are determined for considered criteria. The result of this step is provided in Table 9.

Table 9. Ideal and non-ideal alternative

Ideal and non-ideal alternatives	Lean	Agile	Green
Ideal	0.209	0.214	0.198
Non-ideal	0.183	0.19	0.147

Finally, according to steps 4-6, the distance from ideal and non-ideal alternatives is displayed in the second and third rows of Table 9, respectively. Finally, the ranking of alternatives is displayed in the last column of Table 10. According to the obtained result, eye department has the best, and the emergency department has the worst performance with regard to lean, agile and green strategies.

Table 10. Ranking of alternatives

Departments	S_j^+	S_j^-	$S_j^+ + S_j^-$	RC_i	Ranking
Emergency Department	0.062	0.001	0.063	0.010	3
Burns Department	0.021	0.044	0.065	0.683	2
Eye Department	0.001	0.062	0.062	0.992	1

4.2. Interval-valued Fuzzy TOPSIS Approach

This section discusses the obtained results of interval-valued fuzzy TOPSIS approach. According to research methodology, the interval-valued fuzzy decision matrix and weights are tabulated in Table 11. The simple average of fuzzy pairwise comparison matrices provided by the experts have been applied to fill the table. In other words, the values tabulated in Table 11 are calculated based on arithmetic mean of experts' judgments. Therefore, the representation of numbers shown in this Table are different from Table 4.

Table 11. interval valued fuzzy decision matrix and weights

Department	Lean					Agile					Green				
Emergency Department	1,	2.3,	3.8	5.3	6.3	1.9	3.06	4.6	6	5.9	1.4	2.7	4.2	5.6	6.7
Burns Department	1.4,	2.7,	4.2	5.6	6.7	2.3	3.5	5	6.3	7.5	3.3	4.3	5.8	7.1	8.3
Eye Department	1.9,	3.06,	4.6	6	5.9	2.8	3.9	5.4	6.7	7.9	3.7	4.7	6.2	7.4	8.7
Weight	0.59,	0.71,	0.81	0.87	0.93	0.41	0.52	0.6	0.66	0.71	0.45	0.57	0.7	0.83	0.86

Similar to previous approach, the decision matrix is normalized and tabulated in Table 12. Next, according to step 2, the columns of the matrix are multiplied by their weight to determine weighted matrix as tabulated in Table 13.

Table 12. Normalized decision matrix

Department	Lean					Agile					Green				
Emergency Department	0.15	0.34	0.57	0.79	0.94	0.24	0.39	0.58	0.76	0.75	0.16	0.31	0.48	0.64	0.77
Burns Department	0.21	0.40	0.63	0.84	1	0.29	0.44	0.63	0.80	0.95	0.38	0.49	0.67	0.82	0.95
Eye Department	0.28	0.46	0.69	0.90	0.88	0.35	0.49	0.68	0.85	1	0.42	0.54	0.71	0.85	1
Weight	0.59	0.71	0.81	0.87	0.93	0.41	0.52	0.6	0.66	0.71	0.45	0.57	0.7	0.83	0.86

Table 13. Weighted normalized matrix

Department	Lean					Agile					Green				
Emergency Department	0.09	0.24	0.46	0.69	0.87	0.10	0.20	0.35	0.50	0.53	0.07	0.18	0.34	0.53	0.66
Burns Department	0.12	0.29	0.51	0.73	0.93	0.12	0.23	0.38	0.53	0.67	0.17	0.28	0.47	0.68	0.82
Eye Department	0.17	0.32	0.56	0.78	0.82	0.15	0.26	0.41	0.56	0.71	0.19	0.31	0.50	0.71	0.86

According to step 3 and 4, the distance from ideal and non-ideal alternative is calculated and tabulated in Table 14. Next, according to step 5 and 6, RC and final ranking of alternatives are calculated and tabulated in Table 15. According to the obtained result, eye department is the best and emergency department is the worst section of hospital with regard to lean, agile, and green considerations.

Table 14. Distance from ideal and non-ideal alternative

Department	[D1+, D2+]		[D1-,D2-]	
Emergency Department	[2.052,	1.836]	[1.205,	1.413]
Burns Department	[1.880,	1.630]	[1.383,	1.668]
Eye Department	[1.786,	1.551]	[1.482,	1.698]

Table 15. Interval-valued RC

Department	RC1	RC2	RC_i*
Emergency Department	0.435	0.370	0.402
Burns Department	0.506	0.424	0.464
Eye Department	0.523	0.453	0.488

5. Concluding Remarks

This research developed an integrated fuzzy TOPSIS approach to evaluate different departments of a hospital. In other words, different metrics of lean, agile and green manufacturing strategy were translated to a framework to assess the performance of a hospital. In this regard, specific metrics of these strategies were developed from previous literature. Therefore, the specific metrics of lean, agile, and green strategy to assess the performance of hospitals were the main output of this phase. As discussed, different departments of a hospital are compared with regard to lean, agile, and green strategy. To do so, a classic fuzzy TOPSIS approach was developed to assess three departments of a hospital. The obtained result of this phase showed that eye department has the best performance comparing to others. In addition, the emergency department has the worst performance of hospital. The results were reassessed by an interval-valued fuzzy TOPSIS approach. Similarly, the second approach provided the same results. In other words, the order of best departments were not different in both approaches. Regarding the contribution, according to the obtained results of both approaches, different MCDM techniques might provide a same result. In other words, using simple and complex MCDM techniques did not provide different results. Furthermore, the developed methodology can be easily applied to assess and compare different departments. In addition to contribution, there are some managerial insights linked with this research. Firstly, the developed measures, metrics, and framework of this research can be applied to assess the performance of hospitals from lean, agile, and green perspectives. In other words, the developed framework provides a sole or integrated overview on performance of hospitals from lean, agile, and green perspectives. Furthermore, the results of this research can be applied to make a better decision with regard to different departments of a hospital. In other words, poor departments can be determined and different managerial decisions are implemented to improve them. As a direction for future research, other strategies can be added to enrich the model. In addition, more departments can be compared to have a better overview on the hospital.

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