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Abstract: Improving the method for selecting risk-based competing improvement strategies has equal importance with failure risk quantification in the FMEA methodology. Nevertheless, there are few studies which focus on this issue. Furthermore, the influence of factors relating to the business environment which may support or derail improvement efforts is not considered in previous studies. In order to address these limitations, a model is proposed in which the impact of environmental factors is considered by integrating SWOT analysis into the FMEA method in order to support the appraisal of competing risk-based improvement efforts. The impact of SWOT variables is deployed using a decision support model based upon the benefit, cost, opportunity, risk and organisational readiness index (BCOR2) approach in order for the FMEA team to select from competing corrective actions. A case example from industry is provided in which the proposed model is applied. This example illustrates that this new model contributes successfully to good practice by identifying the most appropriate corrective action option to take and improves upon the decisions provided by existing developments of the FMEA methodology.

Keywords: FMEA; SWOT analysis; BCOR; organisational readiness; corrective action.

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1 Introduction

As a sector which is having growing contribution to global economy, delivering reliable service operation is important for sustaining future economic growth (Gėcky et al., 2010; Zaman and Anjalin, 2011). At the other side, uncertainty in business environments enforces business practitioners to develop tools and methodologies to consider the impact of business uncertainty to prevent derailment of business operations (Wielle et al., 2011). In this context, innovativeness in rectifying service quality problems is important for sustaining the business operation and FMEA is often applied as a risk appraisal tool (Hensley and Utley, 2011). By using FMEA, business practitioners can evaluate potential critical business failures and find appropriate ways to prevent the escalation of their business losses. Within the FMEA approach, responding appropriately with corrective actions to identified risks is as important as assessing the score of the risk priority number (RPN). Approaches such as the use of cost-benefit analysis (CBA), Pareto chart and cause and effect matrix can be used in selecting improvement initiatives as surveyed by Bañuelas et al. (2006) as cited in Marriot et al. (2013). However, owing to its simplicity and ease for use for practical purposes, the RPN which commonly based on the 1–10 ordinal scale of failure occurrence, detect ability and severity ratings is still the most commonly used basis for ranking the risk of failure modes that demand immediate actions (Ram, 2013). Nevertheless, relying only on the RPN Index as the basis for selecting improvement initiatives has serious limitations. In particular, ignorance of the relative importance of the RPN constituting factors in accessing criticality of failure mode, the inability to measure the effectiveness of corrective action implemented and the inability to measure the economic impact of failure occurrences are often suggested as key weaknesses. Prior studies have addressed these limitations by using various methods such as fuzzy logic, costs basis, grey theory as represented by Liu et al. (2012).

Similarly, many attempts have been proposed to improve the quality of improvement strategy selection in risk-based improvement framework. For example, Niu et al. (2009) use grey theory to rank corrective actions by considering some of its corresponding factors such as implementation time and implementation cost, the estimated change of the RPN prior and after implementing corrective action, its probability of success and its effects. Sachdeva et al. (2008) present an improved maintenance decision selection methodology for ranking criticality of equipment failures based on multi factors by using AHP instead of relying on the RPN in FMEA. Arunranj and Maiti (2010) describe a model to select maintenance strategies based on risk of failure and maintenance cost by integrating AHP and goal programming methods. Kumar and Chaturvedi (2011) demonstrate the use of fuzzy logic and approximate reasoning approaches to prioritise maintenance task selection for the critical equipment failures in a steel rolling mill. Rewilak (2011) introduced FMEA risk overload index (ROI) and detection overload index (DOI) as means to measure effectiveness of FMEA implementation measures. Braglia et al. (2013) embody integer linear programming into reliability centred maintenance in order to identify suitable maintenance strategies to overcome critical failure modes in a paper mill. Marriot et al. (2013) use the integration of process activity mapping (PAM) and FMEA as basis for process improvement prioritisation in a low volume manufacturing setting. Wang et al. (2014) utilise a failure propagation graph as a means of advancing failure rectification methodology by considering the interrelationship among failures using the example of a CNC machine.

The outcomes of these studies focus on improving the quality of the corrective action selection at the process level but do appear to be less strong in considering the impact of the factors associated with the business environment. This is particularly important for practitioners who are using the FMEA approach to address the root causes of business problems. From this wider perspective, it is possible that the decision maker may overlook the positive impacts and underestimate the negative impacts of environmental factors when appraising competing improvement strategies. Consequently, this situation requires the integration of strategic assessment tools within the FMEA approach in order to strengthen the usefulness of FMEA when considering the impact of business environment factors in risk-based improvement decision making.

Considering such limitations and the scarcity of prior research into improving the quality of risk responses suggested by Seyedhoseini and Hatefi (2009), this study explores the use of a model that integrates SWOT analysis, a commonly used strategic assessment tool, into the FMEA method. The overall objective is to provide a research contribution comprising of an improved approach to corrective action selection when a number of potential actions are available. In order to do this, the model incorporates a quantification (i.e., scoring and weighting) of SWOT analysis variables to represent the impact of business environment factors. These are then integrated in to a decision support model which uses a *benefit*, *opportunity*, *cost*, *risk and organisational readiness index* (known as BCOR2) approach. The remaining part of this study is presented as below:

In Section 2, an overview of FMEA and SWOT analysis is presented and followed by a model formulation to estimate the impact factor of SWOT (IF) variable in Section 3. In Section 4, by using the BCOR2 model, corrective action index (CAI) which represents the FMEA team preference in choosing competing CAs is formulated. In Section 5, illustrative example in using quantitative SWOT analysis for prioritisation of service FMEA-based corrective actions selection is provided. At last, discussions and managerial implications from the illustrative case study are presented in Section 6. Section 7 relates to conclusions and opportunities for further investigation.

2 Overview of FMEA and SWOT analysis

2.1 FMEA

Born from military sector in the 1950s, FMEA can be defined as a risk appraisal tool for the occurrence of critical failures which aids attempts to propose solutions to avoid the recurrence of the failures in the future. In FMEA, criticality of a failure effect is measured by the metric known as RPN. The RPN is the product of severity failure ratings, detection of failures ratings, and occurrence of failure ratings. For detailed definitions, classifications, and criteria of the ratings can be referred to such as Chang and Sun (2009). By using and updating the findings from FMEA implementation, company can obtain invaluable failure knowledge in tackling problems in their future business operation. Among other quality improvement tools, FMEA has special characteristics as it enables decision makers to rank the risk of critical failure occurrence and attempted finding appropriate ways for its alleviation. Due to its beneficial impacts, the FMEA methodology is continuously developed and applied to many different industries such as car battery (Khorshidi et al., 2013), stainless steel tube (Bevilacqua et al., 2011). Furthermore, its applications are getting more versatile in non-product design and knowledge management (Sivakumar et al., 2008). For example, FMEA is applied as a means to portray the severity of defective service provision based on the calculation of service loss in a passengers transportation service (Jeegadeshan et al., 2007). In healthcare, Ookalkar et al. (2009) use FMEA to map critical failure modes in a haemodialysis process and propose relevant corrective actions to mitigate the adverse effects to patient safety. In foodstuffs, Ozilgen (2010) uses FMEA to identify and rank critical failure modes affecting the safety and quality of confectionary products for consumers. In consumer goods trading, Chuang (2010) uses FMEA to estimate a disservice index for hypermarket service provision derived from SERVQUAL's service quality dimensions. In an attempt to improve performance of military logistics, Chapman et al. (2012) use FMEA to reveal the cause of lead time variability. Waterworth and Eldridge (2011) develop a model of FMEA to appraise criticality of failure modes in the e-commerce environment and propose corrective measures for their alleviation. To prevent potential loss in service outsourcing, Nassimbeni et al. (2012) use FMEA to highlight the risk factors and corresponding preventative measures in service outsourcing/off shoring.

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In an attempt to strengthen the capability of FMEA, integration with other improvement approaches is becoming more prevalent. For example, Tanik (2010) integrates quality function deployment (QFD) with FMEA for assuring the quality of an order handling process in food product packaging activities. Khrisnaraj et al. (2012) present a model of total FMEA in which quality problems in foundry product manufacturing are addressed holistically by integrating all the departments in finding and reducing the risks of failure. Mariajayaprakash and Senthilvelan (2013) integrate root cause analysis (RCA), FMEA and Taguchi methods to rectify machinery problems in the sugar processing industry. Chen (2013) similarly integrates RCA and FMEA to develop a model for autonomous maintenance to improve productivity in the semiconductor manufacturing industry.

Adaptations of FMEA to accommodate specific decision making applications are also becoming more common. For example, Chen and Wu (2013) present a modified FMEA as a means of appraising the risk in selecting suppliers within the context of a supply chain while Lee and Chang (2011) position FMEA as means to rank problem criticality in a continuous improvement framework that combines the theory of constraints (TOC), RCA and Six Sigma.

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2.2 SWOT analysis

The strengths, weaknesses, opportunities and threat (SWOT) analysis is a strategic assessment tool which enables an organisation to understand its internal and external strengths and weaknesses and to adjust its strategic position by identifying any potential benefits based on the recognition of opportunities and threats. Al-Rousan and Qawasmeh (2009) define *strength* in SWOT analysis as "any organisational characteristics that can be used to compete against their competitors". According to Laaksolahti (2005), some organisational characteristics such as talent, speed, collaboration, shared mind-set and coherent brand identity, accountability, learning, leadership, customer connectivity, innovativeness and efficiency can be organisational strengths. Floris and Yilmaz (2010) define *weakness* in SWOT analysis as "any organisational capability shortage which may make organisations fail to compete against their competitors or any organisational attributes which company does not do well". Both strengths and weaknesses variables are located in the internal company environment and are thus easier to control and manage than threats and opportunities which usually come from external environment. According to Trzcieliňski and Trzcieliňska (2011), *opportunity* in SWOT analysis is defined as "any internal and external favourable factors which can be solutions to the problems faced by companies". Meanwhile, *threats* are defined as "any unfavourable factors which hinder the achievement of company objectives".

Consequently, SWOT analysis classifies two important factors of business system:

- *internal factors:* the internal strengths and weaknesses of the company
- *external factors:* the opportunities and threats represented by the company's external environment.

With regard to the influence of internal and external factors, strength and opportunity variables have a positive impact on the organisation while the existence of weakness and threat variables has a negative impact. By using SWOT analysis, organisations may estimate what internal and external business factors may occur and are harmful or beneficial to their businesses. Thus, they may take preventative measures to avoid any potential losses or to reap any potential benefits from those occurrences. Owing to its beneficial impact for decision makers in establishing strategy, SWOT Analysis has been integrated into a variety of decision making tools such as AHP,ANP, and BSC in studies as described by Ghazinoory et al. (2011) and with engineering design and economic management tools such as QFD, NPV and pay back method as exemplified by Frank et al. (2013). As discussed earlier, many studies have already been presented to improve the capability of FMEA by integrating it with other tools and, similarly, the integration of SWOT analysis with other decision support tools has been proposed. Nevertheless, none of the previous studies has focused on improving the capability of FMEA by considering the impact of the business environment in proposing corrective or preventative measures. One solution to this limitation which has not previously been investigated could be to integrate SWOT analysis into the FMEA methodology. For this to be successful, correctly quantifying SWOT variables is extremely important (Helms and Nixon, 2010) as decision makers may still wrongly select appropriate strategies if they assume each of SWOT variables has equal importance. Consequently, it is necessary to establish a model to quantify the impact of SWOT variables by considering organisational maturity, organisational resilience, and organisational ability to utilise resources in exploiting the strength variable and avoiding the weakness variable. This is missing in SWOT quantification studies and is a clear justification to develop a new model for appraising the weight of SWOT variables.

3 Quantifying the impact factor of SWOT variables – model development

As introduced earlier, quantifying the impact factor of SWOT variables is a basis for considering impact of business environment factors. Taking into account that the classification and categorisation of SWOT variables remains an unresolved issue in utilising SWOT analysis (Helms and Nixon, 2010), some underlying assumptions and notation used in this study are described below:

1. The occurrence of each SWOT variable is independent of the others. This assumption is based on idea that without holding assumption 1, FMEA users will find difficulty in determining impact of every SWOT variable.
2. Every single opportunity occurrence will only affect one economic benefit. Similarly, each threat will also yield into one single loss. The assumption 2 is used to simplify calculating the magnitude of the impact factor of each of the SWOT variables.
3. The passage of time as a determining factor for SWOT variable recognition is ignored. Considering that the determination of the SWOT variable is time dependent should be neglected in assigning the status of SWOT variables in order to avoid the confusion of the status of each SWOT variable when the SWOT Analysis is carried out.

The notation method adopted for the variables is as follows:

O_k opportunity variable k

IFO_k impact factor of opportunity variable k

T_l threat variable l

IFT_l impact factor of threat variable l

S_m strength variable m

IFS_m impact factor of strength variable m

W_p weakness variable p

IFW_p impact factor of weakness variable p

BCA_{ik} benefit of implementing corrective action i for failure mode k

$PSCA_{ik}$ preference score to select corrective action i to failure mode k

$ICCA_{ik}$ implementation cost of corrective action i to failure mode k

OCA_{ik} opportunity to corrective action i to failure mode k

RCA_{ik} the risk of implementing corrective action i to failure mode k

EO_k expected value of opportunity variable k

MO_k company's maturity index to the opportunity variable k

$ORCA_{ik}$ organisational readiness to implement correction action i to failure mode k.

With m, p, k, l = 1, 2, 3,….

3.1 Impact factor of opportunity variables

Based on ultimate company's goal in obtaining business benefit, the impact factor of opportunity variables can be estimated based on their possibility to trigger numerous economical and operational benefits (Lee, 2010). Nevertheless, besides the expectation of economic benefit, the company must also consider its resources capability and maturity in recognising and utilising the opportunity. No matter how big the opportunity variable is, its corresponding impact will be low when the scale of organisational maturity in observing and chasing it is low. From this point of view, the attractiveness of an opportunity variable equals to the expected economic benefit that may occur and the organisational maturity index in recognising the opportunity variable. The score of impact factor of opportunity variable k is then formulated as

$$IFO_k = EO_k MO_k \tag{1}$$

Based on the work of Shah et al. (2009), the details on criteria, ratings, and characteristics to determine the maturity index for business opportunity k are given in Table 1.

Table 1 The maturity index on business opportunity (MIBO)

Rating	*Criteria*	*Characteristics*
0	Organisation is ignoring and unable to recognise the existence of business opportunities	• Unaware of the importance of opportunity recognition • No resource available to determine opportunity recognition
1	Organisation is starting to recognise the opportunity, but determination of opportunity is still accomplished irregularly and in qualitatively manner.	• Opportunity is monitored and analysed but accomplished qualitatively and occasionally
2	Organisations are recognising opportunity and attempt to determine opportunity in quantitatively manner	• Opportunity is monitored, analysed in quantitatively manner • Opportunities are well documented but not yet followed up with resource allocations
3	Organisations forecast opportunity based on past data/experience and use the result of such estimation to determine strategy for future strategy deployments. The effectiveness of the strategy deployment is reviewed and adjusted in regularly manner.	• Opportunity is counted in a regular basis and prediction on opportunity in future is accomplished • Organisation showed the evidence of commitment to follow up the opportunity with resources allocation and re-evaluation on the effectiveness of strategy deployment

Source: Modified from Shah et al. (2009)

3.2 Impact factor of threat variables

In running their businesses, companies are often faced with unfavourable situations which may hinder achievement of their business goals. In these situations, the existence of any events that possibly hinder company to achieve its goals are called 'threats' (Trzcieliňski and Trzcieliňska, 2011). In this study, business threat quantification is estimated based on its expected loss in monetary terms and its resilience index RT_l. The expected loss of threat occurrence is a function of the threat possibility occurrence, the capability of threat agent and the company's vulnerability against threat attack (Jones and Ashenden, 1995).

Based on idea that the impact of a threat occurrence is equal to the expected loss it may incur and reversal with resilience of the company in absorbing its negative impact, the score of impact factor of threat variables *l* is therefore formulated as in equation (2).

$$IFT_l = \frac{EL_l}{RT_l}. \tag{2}$$

The loss value and its corresponding metrics due to potential threats attack can be estimated based on Patel and Zaveri (2010).

3.3 Impact factor of strength and weakness variables

Similarly with threat variables, the existence of weakness variables negatively affects the company. The weakness variable resists the company's operation in achieving its goal. The presence of weakness variables hinders the company's operation in reaching its business objective. By viewing that the existence of weakness variable may give negative risk to the firm, then the amount of negative impact of weakness variable is estimated by two factors, namely:

- the seriousness of the impact of the weakness variable in resisting the company's operation (SW_p)
- the company's difficulty scale to avoid and or solve the weakness variables.

Since the impact factor of weakness variables is equal to those factors, the impact factor of weakness variable *p* is then represented by equation (3)

$$IFW_p = SW_p DW_p. \tag{3}$$

Contrary to the weakness variable, the existence of strength variables positively affects endeavour in achieving company's business goals. If IFS_m represents the impact factor of the strength variable, its score can be estimated based on criteria such as:

- capability of strength variable to accelerate the company's operation to achieve its business goal (CS_m)
- company's capability scale to utilise the strength variable in solving business problems (CCS_m).

Based on the above criteria, the impact factor of strength variables can then be formulated as

$$IFS_m = CS_m CCS_m. \tag{4}$$

For the sake of simplicity, determination of the scale of above elementary criteria can be based on a Likert ordinal scale using the discretion of the FMEA team.

3.4 Linking corrective action options with SWOT variables

In order to link each corrective action (CA) option and the SWOT variables, the coefficient of correlation r can be used. Depending of the typology of impact that may incur, the form of relationship between a particular CA and SWOT variables may be negative or positive. If a corrective action will increase the likelihood of opportunity and strength variables to occur, the value of correlation coefficient between corrective action and those variables will be positive. In reverse, if the corrective action prevents the possibility of occurrence of threat and reduce the weakness of the company, the correlation coefficient will be negative. In this regard, some rules in assigning the score of such correlations are given as below:

1 if the corrective action increases the likelihood of the SWOT variables' occurrences, assign 0.9, 0.6, and 0.3 to their strong, moderate, and weak correlation, respectively

2 if the corrective action prevents the possibility of the SWOT variables' occurrences, assign –0.9, –0.6, and –0.3 to their strong, moderate, and weak correlation, respectively

3 if there is no relation between the two then assign 0 to their correlation.

Table 2 depicts relationship between each corrective action and corresponding SWOT variables.

Table 2 Correlation matrix between corrective actions and SWOT variables

Corrective actions	*Strength*			*Weakness*			*Opportunity*			*Threat*		
	S_1	…	S_m	W_1	…	W_p	O_1	…	O_k	T_1	…	T_l
	IFS_1	…	IFS_m	IFW_1	…	IFW_p	IFO_1	…	IFO_k	IFT_1	…	IFT_l
CA_{11}	$R_{CA_{11}S_1}$	…	$R_{CA_{11}S_m}$	$R_{CA_{11}W_1}$	…	$R_{CA_{11}W_p}$	$R_{CA_{11}O_1}$	…	$R_{CA_{11}O_k}$	$R_{CA_{11}T_1}$	…	$R_{CA_{11}T_l}$
CA_{12}	$R_{CA_{12}S_1}$	…	$R_{CA_{12}S_m}$	$R_{CA_{12}W_1}$	…	$R_{CA_{12}W_p}$	$R_{CA_{12}O_1}$	…	$R_{CA_{12}O_k}$	$R_{CA_{12}T_1}$	…	$R_{CA_{12}T_l}$
…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…
CA_{1n}	$R_{CA_{1n}S_1}$	…	$R_{CA_{1n}S_m}$	$R_{CA_{1n}W_1}$	…	$R_{CA_{1n}W_p}$	$R_{CA_{1n}O_1}$	…	$R_{CA_{1n}O_k}$	$R_{CA_{1n}T_1}$	…	$R_{CA_{1n}T_l}$

By considering the impact factor of the SWOT variables, estimating the preference score ($PSCA_{ik}$) of corrective action CA_{11}, for example, can be carried out using equation (5).

$$\begin{aligned} PSCA_{11} = {} & \sum_{i=1}^{m} R_{CA_{11}S_i} IFS_i - \sum_{i=1}^{p} R_{CA_{11}W_i} IFW_i \\ & + \sum_{i=1}^{k} R_{CA_{11}O_i} IFO_i - \sum_{i=1}^{l} R_{CA_{11}T_i} IFT_i \end{aligned} \tag{5}$$

By linking with the criticality of certain failure mode, as represented by its corresponding RPN score, and the impact factor of the SWOT variables, prioritisation of corrective action based upon the benefit index of a corrective action (BCA_{ik}) can be carried out using the following equation (6):

$$\text{Benefit index } (BCA_{ik}) = RPNFM_k PSCA_{ik} \quad (6)$$

4 Selecting competing corrective actions by using the BCOR2 model

Selecting an improvement strategy is a complicated task since many factors such as the estimated amount of benefit could be reaped, opportunity to implement, risk of implementing corrective action, complexity of implementation, and corresponding implementation cost should all be taken into consideration. By considering such complexity above, a model based on the BCOR2 approach which stands for benefit, opportunity, cost, risk, and organisational readiness in implementing a corrective action is proposed.

The benefit element in BCOR2 approach is defined as any positive impact resulted from implementing an improvement effort. The impact of a corrective action can be defined as the amount of benefit that can be achieved if a corrective action is implemented. Following El-Haik and Al-Oumar (2006), the benefit of improvement strategy can be categorised into three classes; financial, operational, and organisational. Depending on the benefit category, the value of strategy benefit can be defined using some quantitative and qualitative dimensions such as the increase in the level of customer and employee satisfaction, reduction in operations costs, time delays and quality deficiencies and so on. Considering that the employee is inseparable part in implementing corrective action, the priority to select a certain improvement strategy shall be given to that which can give maximum benefit not only to shareholders and customers but also to employees (Chuan and Raghavan, 2004). In order to weight competing corrective actions by considering their compatibility with company specific goals, the analytical hierarchy process (AHP) can be used as a decision support tool. Based on these ideas, the weight of the benefit of a corrective action, which represents its impact, is given in equation (7):

$$BCA_{ik} = KCA_{ik} WCA_{ik} \quad (7)$$

The criteria for weighting corrective action impact factors are as depicted in Table 3.

Table 3 Criteria on classifying impact factor of corrective improvement strategy

Score KCA_{ik}	*Linguistic evaluation of strategy impact factor*	*Criterion: affected parties*
1	Low impact	Customers only
3	Medium impact	(Shareholder-customer)
6	High impact	Employee-shareholder-customer

The opportunity component OCA_{ik} in the BCOR2 model represents any positive attributes arising from implementing a corrective action and it can be accessed by proposing questions pertaining to the positive outcome from implementing certain CA such as: what can go well? What is the chance that it will go well? And what are the consequences if it goes well?

In the BCOR2 model, the cost component $ICCA_{ik}$ is defined as the amount of money that will be spent to implement specific improvement efforts. It can be in the form of infrastructure cost, such as cost of facilitating devices and tools, and the cost of manpower spent to execute the corrective action. The risk element RCA_{ik} in the BCOR2 represents any unintended outcome from implementing a corrective action and it can be in the form of employee resistance, escalating cost, time overrun and so on. According to typologies proposed by Fijnvandraat and Bouwman (2010) and Cagno and Guido (2011), the risks inherent in selecting strategy may be classified into some categories such as goals, resources, competitors, and customers, political, technical and managerial risks.

Consequently, there can be situations when the risk elements of implementing corrective actions have different units of measurement. In these situations, the loss score borrowed from Taguchi loss function can be used. Considering that company management is a profit seeker, the loss function in terms of' the smaller the better' will fit for quantifying the risk corresponds to the corresponding corrective action. Oordobadi (2009) provides a useful exemplary model to estimate and quantify the risk components by using Taguchi loss function.

The last component in the BCOR2 approach, the organisational readiness $ORCA_{ik}$ reflects the readiness of an organisation to implement corrective action. The readiness contained in this component in the BCOR2 relates to the accommodating ability for any compensation pertaining to the selection and implementation of a specific improvement effort (Keese et al., 2006). For ease of use in practical situations, the OR component is quantified by ordinal scale 1–10 which 1 represents a potential change that can be implemented immediately without cost, and a 10 represents a potential change that in feasible to be implemented.

By considering all elements in the BCOR2 approach, with the severity of failure loss assumed constant over time from initial failure detection point, the preference score to select a corrective action, which is called CAI CAI_{ik}, is given by equation (8):

$$CAI_{ik} = \frac{RPNFM_k PSCA_{ik} WCA_{ik} OCA_{ik}}{ICCA_{ik} LCA_{ik} ORCA_{ik}}. \quad (8)$$

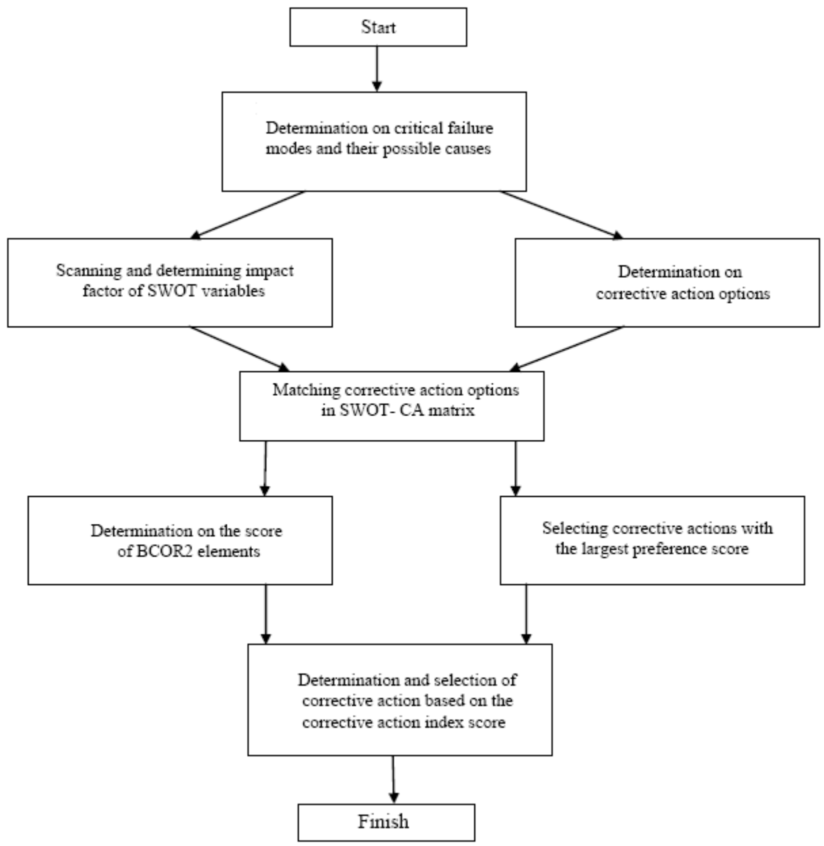
The corrective action with the largest value of CAI will have the highest priority to be selected and implemented. Table 4 depicts the above mentioned components.

Table 4 A matrix depicting the BCOR2 components

Failure mode	*RPN*	*Impact components*			*Effort component*			*RCA*
		PCSA	*WCAIK*	*OCA*	*ICCA*	*LCA*	*ORCA*	
FM_1	RPN_1	PCA_{11}	WCA_{11}	OCA_{11}	$ICCA_{11}$	LCA_{11}	$ORCA_{11}$	RCA_{11}
FM_2	RPN_2	PCA_{12}	WCA_{12}	OCA_{12}	$ICCA_{12}$	LCA_{12}	$ORCA_{12}$	RCA_{12}
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
FM_k	RPN_k	PCA_{ik}	WCA_{ik}	OCA_{ik}	$ICCA_{ik}$	LCA_{ik}	$ORCA_{ik}$	RCA_{ik}

The framework of integrating SWOT analysis into FMEA in solving critical failure mode is given in Figure 1.

Figure 1 A chart depicting integration of SWOT analysis into FMEA



5 Illustrative example of application

In this study, a case study adopted from a FMEA application in a gas tube production and distribution company is used for illustrative purposes. According to Yin (1994), the case study is used to demonstrate the application of new theory with limited knowledge to obtain much better understanding and the study is intended to answer 'what?' and 'why?' research questions.

The focus of applying FMEA is on determining critical failure modes, possible root causes and corresponding corrective actions. The FMEA session is accomplished by the company team which consists of distribution, operation, marketing and maintenance staff and the result of their FMEA session is summarised as in Table 5.

Table 5 FMEA sheet of case example in gas distribution company

No.	*Failure mode*	*Effects*	*Possible causes*
1	Inaccurate gas order forecasting RPN = 108	a Shortage of gas inventory b Loss sale c Company resource wastage	1 Poor forecasting 2 Inadequate marketing research 3 Inappropriate customer relationship management
2	Low gas fleet availability RPN =140	a Customers complaint b Loss sale c Decrease customers loyalty	1 Poor fleet maintenance 2 Financial shortage 3 Poor delivery planning
3	Lengthy distribution administrative process RPN = 90	a Customer complaint b Decrease in company's productivity	1 Poor administrative process 2 Ineffective administration
4	Mismatch on gas dispatching documents with gas identity data in delivery process RPN = 170	a Increasing administrative time b Affect customers' safety	1 Ineffective finished gas inspection procedures 2 Bad warehousing activities
5	Unavailability of empty gas tubes at customers' place when picking time is due RPN = 112	a Loss sale b Distributor loss time c Escalation in picking the empty gas tubes' cost	1 Poor customers communication 2 Unclear picking time 3 Bad gas tube circulation design

The company's management has set a threshold RPN value of 130 for critical failure as the basis for failure alleviation. As can be seen in Table 5, the critical failures that should be rectified are 'mismatch in gas dispatching documents with gas identity data in delivery process (FM_4)', and 'low gas fleet availability (FM_2)'. On completion of the discussion between the FMEA team members on potential corrective actions to tackle the critical failures, the corresponding corrective action options with critical failures are presented in Table 6.

Table 6 Critical failure mode and potential corrective action

Failure mode	*Possible cause*	*Potential corrective action*
Mismatch in gas dispatching documents with gas identity data in delivery process RPN = 170	1 Ineffective finished gas inspection procedures 2 Bad warehousing activities	1 Improving finished inspection procedures (CA_{11}) 2 Strengthening collaborative inspection among gate security, outgoing inspection staff and fleet drivers (CA_{12}) 3 Re-identifying gas tube colours and numbering models according to gas types (CA_{13})
Low gas fleet availability RPN =140	1 Poor fleet maintenance 2 Financial shortage 3 Poor delivery planning	1 Activating fleet checking list (CA_{21}) 2 Increasing fleet spare part stocks (CA_{22})

The identification of SWOT variables is accomplished by using internal and external factor analysis by the FMEA team. Upon identifying the SWOT variables, the corresponding impact factor of each SWOT variable is then estimated based on equations (2), (3), (4) and (5). The scale to quantify the impact score of SWOT variables uses a 1–5 ordinal scale. The result of estimating impact factor of SWOT variables and the preference score to select corrective action based on the impact factor of SWOT variables are presented in Table 7 and Table 8.

Table 7 Quantification of impact factor of SWOT variable

No.	*SWOT variables*	*Quantification criteria*		*Impact factor IF*
	Strength	CS_k	CCS_k	IFS_k
1	Possessing strong financial liquidity	5	5	25
2	Good company reputation	4	3	12
3	High ability to produce various gas types as demanded by different customers	5	5	25
4	Certified gas producer	5	5	25
5	Possessing good gas networking	5	5	25
	Weakness	SW_k	DW_k	IFW_k
1	Aging equipment	5	5	25
2	High skill variation among employees	3	4	12
3	Dependability to single electricity provider	5	5	25
4	Slow in capital investment	4	3	25
5	Too tight on sales procedures	2	3	6
	Opportunity	EO_k	MO_k	IFO_k
1	Prosperous gas market	5	3	15
2	Government support for gas investment	3	1	3
3	Customer' growing awareness to use certified gas producer	5	3	15
4	Growing demand on gas pipe installation	3	2	6
	Threat	EL_k	R_k	IFT_k
1	Entrance of new competitors	5	1	5
2	Competitors using very flexible in gas sales procedures	3	3	1
3	Possibility on gas tube lost at remote customers	5	4	1.25
4	Possibility on profit loss due to reconstruction of gas plant by some of current customers	5	1	5
5	The entrance of gas substitution material into the gas market	5	1	5

Table 8 Correlation matrix of SWOT variable and corrective actions

SWOT variable		*Impact factor*	*Failure mode*: *Mismatch in gas dispatching documents with gas identity data in delivery process RPN = 170*			*Low gas fleet availability RPN =140*	
			CA_{11}	CA_{12}	CA_{13}	CA_{21}	CA_{22}
Strength	S1	25	0.8	0	0	0	0
	S2	12	0.4	0.9	0.6	1	0.9
	S3	25	0.9	0.6	1	0.3	0
	S4	25	0.1	0.7	0.7	0	0
	S5	25	0	0.9	0.3	0.9	0.9
Weakness							
	W1	25	0	0	0	0	–0.3
	W2	12	0.7	–0.9	0	–0.1	0
	W3	25	0	0	0	0	0
	W4	25	0.2	0	0.3	0	0.3
	W5	6	0.3	0.5	0	0	0
Opportunity							
	O1	15	0.4	0.8	0.9	0.2	0.5
	O2	3	0.2	0.2	0	0	0.1
	O3	15	0.5	0.6	0	0	0
	O4	6	0	0	0	0	0
Threat							
	T1	5	0.2	–0.5	–0.6	–0.1	–0.4
	T2	1	0	0	0	0	0
	T3	1.25	0	0	–0.8	0	0
	T4	5	0	0	0	0	0
	T5	5	0.1	0	0	0	0
Preference score			44	82.5	67.2	46.7	43.1

Considering the impact factor of the SWOT variables, the corrective action preferred for solving the first critical failure ‘mismatch in gas dispatching documents with gas identity data in delivery process’ is CA_{12} (strengthening collaborative inspection among gate security, outgoing inspection staff and fleet drivers) and CA_{21} (activating fleet checking list) is preferred for solving second critical failure mode ‘low gas fleet availability’.

The impact and effort ratio for each corrective action needs to be considered in selecting the most preferred corrective action. The impact of a corrective action is estimated by the score of the affected parties if implemented. The criteria to estimate the weight of the impact variables by using the AHP are consumer safety, distribution on time delivery and cost reduction. Besides distribution, on time delivery and cost reduction aspect, consumer safety also become criteria in appraising the benefit of corrective actions based on the fact that gas production, distribution and consumption are very sensitive to safety requirements and the possibility of a gas explosion. In order to quantify the loss that may occur when implementing the corrective action, the Taguchi loss function (smaller the better type) and a 1–10 ordinal scale is used to scoring the organisational readiness index in implementing each corrective action. For example, the risk may incur for implementing CA_{12} for FM_1 (mismatch on gas dispatching documents with gas identity data in delivery process) is the possibility of creating extra administrative time for employee. The result of estimating the impact and effort ratio of each corrective action is summarised in Table 9. By considering the impact and effort components from the BCOR2 approach, for solving FM_1, CA_{12} should be chosen and for solving FM_2, CA_{21} is more appropriate to be selected.

Table 9 Impact and effort ratio of each CA of case example

FM_k	CA_{ik}	*Impact components*			*Effort components*			CAI_{ik}
		$PSCA_{ik}$	WCA_{ik}	OCA_{ik}	$ICCA_{ik}$	LCA_{ik}	$ORCA_{ik}$	
Mismatch in gas dispatching documents with gas identity data in delivery process RPN = 170	Improving finished inspection procedures (CA_{11})	44	0.2098	0.4545	0.4053	36	4	12.220
	Strengthening collaborative inspection among gate security, outgoing inspection staff and fleet drivers (CA_{12})	82.5	0.5499	0.4546	0.4085	196	3	14.596
	Re-identifying gas tube colours and numbering models according to gas types (CA_{13})	67.2	0.2402	0.0909	0.1852	64	7	3.006
Low gas fleet availability RPN =140	Activating fleet check list (CA_{21})	46.7	0.3772	0.2191	0.6550	36	4	5.728
	Increasing fleet spare part stocks (CA_{22})	43.1	0.6228	0.7809	0.3450	25	8	42.53

6 Discussions

In this paper, a model to consider impact of business environment factors is introduced by integrating SWOT analysis in risk-based improvement selection process. Instead of relying solely on the risk dimension as represented by the use of RPN as commonly utilised in earlier FMEA studies, the impact of SWOT variables is incorporated prior to choosing suitable corrective actions. By using this model, FMEA practitioners can take advantage of the positive impact from internal and external business factors which may beneficial to the achievement of company’s goal when alleviating business problems, and vice versa. Next, the proposed model of quantifying the impact of business variables also considers company maturity, vulnerability and resilience in order to make it possible for management to estimate the value of expected loss and gain which is representative of the overall business situation.

In spite of the benefit offered by the proposed model, the study has some clear limitations. First and foremost, relying on single case example only is certainly not sufficient to claim validity and reliability of proposed model. As the case example in the study is based on gas tube production and distribution, general applicability may be limited. Realising that different business operations may have different characteristics which may influence decision makers in choosing improvement initiative, replication of the model in various cases in different business sectors is recommended to strengthen its validity and generalisation. Next, the utilisation of a relatively sophisticated AHP method to score the impact and effort components may be difficult for some FMEA team members who are not confident or regular users of mathematical methods. To eliminate the difficulty in using AHP, the use of ordinal Likert scales is suggested for ease of implementation in order to represent the impact and effort components. Another limitation of the model which must be considered carefully for practical application relates to the model's ignorance of the risk perceptions of decision makers in various industries in choosing improvement initiatives. According to Bossuyt et al. (2012), for risk – averse industries, such as nuclear and aerospace, practitioners tend to choose the least risky improvement strategy. However, the opposite may be true in the web development industries where the consequences of failure may be less severe. Integrating utility theory to take into account the risk behaviour of FMEA teams in appraising multiple improvement strategies would be an appropriate future development of the model.

6.1 Theoretical implications

This study has developed a framework for integrating SWOT Analysis into the FMEA methodology. The proposed framework is consisted of three parts: the classification of critical failure modes and their potential corrective actions to be chosen; the determination of SWOT variables and their impact factors; and the appraisal of competing corrective actions based on the BCOR2 model. This framework and the associated model is a novel contribution to current research into enhancing the capability of FMEA.

In appraising the weight of SWOT variables, this research offered new ideas for quantifying the impact of SWOT variables. Instead of the multi criteria decision making tools commonly used in the previous SWOT analysis literature, the study uses a simpler calculation method which considers, simultaneously, organisational maturity in recognising opportunities, organisational resilience in considering the impact of the external business environment (threat and opportunity variables) and organisational capability in getting rid of the weakness and utilising strengths prior to selecting an improvement strategy in taking into account the impact of the internal business environment (strength and weakness variables).

By integrating the risk factors of critical failures in term of their corresponding RPN and impact of environmental factors in the appraisal of corrective action, the study includes benefit, cost, opportunity, risk and organisational readiness considerations which is supplementary to previous studies which rely only on cost and benefit analysis. Inclusion of opportunity and risk elements provides a more representative and rounded analysis of corrective action options that considers the uncertainty of outcomes together with the organisational readiness for implementation.

6.2 Managerial implications

Some implications pertaining to strategy selection based on integrating SWOT analysis into FMEA are described in the following below:

6.2.1 Inclusion of impact factor of SWOT variable and the BCOR2 approach in risk-based improvement selection methodology

In FMEA literature, the usual basis to determine corrective and or preventative measures against the riskiest failure modes are based on a risk dimension, the RPN, and an economic measure, the expected cost. The case study example illustrates that the impact of business environmental variables is facilitated by integrating SWOT analysis in FMEA. If the impact factors of company's business environment are excluded from the FMEA generation session, each corrective action for corresponding failure mode with highest RPN will have equal chance of being chosen. For instance, in solving FM_1 'mismatch in gas dispatching documents with gas identity data in delivery process (RPN = 170)', 'improving finished inspection procedures' (CA_{11}), 'strengthening collaborative inspection among gate security, outgoing inspection staff and fleet drivers' (CA_{12}) and 're-identifying gas tube colours and numbering models according to gas types' (CA_{13}) can be chosen simultaneously. However, by considering the correlation of the SWOT variables of the company's operation with the available corrective action option and the score of impact and effort components of the corresponding corrective action, 'strengthening collaborative inspection among gate security, outgoing inspection staff and fleet drivers' (CA_{12}) is finally chosen.

6.2.2 Quantifying the weight of SWOT variables

In an attempt to select an improvement strategy using SWOT analysis, quantification of SWOT variables ranging from the simplest model, the ordinal scoring model as exemplified in Wheelen and Hunger (2008), to a more advanced one, using multi criteria decision methodological basis such as (Tahernejad et al., 2011), have already presented before. Nevertheless, organisational maturity and resilience level which contributes quantitatively to the quantification of SWOT variables is overlooked. This may yield inaccuracies in weighting the impact factor of SWOT variables that, in turn, may cause the selection of an inappropriate corrective action. In this study, FMEA practitioners are provided with a much more accurate reflection of the impact of the business environment when identifying the most appropriate corrective action.

7 Conclusions

This paper presents a model for selecting corrective actions based on integration of SWOT analysis and FMEA. Previous studies have been presented to overcome the limitation on the use of the RPN as foundation to determine the rank of competing improvement efforts but have neglected the impacts of events occurring within the organisations' internal and external business environments within a company's day to day operation. Ignoring the impact of these events can result in a corrective action being chosen will either create business losses owing to the presence of threats and weaknesses in the company or not take advantage of potential opportunities and company strengths. This paper presents a model for FMEA practitioners to use which encompasses these broader business factors and enables them to make the appropriate decisions when selecting corrective actions.

Despite the contributions offered by this paper to both theory and practice in managing quality, the model proposed has limitations. The role of the timing of events is ignored and this needs to be developed in order to consider the failure time occurrence and its influence on determining the amount of resource allocation and timing of corrective action implementation. The study needs to be replicated in a wider variety of industries and business environments to test the reliability and validity of the model. Further development of the model to incorporate other business improvement strategies such as QFD and TOC should be considered while the interaction between SWOT variables needs further investigation. Nevertheless, the current model provides a robust foundation upon which to base these new developments.

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