Journal of King Saud University – Engineering Sciences (2025) 37:70
https://doi.org/10.1007/s44444-025-00064-0

ORIGINAL PAPER

Fuzzy analytic hierarchical process implementation for enhancing manufacturing responsiveness

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Received: 25 January 2021 / Accepted: 24 October 2021

Abstract

The emergence of Industrial Revolution 4.0 has demanded manufacturing firms across the world to adapt changes and be more responsive. In Malaysia, the current trend shows a lot of efforts that have been made by manufacturing firms to be more responsive. Responsiveness is a key practice for manufacturing forms' survival in the current competitive market. This research attempts to come up with a responsive- ness practices hierarchical guide through current manufacturing challenges and competitiveness for manufacturing firms, especially in Malaysia. Based on literature reviews, data reduction, and factor anal- ysis, the significant practices of manufacturing responsiveness have been extracted and classified accordingly. Then, the fuzzy analytic hierarchical process (FAHP) is used as a multi-criteria decision-making method to sort the practices according to the priority. Respondents were selected based on experience and trustworthiness in providing reliable responses from the Malaysian industry. After making certain revisions to the classification names, there are three classifications of manufacturing responsiveness practices (RMP—manufacturing responsiveness practices) which are information, market, and opera- tional responsiveness. To complete the research, these practices are arranged according to their priority level using FAHP. The data collected are related to the importance level of each practice. The final result suggested the top priority to be information responsiveness practices with a weightage of 0.5053, which emphasize on reliable information in communication, effective communication medium, and providing adequate organizational support. The hierarchy continued with market and operational responsiveness practices weightage by 0.4819 and 0.0128, respectively. The result is very useful for decision-makers to choose the highly impacted practices to remain competitive in the market.

Keywords Multi-criteria decision-making process · Manufacturing responsiveness · Malaysian industry

Peer review under responsibility of King Saud University.

This is a republication. The article was published in press in Journal of King Saud University – Engineering Sciences at Elsevier. https://doi.org/10.1016/j.jksues.2021.10.006.

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Abbreviations

IR	Industry revolution
FAHP	Fuzzy Analytic Hierarchical Process
RMP	Manufacturing responsiveness practices
TFN	Triangular fuzzy number

1 Introduction

Rapid developments in technology have had numerous positive impacts on the manufacturing industry. The manufacturing indus- try has experienced four revolutions from this technology develop- ment. Out of these revolutions, the Industrial Revolution (IR) 3.0 and IR 4.0 are primarily resulted from technological changes, including the introduction of computer-integrated manufacturing and automation for IR 3.0 and Internet of things for IR 4.0 (Rosdi et al. 2019; Sorooshian and Panigrahi 2020). There are many pub- lished articles that discuss

Published online: 11 December 2025

IR benefits and needs. Among the most stated benefits are increasing production capability (Szalavetz 2019); reducing human involvement by implementing automation and machine learning concepts (Rojko 2017); the innovation of product variety (Chuah et al. 2020); and improvement in energy consumption, efficiency, and operation safety (Sorooshian and Panigrahi 2020).

1.1 Research objectives

There are two main objectives of this research. The first objective is to extract the significant and relevant manufacturing responsiveness practices in the current manufacturing environment. Once the first objective is accomplished, then comes the needs to arrange the manufacturing responsiveness practices based on its priority level. Both objectives could be represented by a single framework of enhancing manufacturing responsiveness practices.

2 Literature review

It is obvious that manufacturing firms nowadays require a large amount of acquisition costs and investment for machineries and equipment to be competitive (Haleem and Javaid 2019). Manufac- turing firms with unstable and fluctuating financial states are fac- ing difficulties due to this. In Malaysia, small and medium enterprises (SME), as the biggest community business, are the most impacted in financial difficulties (Teh and Kee 2019). Looking into the numbers of lucrative IR 4.0 benefits, the Malaysian manu- facturing industry has to put extra efforts toward financial solu- tions to avoid worsening the Malaysian economy.

In addition, the current manufacturing environment has created a competitive environment in the manufacturing industry due to increasing production capability and equal product quality (Gunasekaran et al. 2019; Imran et al. 2019). The ability to meet stakeholders and market demands opens up opportunities for each manufacturing firm to compete in the market. Particularly in Malaysia, the competitiveness of Malaysian export is increased by the gross domestic product increment trend before the world pandemic coronavirus (COVID-19) happened (Idris 2019). Never- theless, the level of firms' competitiveness also depends on their adaptability on this challenging environment (Imran et al. 2019). Competitiveness and responsiveness are very closely related, where responsive practices will provide greater competitive ability.

Apart from the technological aspects, another essential is manufacturing responsiveness practices (RMP) adaptation, especially in Malaysia as the research focus (Lee et al. 2019). In the manufactur- ing industry, there are various key areas to be responsive to, such as market demand and operational performance (Shanmugan et al. 2019; Yusof et al. 2019), supply chain (Shabbir et al. 2019), export regulations and exchange rate (Choong and Khalifah 2019), and stakeholder demands (Shanmugan et al. 2019).

2.1 Responsive manufacturing practices

Effective RMP implementation has become the driving force for manufacturing forms to stay relevant in the market (Järvenpää et al. 2018). The implementation of the best RMP has been high- lighted by countries from most regions of the world. However, the significance of RMP to manufacturing firms is still at a low level in the Africa region. Some examples of the research showing the significance of RMP are listed in Table 1.

The RMP views listed in Table 1 are chosen to represent the cor- responding region across the world. RMP has been a significant fac- tor in the manufacturing industry in

Table 1 Responsive manufacturing practices worldwide

No	Country	RMP view	Reference
1	Italy (Europe)	Best practices of RMP will be beneficial for manufacturing firms during pandemic COVID-19 and IR 4.0 era	(Lepore et al. 2021)
2	Honduras (South/Latin America)	The plant responsiveness with reconfiguration systems and technologies leads to supply chain customer responsiveness as the ultimate goals	(Ortega-Jimenez et al. 2020
3	India (Asia & Pacific)	Responsiveness in production is a major factor for productivity and overall performance improvement	(Mangla et al. 2020)
4	China (Asia & Pacific)	Supply chain responsiveness mediates the environmental scanning and supply chain integration with operational performance	(Yu et al. 2019)
5	Turkey (Europe)	Supply chain responsiveness is positively associated with supply chain risk management that provides potential risk sources and appropriate strategy implemented	(Can Saglam et al. 2020)
6	Saudi Arabia (Middle East)	The foremost priority is to establish an agile responsiveness supply chain by maintainability and serviceability	(Al-Zabidi et al. 2021)
7	Zimbabwe (Africa)	The strategy formulation did not executed accordingly thus required balancing between process and responsiveness	(Mashingaidze et al. 2021)

all regions except Africa. There is still a lack of evidence of RMP study and implementation among African nations (Sharma et al. 2020).

According to the review of manufacturing responsiveness by Sharma et al. (2020), the research publication trend on manufac- turing responsiveness is increasing, whereas the desirable outcome is supply chain responsiveness to satisfy customers. Fig. 1 shows the framework developed by Sharma et al. (2020) from the system- atic review. This framework will be enhanced with the RMP that should be implemented to optimize the performance of supply chain and customer satisfaction.

2.2 Responsive manufacturing practices in Malaysia

RMP consists of several practices that could be classified into classifications. Mostly adapted from Rosdi et al. (2019), Zaki et al. (2017), and Nallusamy (2017), which have reviewed over 90 arti- cles on RMP come out with 18 RMP. Furthermore, in order to extract the relevant and significant practices out of them, data reduction and factor analysis were implemented, which resulted in the elimination of 6 RMP and the formation of the other 12 RMP into three classifications (Rosdi et al. 2019). These findings are later reformed in a hierarchical level, as shown in Fig. 2 (Mohd Rosdi et al. 2020).

The divisions among RMP are adapted from Rosdi et al. (2019) and Nallusamy (2017), but the title of each classification has been revised to avoid future misunderstanding caused by unsuitable words used (Drew and Dollery 2016). Information and market responsiveness title is identical with present research (Singh 2017; Zaki et al. 2017), where the RMP classed in them quite sim- ilar. In fact, the word information and market are clearly under- standable within the manufacturing industry (Edelman 2007). The other classification is operational responsiveness, which is related to practices during production operation and business development (Bai et al. 2019). Operational not only focuses on the manufacturing process, but it is also inclusive of all routines practiced within the firm, such as product, production support sys- tem, complying with certain requirements, innovation activity, and customer service (Trattner et al. 2019).

However, having the lists does not solve any problem. It only provides awareness of practices that should be implemented. The first objective of this research paper is achieved by the development of Fig. 2. These lists will be used in further analysis by sorting them according to the prioritization of the Malaysian manufacturing industry.

2.3 Fuzzy integration in the multi-criteria decision-making method

Fuzzy is a well-known set of theories that has been implemented in various research areas dealing with flexible and uncer- tain data. Currently, the fuzzy set of theory has been implemented in ranking, decision-making, graphic designs, arrangements, and algorithm development (Jafari et al. 2019). Its wide range of appli- cations has attracted researchers from various backgrounds to study and produce new methods integrated with fuzzy theory. The fuzzy theory has been emphasized on its ability to deal with uncertain and vagueness data (Vaishnavi and Suresh 2020). Its capability

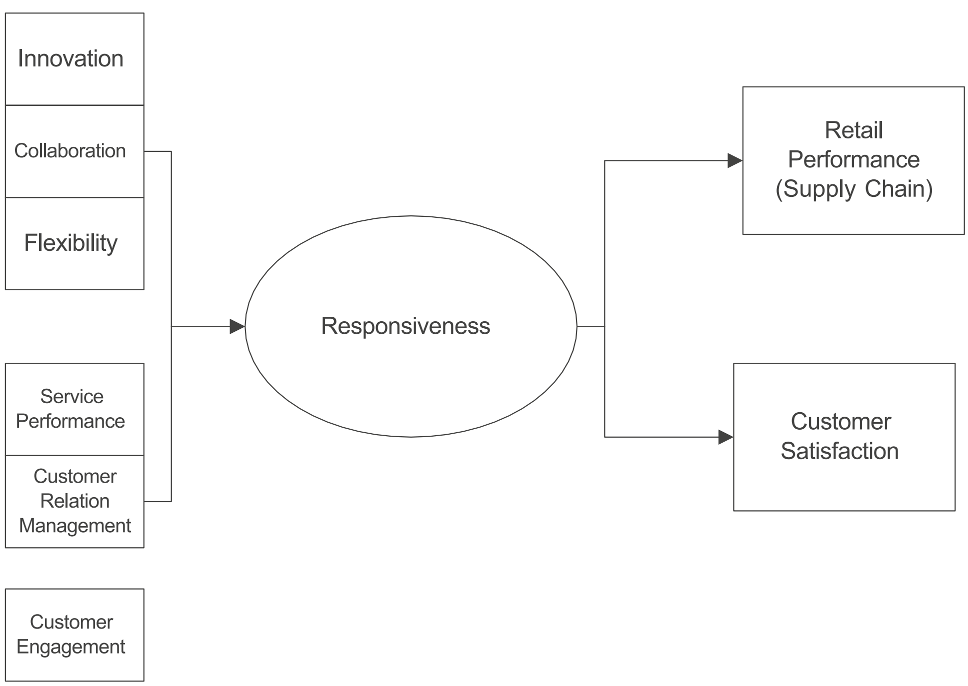


Fig. 1 Manufacturing responsiveness framework (Sharma et al. 2020)

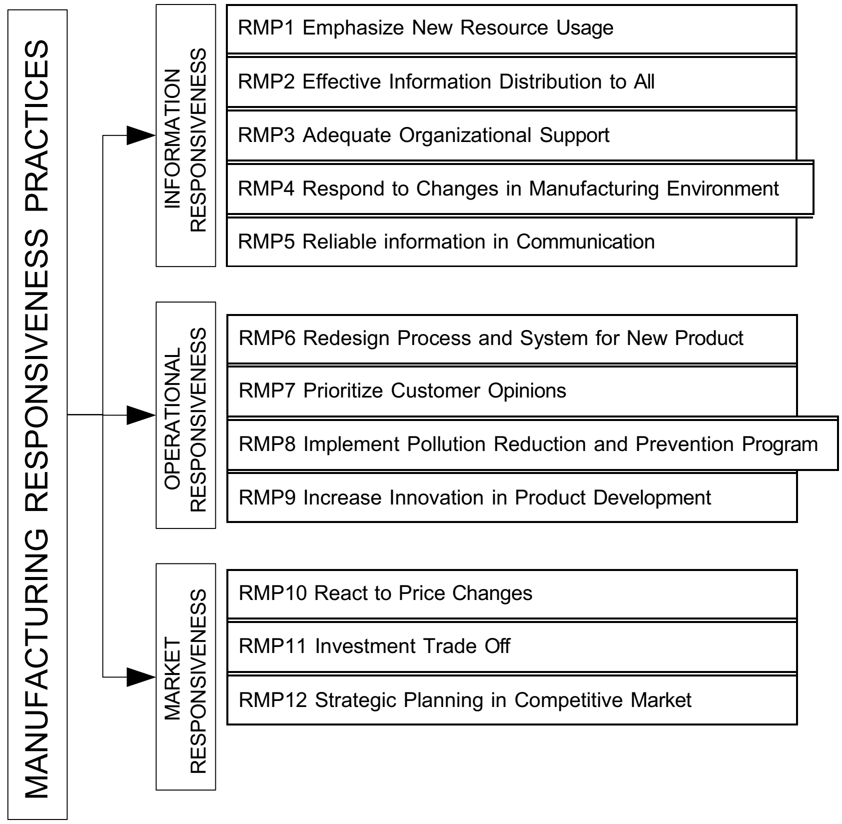


Fig. 2 Responsive manufacturing practices hierarchical level (Mohd Rosdi et al., 2020; Nallusamy 2017)

to evaluate flexible criteria with uncertain data has expressed its usefulness, which could not be done by other sets of theory (De Mol et al. 2017).

Particularly, this research will integrate fuzzy theory into a multi-criteria decision-making method, namely the analytic hier- archical process (AHP) introduced by Saaty (Wind and Saaty 1980). AHP relies on the assumption that expert personnel are able to provide absolute judgments in the pair-wise comparison (Attri and Grover 2015). AHP implemented a scaling number from 1 to 9 in the pair-wise comparison method, which will be transformed into matrices (Halim et al. 2019). Table 2 listed the standard scale used in AHP.

However, as time goes by, AHP has been criticized due to its inability to deal with respondents' judgments to a numbering scale (Soh 2010). Even though AHP used 9 scales, the argument on its judgment precision is always questionable. Then, the fuzzy theory has been integrated with AHP, which allows expansion of judg- ments into three values representing *'low,' 'medium,'* and *'high'* by transforming the judgments using the triangular fuzzy number (TFN) concept as illustrated in Fig. 3 (Tseng and Yip 2020).

Eventually, this integration, which is called fuzzy analytic hierarchical process (FAHP), has been agreed upon as a solution to the arguments as stated earlier. A fuzzy set of theories has been accepted in complex multi-criteria decision-making method and has been implemented widely in the area. The detailed transforma- tion from ordinary matrix to TFN matrix is described in the next section.

Table 2 AHP pair-wise comparison scaling (Mohd Rosdi et al., 2020)

Scale	Importance	Explanation
1	Equal	Two activities equally contribute/preferred
3	Moderate	Slightly prefers one over another
5	Strong	Strongly prefers one over another
7	Very strong	Dominance prefer over another
9	Extreme	Proven to be preferred in high dominance over another
2, 4, 6 and 8 Reciprocal of above numbers	Intermediate from above For inverse comparison	When compromise is needed

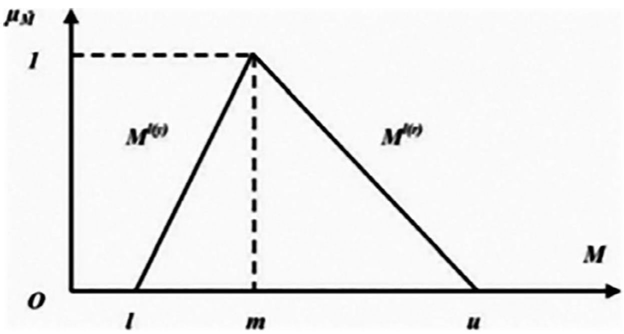


Fig. 3 Triangular fuzzy number (Tseng and Yip 2020)

3 Methodology

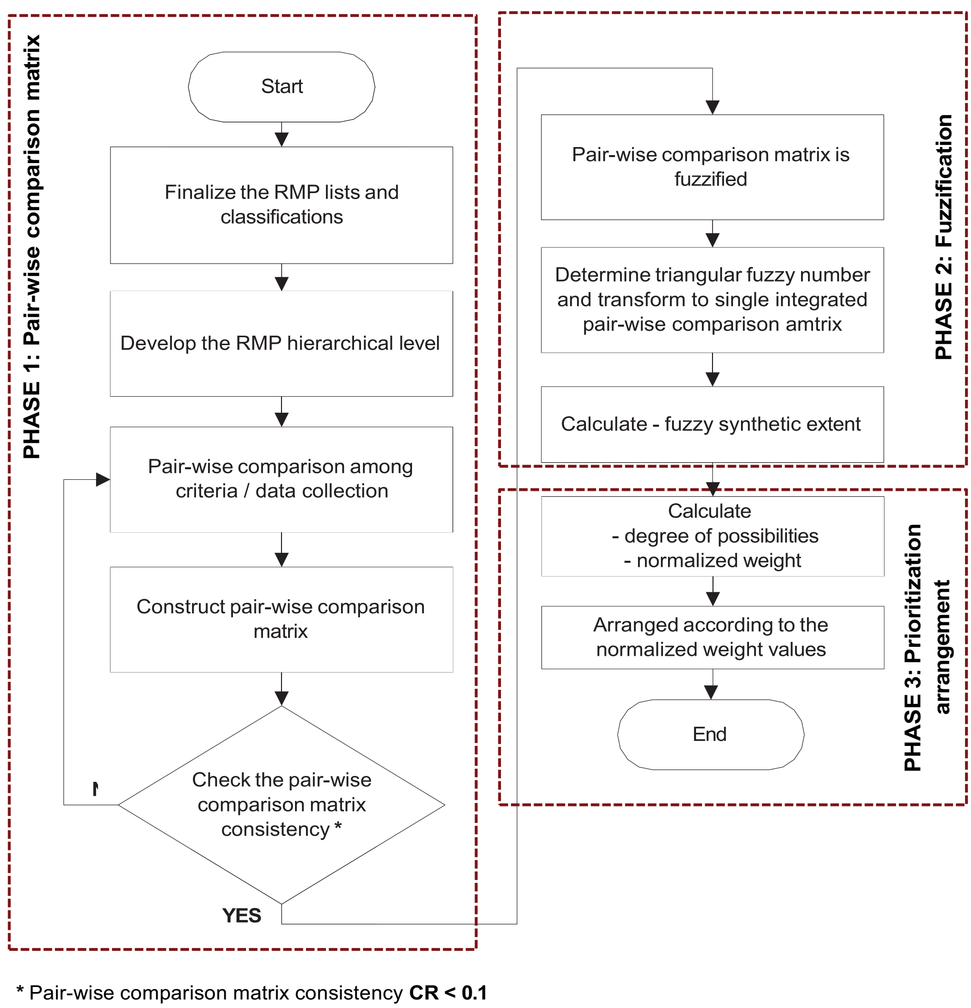
This research purpose is to provide a list that is sorted by prior- ity of RMP that are significant toward becom- ing a responsive man- ufacturing firm. Adapting the lists published from a recent article, the steps and methods used are hierarchical level, FAHP, and normalized weight calculations. The methods involved are adapta- tions from recently published articles within a similar research area. However, the adapted steps have been revised, combined, and simplified into three phases, as illustrated in Fig. 4.

3.1 Phase 1: Pair-wise comparison matrix

This research was initiated by the list of manufacturing responsiveness classifications and practices as shown in Fig. 2 constructed from a list of significant RMP. The hierarchy is useful to show the RMP lists in a more understandable manner. The hierarchical level has been used worldwide, especially in the organizational chart where it was similarly described by all people (Taherdoost and Brard 2019). Besides that, the hierarchical level also will provide a clear view on the pair-wise comparison needs and the number of matrices that will be involved in FAHP.

Then, the hierarchical level is used to construct the pair-wise comparison form. This form is used as data collection recording aid during the interview session. The pair-wise comparison form compares the importance level between

Fig. 4 Research flowchart



each RMP classification and among practices within the same classification. Similar to the ordinary survey, pair-wise comparison also implemented scaling technique. The scaling used is listed in Table 2 (Mohd Rosdi et al. 2020).

Next, the purposive sampling technique is applied where the researcher, by their own judgment, is allowed to determine the number of samples in exploratory research similar to this research (Hoeber et al. 2017; Rahi et al. 2019). The aim of purposive sam- pling is to collect a set of reliable data from experienced and knowledgeable target respondents on the research area. The review of sample size with similar research areas appeared to range from 4 to 15 samples. Particularly, in accordance with the sample size requirement and characteristics of the interviewees, this research involved six samples addressed to experts who have been identified and chosen as interviewees. After completing the data collection, the responses are transformed into a matrix dia- gram. The matrix dimension refers to the number of classifications and practices included in the pair-wise comparison. Taking opera- tional responsiveness as an example, MR2 will be asked about its importance level toward MR8, MR9, and MR10. If MR2 appeared to be very important from MR8, the scale might be 7. On the con- trary, if MR2 is less important than MR8, the scale might be 1 = 7 or any reciprocating number from 2 until 9. The same method applied for each RMP is involved. This research involves 4 matrices, whose dimensions are as follows: RMP classifications 3 × 3; information responsiveness 5 × 5; operational responsiveness 4 × 4; and market responsiveness 3 × 3.

Lastly, before proceeding to the second phase, it is required to ensure all matrices developed are consistent. In order to obtain that, Eqs. (1) and (2) are used to calculate the consistency ratio (CR). The values of random indexes are constant depending on the matrix dimension as referred to in Table 3.

$$CR = \frac{CI}{RI} \quad (1)$$

where RI = random index, CI = consistency index

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where n = matrix dimension, kmax = average value of entire criteria.

The requirement is that CR value should be less than 0.1. If the CR appeared to be 0.1 or bigger, the respective interview session needs to be done again.

3.2 Phase 2: Fuzzification process

The second phase focused on the fuzzification process and their integration toward a single integrated matrix from numbers of experts involved. The fuzzy element is adapted due to its ability to express certainty from any ambiguous and unclear judgments (Mohd Rosdi et al. 2020). In addition, FAHP also could be useful for research with small number of knowledgeable sample size available or shaky judgment and responses from the respondents (Hu et al. 2018). The standard guideline to transform normal number to TFN is shown in Table 4. Equation (3) and Table 4 have been implemented integratedly to transform the ordinary matrix into TFN matrix (Tukimin et al. 2019).

$$A_{ij(nXn)} = \begin{bmatrix} 1,1,2 & l_{12}, m_{12}, u_{12} & \cdots & l_{1n}, m_{1n}, u_{1n} \\ l_{21}, m_{21}, u_{21} & 1,1,2 & \cdots & \vdots \\ \vdots & \vdots & 1,1,2 & \vdots \\ l_{n1}, m_{n1}, u_{n1} & \cdots & \cdots & 1,1,2 \end{bmatrix} \quad (3)$$

where i and $j = 1,2,\cdots,n$; and $i \neq j$

The guideline in Table 4 is implemented in Eq. (3) before to develop TFN matrices. After that, further calculation is done using Eq. (4) until (7) (Tukimin et al. 2019).

Table 3 Value of random consistency index

Matrix dim	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Table 4 Guideline of triangular fuzzy numbers transformation (Mohd Rosdi et al., 2020)

Scale	Description	TFN	Reciprocal triangular fuzzy number l, m, u
1	Equally important	1,1,2	$\frac{1}{2}, 1, 1$
3	Moderately more important	2,3,4	$\frac{1}{4}, \frac{1}{3}, \frac{1}{2}$
5	Strongly more important	4,5,6	$\frac{1}{6}, \frac{1}{5}, \frac{1}{4}$
7	Very strongly more important	6,7,8	$\frac{1}{8}, \frac{1}{7}, \frac{1}{6}$
9	Extremely more important	8,9,9	$\frac{1}{9}, \frac{1}{9}, \frac{1}{8}$
2,4,6,8*(x = 2,4,6 or 8)	Intermediate references (as above)	x-1,x,x + 1	$\frac{1}{x+1}, \frac{1}{x}, \frac{1}{x-1}$

$$M1 + M2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$
$$M1 \otimes M2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$$
$$M1^{-1} = (l_1, m_1, u_1)^{-1} \approx \left(\frac{1}{u_1}\right), \left(\frac{1}{m_1}\right), \left(\frac{1}{l_1}\right)$$

where M1 and M2 are identical matrix dimension in TFN numbers l = lower number; m = middle number; u = upper number

$$S_i = \sum_{j=1}^{k} M_{g_i}^{j} \otimes \left\{ \sum_{i=1}^{n} \sum_{j=1}^{k} M_{g_i}^{j} \right\}^{-1} \quad (4)$$

where $M_{g_i}^1, M_{g_i}^2, \ldots M_{g_i}^m$ $i = 1,2, \ldots, n$ and.

$M_{g_i}^j (j = 1,2, \ldots, k)$ are in TFN numbers.

Si = fuzzy synthetic extent, n = matrix dimension, k = number of experts

$$M_{g_i}^j = \frac{l_{ij} + 4m_{ij} + u_{ij}}{6} \quad (5)$$

$$\sum_{j=1}^{k} M_{g_i}^j = \left(\sum_{j=1}^{k} l_j, \sum_{j=1}^{k} m_j, \sum_{j=1}^{k} u_j\right)$$

where $\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j$

$j = 1,2, \cdots, m$ *is the TFN numbers for each matrix*

$$\sum_{i=1}^{n} M_{g_i}^j \text{ is the pairwise comparison matrix in TFN numbers} \quad (6)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j\right) \quad (7)$$

At the end of the second phase, it is expected that only one integrated TFN matrix for each pair-wise comparison representing all experts has been developed.

3.3 Phase 3: Prioritization arrangement

The steps involved in the final phase are dedicated to achieving the objective of this research. Through this phase, the degree of possibility will be calculated for each RMP by Eq. (8) (Mohd Rosdi et., 2020).

$$V(S_1 \geq S_2) = \begin{cases} 1, \text{if} m_1 \geq m_2 \\ 0, \text{if} l_2 \geq u_i \\ \frac{l_2 \geq u_i}{(m_1 - u_i) - (m_2 - l_2)}, \text{otherwise} \end{cases} \quad (8)$$

where S1 and S2 = the fuzzy synthetic extent values of respective elements V = the degree of possibilities.

Lastly, the values of V obtained are converted into normalized weight value to determine the percentage or index value before being sorted and arranged according to the priority level.

4 Results

This section will discuss the results that were obtained by referring to the methods described in the previous section. The example shown in this section is the response from Expert_1 only, while similar steps were also done to the other five experts' responses. However, the final result included all the gathered.

4.1 Phase 1: Pair-wise comparison matrix

Originated from the responses from six identified experts, pair-wise comparison matrices responded by the six experts are used as the primary data to be processed. This means four sets of matrices will be developed from each expert's responses with respective matrix dimensions as stated.

Table 5 shows the responses from Expert_1 on the pair-wise comparison in matrix form. Referring to the responses, for example, stated that information and market responsiveness are more important than operational responsiveness by 5 levels. Furthermore, among market responsiveness practices, the strategic planning implementation in a competitive market appeared to be the most important for Expert_1.

4.2 Phase 1: Pair-wise comparison matrix consistency

As presented in Fig. 1 research flow, it is required to ensure that all matrices for all experts are consistent before being able to take on the second phase. Here, Eqs. (1), (2), and Table 3 are applied. From the sample matrices of Expert_1 in Table 5, operational responsiveness is taken as an example here with 4 × 4 matrix dimension.

$$CI = \frac{4.1182 - 4}{4 - 1} = 0.0394$$

$$CR = \frac{0.0394}{0.89} = 0.044$$

According to published articles, the CR value must be less than 0.1 to be considered consistent (Mohd Rosdi et al. 2020). The calculation above proves that the matrix is consistent and able to undergo further steps. In summary, all pair-wise comparison matrices have been found to be consistent.

4.3 Phase 2: Fuzzy transformation

Phase 2 begins with the transformation of the ordinary matrix to TFN matrix form. This transformation is done by embedding the guideline from Table 4 into Eq. (3). Table 6

Table 5 Pair-wise comparison matrix for Expert_1

Hierarchy stage	Pair-wise comparison matrix
Manufacturing responsiveness (3 classifications)	$\begin{bmatrix} 1 & 1/5 & 1/5 \\ 5 & 1 & 1/2 \\ 5 & 2 & 1 \end{bmatrix}$
Operational responsiveness (4 practices)	$\begin{bmatrix} 1 & 1/3 & 5 & 1 \\ 3 & 1 & 3 & 2 \\ 1/5 & 1/3 & 1 & 1/3 \\ 1 & 1/2 & 3 & 1 \end{bmatrix}$
Market responsiveness (3 practices)	$\begin{bmatrix} 1 & 1 & 1/5 \\ 1 & 1 & 1/5 \\ 5 & 5 & 1 \end{bmatrix}$
Information responsiveness (5 practices)	$\begin{bmatrix} 1 & 7 & 3 & 1 & 1 \\ 1/7 & 1 & 1 & 1/4 & 1/5 \\ 1/3 & 1 & 1 & 1/2 & 1/3 \\ 1 & 4 & 2 & 1 & 1/2 \\ 1 & 5 & 3 & 2 & 1 \end{bmatrix}$

presents TFN matrix for the sample pair-wise comparison matrix.

Once the TFN matrices have been developed for all pair-wise comparison matrices, it is time to obtain a matrix that integrates all six experts. In order to obtain that, Eqs. (5), (6), and (7) are implemented; meanwhile, the basic mathematical operations for matrix are reminded in Eq. (4). This step is also known as fuzzy synthetic extent or Chang's extent analysis as the founder of this method (Deng 2017). This method consisted of row and column sum besides the equations as stated. The outcome of this step is the l, m, and u numbers representing each practice in the matrix. The sample results are shown in Table 7.

Similar to phase 1, steps involved in phase 2 also have been done to the other matrices within this research area, which is RMP hierarchical level. By obtaining fuzzy synthetic extent values for all 4 matrices involved, phase 2 of this research has been completed.

4.4 Phase 3: Degree of possibilities

All steps in phase 3 aimed to rank all the practices involved. The steps begin with the determination of degree of possibilities where Eq. (8) is applied. Still stick with the same sample, operational responsiveness, Table 8 shows the results.

The method as shown in Table 8 is referred to Eq. (8), which consists of method and result toward the degree of possibilities value determination. The result stated that the

Table 6 Triangular fuzzy number matrix form

Hierarchy stage	Triangular fuzzy number matrix
Manufacturing responsiveness (3 classifications)	$\begin{bmatrix} 1,1,2 & \frac{1}{6},\frac{1}{5},\frac{1}{4} & \frac{1}{6},\frac{1}{5},\frac{1}{4} \\ 4,5,6 & 1,1,2 & \frac{1}{3},\frac{1}{2},1 \\ 4,5,6 & 1,2,3 & 1,1,2 \end{bmatrix}$
Operational responsiveness (4 practices)	$\begin{bmatrix} 1,1,2 & \frac{1}{4},\frac{1}{3},\frac{1}{2} & 4,5,6 & \frac{1}{2},1,1 \\ 2,3,4 & \frac{1}{3},\frac{1}{2},1 & 2,3,4 & 1,2,3 \\ \frac{1}{6},\frac{1}{5},\frac{1}{4} & \frac{1}{2},1,1 & 1,1,2 & \frac{1}{4},\frac{1}{3},\frac{1}{2} \\ 1,1,2 & 1,1,2 & 2,3,4 & 1,1,2 \end{bmatrix}$
Market responsiveness (3 practices)	$\begin{bmatrix} 1,1,2 & \frac{1}{2},1,1 & \frac{1}{6},\frac{1}{5},\frac{1}{4} \\ 1,1,2 & 1,1,2 & \frac{1}{6},\frac{1}{5},\frac{1}{4} \\ 4,5,6 & 4,5,6 & 1,1,2 \end{bmatrix}$
Information responsiveness (5 practices)	$\begin{bmatrix} 1,1,2 & 6,7,8 & 2,3,4 & \frac{1}{2},1,1 & \frac{1}{2},1,1 \\ \frac{1}{8},\frac{1}{7},\frac{1}{6} & 1,1,2 & \frac{1}{2},1,1 & \frac{1}{5},\frac{1}{4},\frac{1}{3} & \frac{1}{6},\frac{1}{5},\frac{1}{4} \\ \frac{1}{4},\frac{1}{3},\frac{1}{2} & 1,1,2 & 1,1,2 & \frac{1}{3},\frac{1}{2},1 & \frac{1}{4},\frac{1}{3},\frac{1}{2} \\ 1,1,2 & 3,4,5 & 1,2,3 & 1,1,2 & \frac{1}{3},\frac{1}{2},1 \\ 1,1,2 & 4,5,6 & 2,3,4 & 1,2,3 & 1,1,2 \end{bmatrix}$

Table 7 Fuzzy synthetic extent value for operational responsiveness

No	Practice	l	m	U
1	Redesign process and support system for new product	0.1145	0.2204	0.4409
2	Prioritize customer feedback on product or service provided	0.2411	0.4856	0.8802
3	Integrate pollution reduction and prevention in operation	0.0594	0.0986	0.2324
4	Encourage innovation among employees on product development	0.0971	0.1954	0.3992

Table 8 Degree of possibilities for operational responsiveness

Element		Condition (1) (m_1 2: m_2)	Condition (2) (l_2 2: u_1)	Condition 3 Otherwise	Degree of possibility (lowest value)
MR2	MR2 2: MR8	False	False	0.430	0.4296
	MR2 2: MR9	1	False	False	
	MR2 2: MR10	1	False	False	
MR8	MR8 2: MR2	1	False	False	1
	MR8 2: MR9	1	False	False	
MR9	MR8 2: MR10	1	False	False	0
	MR9 2: MR2	False	False	0.492	
	MR9 2: MR8	False	0	False	
	MR9 2: MR10	False	False	0.583	
MR10	MR10 2: MR2	False	False	0.919	0.3527
	MR10 2: MR8	False	False	0.353	
	MR10 2: MR9	1	False	False	

highest possibility is MR8 with 100% followed by MR2, MR10, and MR9. This arrangement also represents the priority level in descending order. Furthermore, the degree of possibilities of MR9 appeared as 0. In this situation, researchers have two options of decision to make. MR9 could be directly eliminated from the research or still considered to be included in the research with the lowest priority level.

Particularly, in this research, a practice from each RMP classification has 0 degree of possibilities, which are MR15 (respond to changes in manufacturing environment), MR7 (investment tradeoff), and MR9 (implement pollution reduction and prevention). The decision has been made to let these practices remain in the final result with a suitable legend stating their condition.

4.5 Phase 3: normalized weight

Before completing this research, the degree of possibilities is converted into normalized weightage, where it represents the percentage value. This step is shown in Table 9.

As stated earlier, the sequence is similar to the descending degree of possibilities. The determination of normalized weight of all four matrices completed this research. The complete priority sequence of RMP is elaborated on in the next section.

Table 9 Normalized weight calculation

Practice	Degree of possibilities, V	Normalized weight, $W = \frac{V}{\sum V}$	Priority sequence
MR2	0.4296	0.2410	2
MR8	1	0.5611	1
MR9	0	0	4
MR10	0.3527	0.1979	3
Sum, $\sum V$	1.7823		

5 Discussion

This research considers the enhancement of manufacturing responsiveness practices aiming toward supply chain responsiveness and improving customer satisfaction. Adapting the practices and its classification from the Malaysian manufacturing firms' point of view (Rosdi et al. 2019), FAHP is applied as a multicriteria decision-making method to arrange the RMP by their priority level. Table 10 shows the results from those methods.

Table 10 presents the values of normalized weight for RMP classifications and their practices, which have been sorted in descending order. Among the three classifications of RMP, information responsiveness ranked as the top priority before market and operational responsiveness. However, the difference of normalized weight between information and market responsiveness is very small. Nevertheless, information still ranked first. Within information responsiveness, three top-ranked practices appeared to be weightage by small differences between them. Its prioritization arrangement started with MR18 (reliable information in communication), MR11 (effective information medium used to all), MR14 (adequate organizational support), MR5 (emphasize new resource usage), and MR15 (respond to manufacturing environment changes), respectively. As the top two of the practices appeared to be related to information management, this finding has aligned with other researchers that emphasized the importance of information (Imran et al. 2019; Li et al. 2019; Yusup 2017). It emphasized on the role of reliable information distributed using the effective medium that will have great impact while avoiding any misacting that lead to negative impacts. In addition, information management also caused the existence of barrier between regions in IR 4.0 adaptation (Raj et al. 2020).

Market responsiveness, which placed second emphasis on strategic planning in a competitive market, by dominant weightage value of 0.860. The last classification is operational responsiveness, where it is recommended that manufacturing firms to continue providing good support and reputation for customers (Abualsauod and Othman 2019). This could be achieved by putting customers' opinions first on any area. Operational responsiveness is involved with components that are manageable by manufacturing firms.

There are two points to be highlighted from the result findings as shown in Table 10. Firstly, there are three practices, each practice for each classification, with a 0 value of normalized weight. These practices ranked last in their respective classification, which is still considered to hold significance in this research. The second point is regarding the action that should be taken from the arrangement of RMP classifications. The proper action is to prioritize all the practices of information responsiveness, then market and operational responsiveness orderly. Yet, if the situation happened within the areas that are strongly related to market or operational responsiveness, it could be the priority-based on-site persons' judgment.

Toward the end of this research, it is believed that the findings will be more understandable through framework development. The framework as shown in Fig. 5 is an RMP-enhanced version adapted from Sharma et al. (2020) as presented in Fig. 1. Figure 5 highlights the manufacturing responsiveness part from the original version by determining and organizing the practices considering its priority level.

Manufacturing responsiveness is a reaction or process in which its inputs come from two divisions: process-based (innovation, collaboration, and flexibility) and customer-based (service performance, customer relation management, and customer engagement). Then, manufacturing responsiveness is expected to produce two outcomes, which are improvement in retail performance or supply chain and customer satisfaction. These outcomes are desirable for any manufacturing firms, which also symbolized the firms' overall performance.

In the RMP eclipse, as shown in Fig. 5, it appeared that information and market responsiveness have bigger circles and are positioned before the operational responsiveness. Eventually, these findings could be related to both division of inputs where information and market responsiveness practices are corresponding to them. After that, operational responsiveness practices are affected from those practices included in information and market responsiveness, thus determining the framework output, retail performance or supply chain, and customer satisfaction.

Table 10 Priority arrangement for manufacturing responsiveness practices

Criteria	Seq	Class	Elements	Normalized weight
Manufacturing responsiveness	1	Information responsiveness 0.5053	Reliable information in communication	0.3123
			Effective information distribution to all	0.2762
			Adequate organizational support	0.2679
			Emphasize new resource usage	0.1435
			Respond to changes in the manufacturing environment	0
	2	Market responsiveness 0.4819	Strategic planning in competitive market	0.8600
			React to price changes	0.1400
			Investment trade-off	0
	3	Operational responsiveness 0.0128	Prioritize customer opinion	0.5611
			Redesign process and system for new product	0.2410
			Increase innovation in product development	0.1979
			Implement pollution reduction and prevention program	0

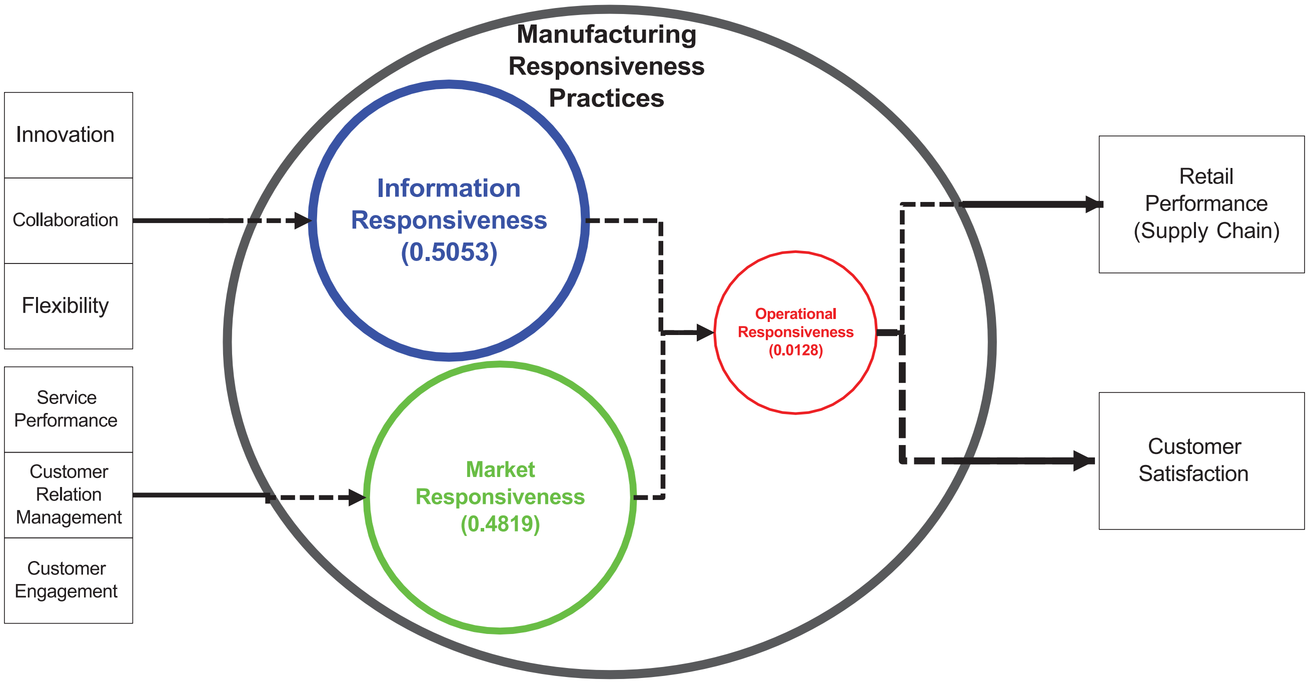


Fig. 5 Manufacturing responsiveness practices enhancement framework

Even though the framework shows that operational responsiveness practices determine the output performance, information and market responsiveness practices are more important. Thus, information and market responsiveness practices have been prioritized before operational responsiveness practices. The effective combination practices of these three RMP will result in supply chain responsiveness and customer satisfaction improvement.

6 Conclusions

In this research, the significant RMP has been determined classified under three main classifications, which are information responsiveness (5 practices), market responsiveness (3 practices), and operational responsiveness (4 practices), respectively, on their priority level. The arrangement of these RMP by classifications and priority is merged and suited to be compatible with the responsiveness framework developed by Sharma et al., (2020). This resulted on the development of an enhanced responsiveness framework highlighted on the RMP that should be included in the responsiveness boundary. The combination implementation of right RMP driven by the system inputs will provide manufacturing firms improvement in retail and supply chain performance and customer satisfaction. These two outputs also determine the manufacturing firms' overall performance. In the future, this research could be done with different demographics and cover larger areas.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mohd Noor Hanif Mohd Rosdi, Wan Hasrulnizzam Wan Mahmood, Muhammad Ashlyzan Razik and Seri Rahayu Kamat. The first draft of the manuscript was written by Mohd Noor Hanif Mohd Rosdi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This research was co-funded by Universiti Teknikal Malaysia Melaka (UTeM) under the FRGS Grant (FRGS/2016/FTK-AMC/F00324) and MyPhD Grant of Ministry of Education and Majlis Amanah Rakyat (MARA).

Data availability The data that support the findings of this study are available but with restricted access to the people within the organization at https://maranet-my.sharepoint.com/my?id=%2Fpersonal%2Fnoorhanif%5Fmara%5Fgov%5Fmy%2FDocuments%2FPhD%20Hanif%2FContinuos%20learning%2FConsistency%20FAHP&ga=1.

Declarations

Competing Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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