Decision support model mitigating scope variability in engineering R&D projects

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Keywords

Scope Variability, Decision Support System (DSS), Decision Support Model (DSM), New Product Development (NPD)

Abstract

Engineering R&D projects have long durations due to intensive researches and iterations. This research aims to develop a decision support model, in assisting engineering R&D project managers in decision making concerning projects continuity. The proposed decision support model comprises of two parts; interrelationships of R&D performance indicators, and a pairwise prioritization calculation to determine the importance of each considered indicators. In-depth interview is the method selected to obtained data for this research. The obtained information was elicited to develop the decision support model, which contributes to the engineering R&D industry by providing a solution-seeking guideline in more efficient manner.

1. Introduction

Project management in the engineering research and development (R&D) sector is known to be challenging due to its susceptibility towards contingencies throughout the product development life cycle. Issues may arise from factors such as long research periods, changes in design regulations or discovery of new technologies.

Dynamic changes in the R&D environment result in a need for decision-making, to determine whether to adapt, improvise or abort the project. The decision-making process is complicated, hence consume time and human resource. This issue is intensified as R&D processes will involve bureaucracy from various departments within the companies. Moreover, in relation to unforeseen circumstances which seldom occur, project managers are required to make swift and accurate decisions. For example, a Belgian bicycle company had started its R&D process since 1998, by working with external designers and experts to facilitate its product innovation. Throughout the years, many experiments were done with various materials, processes, and manufacturing collaborators before a breakthrough product could be delivered (Du et al., 2014). Another US-based, multinational corporation that designs, manufactures and sells commercial aircraft needed strong support across manufacturing engineering projects and production systems. Hence, the company has spent several years with a technology consultant team to facilitate in-house R&D projects, by gathering configuration information compiled with appropriate data. These data have included information from different aspects needed for decision-making, such as production, engineering, quality, design and cost (Accenture, 2017). As such, it can be concluded that engineering R&D project management is a challenging task to organizations with the following key reasons: uncertainty in prediction of its impacts and success rates, complexity of converting milestones to deliver tasks in R&D projects, presence of heterogeneous decision-making strategies involving external stakeholders, and possible misinterpretation of information (Luo and Yu, 2015). Off-the-shelves project managing tools and decision support system (DSS) currently available in the market do not specifically cater to mitigate the erratic changes in engineering R&D projects, hence it is underutilized by project managing teams (Díez and McIntosh, 2009). Due to these problem gap, there is a need to investigate the environment of managing engineering R&D projects' scope variability mitigation strategy.

This research proposes a DSM consisting of multiple performance indicator (PI) and the interrelationships in engineering new product development (NPD) projects, as well as a prioritization method to obtain suggested direction for a solution. Therefore, the research data was elicited based on engineering multinational companies (MNC). MNC is selected as the area of research since 66.7% of MNC have allocated resources in R&D,

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compared to only 44.9% of small and medium enterprises (SME) performing R&D procedures (UTAR, 2018). The project management systems are also more established compared to SME, due to more resources, technological expertise and economies of scale by MNC (Masroor and Asim, 2019).

Studies showed that NPD has three important phases: early, mid, and late, which could be more specifically known as pre-development, development, and post launch or commercialization stages (Frishammar And Ylinenpää, 2007; Millson and Wilemon, 2002). Millson and Wilemon (2002) discovered that R&D success depends on organizational integration throughout the whole of NPD process. However, Frishammar and Ylinenpää (2007) stresses that the integration should focus on other particular co-relations. For example, relating marketing and R&D in the early phase, manufacturing and R&D in the mid phase, and manufacturing and marketing in the late NPD phase would bring different result. As such the emphasis of this research will be placed at the mid-late stage of engineering R&D projects that develops market or customer driven minimal viable products since many studies only focuses on the project selection phase (Stewart, 2016; Tian et al., 2005).

2. Literature Review

2.1 Engineering Research and Development

In order to achieve and maintain a competitive market share, R&D has been an emphasis by engineering companies due to the rising technology complexity and the industry's rapid growth. R&D is assured to be one of the main factors leading to sustainable growth in highly industrialized, modern knowledge-based economies (Abbassi et al., 2014). The raise in development expenditures and high failure rates in engineering R&D projects (see Figure 1), making risk management very crucial in the R&D sector. Figure 1 has highlighted the significance of expenditure has rose in recent 5 years, as the gross expenditure on R&D projects in Malaysia doubled from RM9422 million in 2011 to RM17685 million in 2016. Figure 2 has shown that NPD projects categorised such as capital and consumer goods have considerably high failure rates ranging from 35% - 45%, given the high developmental costs (Castellion and Markham, 2013).

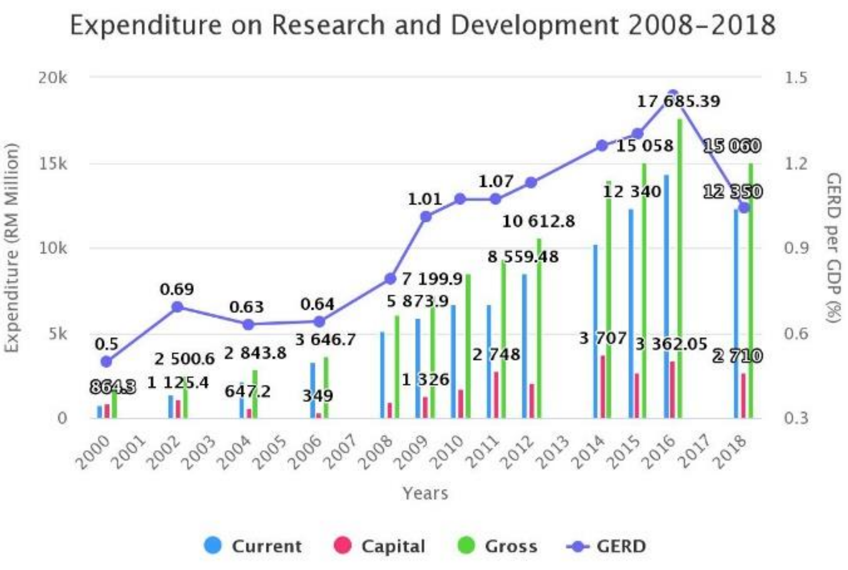

Figure 1. Expenditure on R&D projects on Malaysia from 2008 – 2018. *Source*: "National Survey of Research and Development in Malaysia" (2017)

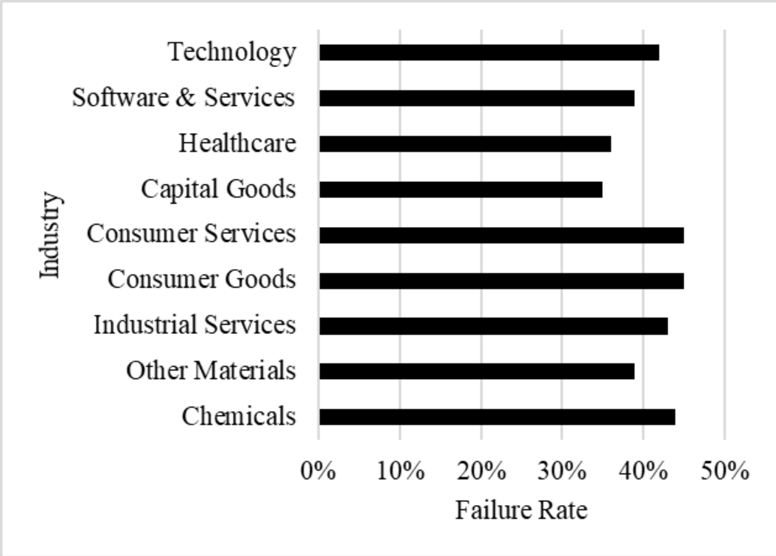

Figure 2. New Product Failure Rate by Industry. *Source*: Castellion and Markham (2013)

R&D projects contain organizational decision-making tasks commonly found in organizations like government funding agencies, universities, research institutes, and technology-intensive companies. Poteralska (2017) proposed a system dedicated for use in the process of generating future research projects based on the subject matter and the results of previously completed projects. Its application gives an indication of future projects and at the same time, projects for which there is sufficient potential within the organisation. It is a tool in supporting decision-making processes concerning the selection of future research directions. There is a multi-stage multi-person decision making process involving a group of decision makers (e.g. external reviewers and panel experts) (Hill et al., 2000). Thus, it can be very hard to manage the decision-making process, especially when the decision makers have heterogeneous decision-making strategies. A decision support system (DSS) is a handy tool in facilitating the decision-making processes for such purposes. The following section will provide further discussion on DSS and its applications.

2.2 Decision Support System

DSS and decision support models (DSM) are tools intended to help project manager in decision-making based on quantitative or qualitative data, and also information generated from derivation of data (Ong, 2017). DSS are interactive software-based systems while DSM are the conceptual building blocks of a DSS (Louw, 2002). The data could be derived from various sources, such as sales figures, cost budget, resource allocation, projected completion date etc. Historically, the focuses of DSS application has generally been transactional processes and organisational automation, which yield to financial and resource advantages. Passive models are DSS that just contain data and organize them as they display data and do not provide a decision. Active DSS process data and display information based on the input. A cooperative DSS contains data collection and analysis. Human component is included to refine the system (Marin, 2005). In some cases, human component added helps in judgement and intuition within the decision-making process. Consistency in making decisions is a concern, due to the presence of human emotion factor in the process, as it tends to lead of cognitive deficiencies in making sensible judgements that includes all considering factors (Luo and Yu, 2015). The final goal of the proposed DSM in this research would be to develop a DSS with a flow as illustrated in Figure .

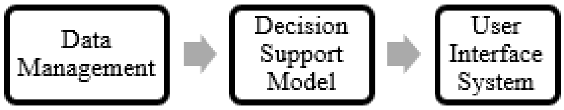

Figure 3. DSS Concept based on research analysis.

Kuhlmann (2018) suggested a system with development of tools in different combinations to assist the decision-making process. To utilise this system effectively, there is a need to integrate evaluation, technology assessment and foresight. However, Kuhlmann (2018) mentioned that combining these methods together is challenging, as the applications varies based on individual needs. Additionally, Louw (2002) showed that DSS could cater to decision-makers in different managerial levels. Top managements generally emphasise long-term planning, therefore trend information is retrieved to help in decision making. Joint analysis is also important, as top management level focuses on risk and uncertainty, potential outcomes, likelihood and probability, and the respective suggested actions to take. Some of the benefits of DSS application are: better control and increased awareness of internal strength, weaknesses, external threats and opportunities. Decision-makers are able to respond faster to changes in the environment and in return improves the long-term profitability by better decisions (Louw, 2002). With the aid of DSM, decisions could be made based on a solid ground and systematically proved data.

In Malaysia, DSS has been applied in a form of feed-in tariff mechanism since 2011, aiming to increase usage of renewable energy in electricity generation. The DSS enables policymakers to carry out analysis and determine the amount of money that must be collected from the end users who are paying for different renewable resources (Shahmohammadi et al., 2015). Shared decision making (SDM) is a concept whereby decisions are made based on a shared understanding and agreement between two parties. In Malaysia, current research on SDM is carried out by public research universities and currently still at infancy stage (Lee and Ng, 2017). However, there are increasing recognition and efforts from the academic institutions and Ministry of Health to conduct research in SDM, developing patient decision support tools and initiate national discussion on patient involvement in decision making (Lee and Ng, 2017).

Since DSS is a useful tool in different stages of a project, DSS is widely applied in early stages of a project, especially project selection and risk management (Stewart, 2016). Project selection before the commencement of a project is crucial due to the complex nature of R&D project selection. A DSS model is a useful application in aiding project selection as it includes complex components such as risk, cost, decision hierarchies, as well as profit concerns and human resources (Iyigun, 1993). Effective tools such as project portfolio selection applications enable senior managers to analyse R&D projects in an organised way while considering company's profitability and long-term growth (Abbassi et al., 2012). The development of the project selection DSS was conducted simultaneously with a database system development for project proposals (Stewart, 2016). An offline interface application with a separate database has been developed for users to collect relevant information which are suitable for the DSS itself (Stewart, 2016). There is also organisational decision support system (ODSS) which is one of the group-based modelling methods developed for R&D project selection (Tian et al., 2005). ODSS is a DSS aiming to coordinate and facilitate decision making across functional areas and hierarchical tiers in order to align decisions with organization. ODSS differs with regular DSS, as one of its main goal is to maintain the organisation’s competitive stand in the market (Adam, Frédéric; Pomerol, 2010). Decision-making process is facilitated by the proposed ODSS, as it supports individual, group and organizational concerns and objectives.

DSS and mathematical models are also developed to help managers manage risks in their projects (Desyatirikova and Belousov, 2017; Lu and Tzeng, 2000). In occurrence of any sudden issue, solutions could be derived via reasoning and data from several entities, which could also have strong interrelationships between each of them. In a DSS, concerns and risks of a project have to be properly identified and prioritized, then time and cost, which are the key assets of resources in a company, shall not be wasted in dealing with risk of losses. Therefore, Wang et al. (2010) has linked individual project risk management with the corporate strategic management, via the assessment of project managers and stakeholders. This is to ensure that managed risks are coped with by the corporate strategy so corporate objectives can be eventually achieved. Gidel et al. (2005) has also developed a decision-making framework for risk management from the cognitive science viewpoint.

In Aslam et al. (2017)'s study, a DSM, with corresponding DSS was developed. The aim is to support practitioners in decision-making for risk assessment and selection of management strategy. In Aslam et al. (2017)'s study, various areas of research gap have been identified proposing the DSS to be linked to different stages of planning in a project. This involve identifying variations in DSS output at different stages of the project. Moreover, it would be interesting to quantify and correlate the benefits of DSS in a real project setting. Desyatirikova and Belousov (2017) have built a DSS to assess the risks of projects in which the initial information on the risk-forming factors is unclear, incomplete and poorly formalized. Their study showed that formalized risk models based on probabilistic, fuzzy-multiple and expert models are the most optimal.

2.3 Performance Criteria and Indicators

In project management, PI for those parameters are often quantitative data, used to represent the input, output and performance dimensions of processes, products, programs, projects and the general outcomes (Ofori-kuragu et al., 2016). Common PI from four perspectives at the R&D department include market value, customer satisfaction, average R&D duration and cost, and core skill coverage ratio (Wang et al., 2010b). There are tools such as balanced scorecard (BSC) and quality function deployment (QFD) which assist project managers and other decision-makers in dealing with risk management activities from a top–down manner. By using BSC, main performance measures of an R&D organization could be determined, based on the organization's vision and strategy. Kaplan (2009) has built the BSC method as a strategic performance management tool to help the breakdown of organizational strategies into implementation plans. Modak et al. (2018) supported BSC method with the inclusion of PI in the multidimensional BSC framework, categorised under four views; financial, customer, internal operations, company learning and growth. The PI within these perspectives are interrelated to each other in a defined manner. These relationships enable better strategizing focus, in line with the organization's strategy to increasing effectiveness.

QFD is a step-by step procedure built to identify risks and aid response planning and control. QFD is applied in the conversion of organizational performance measures into project performance measures. BSC and QFD are both utilized at the same time to develop an integrated risk management framework, which considers corporate strategy and performance measurement system (Dwivedi et al., 2018; Hajikhani, 2013). With this combination, R&D projects are able to focus on achieving the corporate goals and to identify, assess, analyze, and monitor R&D risks effectively throughout the project duration (Wang et al., 2010b). Analytic Network Process (ANP) is another tool that enables a better understanding in the evaluation of a complex decision-making scenario by considering the complex interaction among the aspects within the decision criteria. ANP displays an extensive multidimensional network structure that considers decision maker's thought process on the different aspects and indicators, including problem objective, criteria, sub-criteria, alternatives and their interaction within the group (inner dependence) and also between the groups (outer dependence) (Saaty and Cho, 2001).

Kucukaltan et al. (2016) argued that BSC being an influencing model, has some drawbacks based on the stakeholder theory, where it does not represent all stakeholders' point of view. Hence, in the study, ANP is integrated with BSC to provide a deeper analysis and prioritization of the PI. It is seen that the concepts of BSC, QFD and ANP have been found to be systematic in analysing different PI (Kucukaltan et al., 2016; Modak et al., 2018; Saaty and Cho, 2001; Wang et al., 2010). The combination of these concepts can be deemed suitable to be adapted into the developed DSM for engineering R&D environment.

The proposed DSM requires a systematic literature review identify various parameters and PI that are currently utilized by project managers in assessing their projects. PI are fundamental managerial tools for decision-making in organizations (Gunasekaran et al., 2015). In efforts of including both perception measures and quantifiable PI, employees and managers will be involved in the identification of the criteria (Moullin, 2004). Project managers studied the market prospect during the concept development and testing phase, which are commonly performed on a true existing customer base. The consumers' feedback could then be converted into comparable index as a PI. Financial indicators were the main focus in performance measurement systems in the past (Yang et al., 2009). Currently, due to the importance of a multidimensional structure, both financial and non-financial PI are included for consideration (Gutierrez et al., 2015; Poveda-Bautista et al., 2012). However, it raises the concern of having too many indicators in performance measurement [44]. Furthermore, emphasis of complications are due to interdependencies among indicators in real life situations (Tzeng et al., 2007), since PI are not always completely independent of each other. (Kucukaltan et al., 2016) pointed out that researchers in the field of performance measurement and organizations have not considered this factor. Hence, this research aims to tackle this issue by understanding the interdependencies between PI relevant to the engineering R&D sector.

SME have used the following performance measures: productivity, quality performance, financial, innovation, employee learning, customer performance, meeting customer requirements, customer satisfaction and delivery for the customer (Sousa et al., 2006). This provides a broad base for measuring performance covering many performance areas unlike (Modak et al., 2018) which uses four broad groups of performance measures: financial, learning and growth, customer and internal processes. The limited scope of the BSC's measures makes its more suited to entities with prior experience of key performance indexes (KPI). In Ofori-kuragu et al. (2016)'s study, a set of nine KPI has been developed for Ghanaian contractors; client satisfaction, cost, time, quality, health and safety, business performance, productivity, people and environment. These KPI present a set of common criteria which can be used by Ghanaian contractors to measure and benchmark their performance and by client groups to compare contractor performance. With reference to the study of KPI in other applications as mentioned, this research has identified and summarised PI that are relevant to the R&D management field. These indicators will be included in the result section.

3. Methodology

This research was conducted using qualitative research methods which enables refinement of the pre-conceived notions, prediction of thought processes, analysis and estimation of the issues from an in-depth perspective. This was conducted via one-to-one interviews on specific discussion topic. Therefore, in this research, data collection was obtained via semi-structured, in-depth interviews with guided open-ended questions.

A total of 10 project managers were selected across different engineering industries such as oil and gas, information technology, electrical and electronics, mechanical and chemical industries, to provide information for this research. The selection of stakeholders was mainly based on geographical considerations, as the DSM's applicability in Malaysia is the concern. Thus, these selected stakeholders have at least 5 years of engineering R&D project managing experience in MNC situated across Selangor, Kuala Lumpur, Penang and Johor. Participants were engaged through existing network, professional recommendations and LinkedIn connections. The mode of interviews included phone calls, video calls and face-to-face conversations to facilitate the convenience of the participants. The research design involves two main stages: pilot test and case study validation. The interviews for pilot test stage and case study validation were conducted from January to February 2020, and March 2020 respectively. Each of the session lasted for one hour on average. The interviews aim to obtain information which will be analysed to form the building blocks of the proposed DSM. The outcome has resulted in a clearer understanding of engineering R&D project, categories of problems faced by project managers, measurements of project performance and the interrelationships.

In the pilot test stage, the commonly used R&D project planning PI retrieved from literatures were brought to interview sessions to be discussed with the stakeholders. In this stage, in-depth interviews were carried out with 6 of the selected stakeholders to understand their methods of managing R&D projects, and to obtain their opinion on the PI collected via literatures research and other case studies. The obtained input from pilot test are then used to curate the overall concept of the DSM. The developed DSM was validated by the last 4 of the targeted stakeholders through experiences from past projects. The validation criteria will be based on the accuracy, applicability and display of the developed DSM. Edits and iterations were done based on the feedback obtained. The next section describes the concept of the proposed DSM based on the inputs collected.

4. Result and Discussion

The model's general philosophy is based on situations where a problem is encountered, anytime within the project period. The encountered problem could be identified when one or more important PI were not up to satisfactory level, hence signifying that actions have to be taken in order to mitigate the issue. As soon as a problem is identified, its corresponding PI can be grouped into one of the six main criteria as featured in the DSM, which will be explained in section 4.1. Relevant information regarding the PI shall then be obtained for data analysis, in order to determine its degree of influence to the entire project. The data analysis stage is crucial in providing a better foundation for decision making, as project managers would be able to manage potential risks or make reliable inferences based on the statistic trends. With the inferences and degree of influence determined, project managers would be able to decide whether the detected issue could be forgone, in maintaining smooth progress of the project. In a situation where the issue has considerably low influence on the project, the unsatisfactory PI could be forgone, therefore the manager could decide to adapt to it. On the contrary, if this issue has a significant influence on the project's continuity, an alternative has to be sought to resolve the situation. The proposed DSM will be particularly useful in this situation by proposing an alternative solution, fulfilling its objective in aiding project managers in the decision-making process. The next best alternative identified by the DSM will undergo the same analysis and judgement process mentioned above, with sufficient relevant information. This cycle could be repeated until an alternative solution is able to compensate for the issue. In cases where no alternative is suitable, project managers could consider re-scope, or in the worst scenario, termination. The decision-making flow described is illustrated in Figure 4.

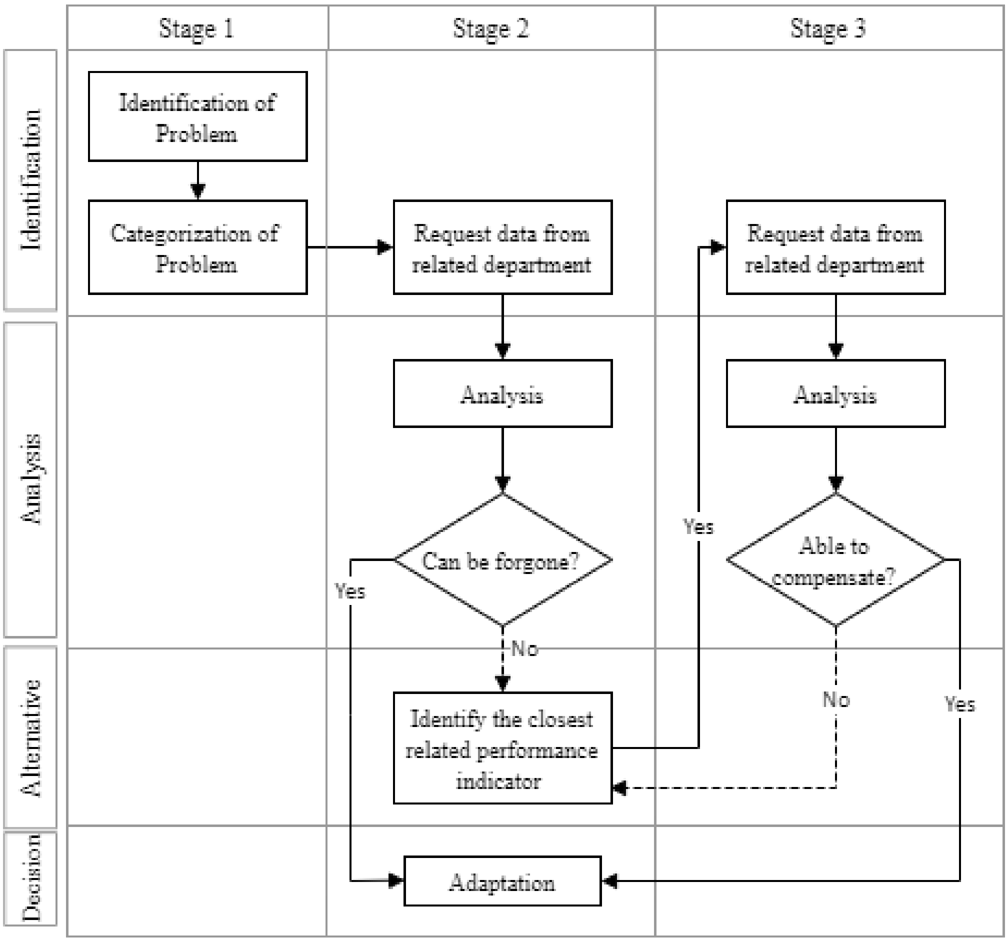

Figure 4. Decision-making flow based on proposed DSM.

4.1 The Proposed DSM

The proposed DSM consists of two PI parts: relationship diagram and prioritization calculation. The pilot test performed with first group of project managers has resulted in a finalized list of PI with its causal relationships, based on the R&D project managing experiences that the stakeholders have had. The finalised PI after discussions are profit margin, sales volume projection, market share, market growth projection, overdue tasks, capacity allocation, product failure rate, customer complaints, energy consumption and rework percentage. The finalised PI have been categorised into six main criteria, namely finance, brand performance, timeline, human resource, product performance and production. Figure 5 has shown the linear and/or inverse relations of each PI, categorised in their respective groups. Each of the arrows points towards other suggested PI, which could be acted upon as a solution to satisfy the PI where the arrow originated. For example, a concern from increasing overdue tasks could possibly be solved by increasing energy consumption in production processes, sacrificing the opportunity of seizing market share while competing with players in the same industry or reducing profit margin by injecting more capital to catch up with the progress.

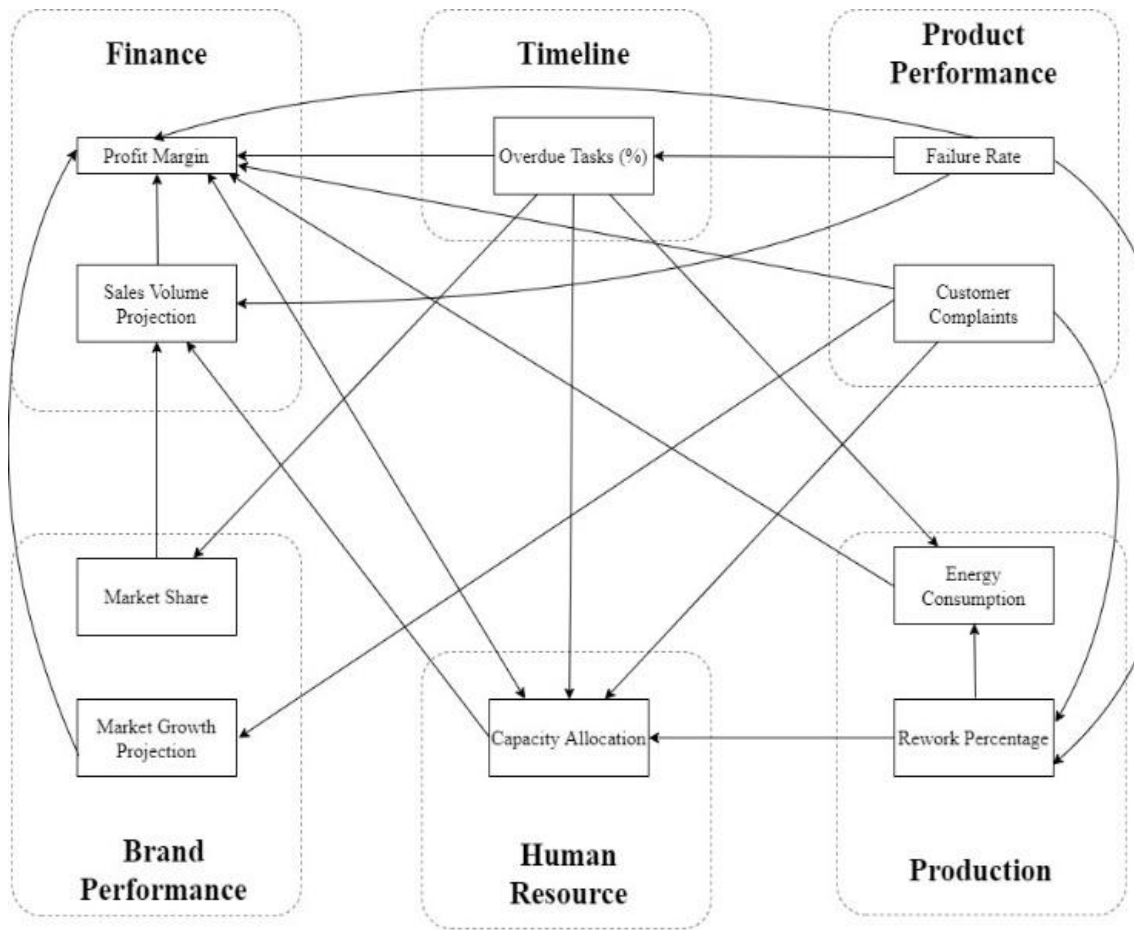

Figure 5. Part I of DSM: Key PI for R&D projects and the interrelationships, categorised in respective criteria.

Researches and pilot test have revealed that different projects would have different focus, resulting in different criteria and PI to prioritize. Therefore, it is important for a DSM to offer a certain degree of flexibility, so as to cater different project focuses and applications. Certain applications would reap more of DSM's benefits especially in time saving, when less criteria are considered during a decision-making process. However, there will be scenarios where more criteria are considered, as performances in most segments cannot be ignored in any circumstances. Therefore, flexibility of this proposed DSM comes from the freedom to select any number of important criteria to be studied. The criteria selected shall include the one containing the concerning PI.

Consequently, the selected group of criteria shall undergo an analysis stage to determine the ranking of PI based on its importance. This signifies that those that are less important, if linked to the concerning PI, would be a suggested variable to be manipulated in resolving the issue. The second part of the proposed DSM covers a method to rank the PI within the selected criteria. Prioritization of PI will be done by comparing each PI to one another in pairs.

The comparison of the pair of PI will be quantified by a linear rating scale of 1-5, also known as Likert scale. Rating 1 will signify that the subject PI is the least significant when compared to another PI, and rating 5 will signify the most significance. The Likert scale is selected for rating as studies have shown that scales that cover more than 5 options require higher cognitive ability, which might cause more complication and time taken when rating. Any scales that are less than 5 ratings have inadequate information, as they might only communicate directions and neutrality without the effect of magnitude (Revilla et al., 2014; Weijters et al., 2010).

A sample calculation of pairwise comparison and prioritization of PI is shown in Table 1. This sample has selected three criteria to be studied, with each of the PI labelled by alphabet letters. The numerical ratings are represented by two letters representing the PI that are being compared at each instance.

Table 1. Part II of DSM: Sample calculation of pairwise comparison and prioritization.

Criteria	Indicators	Sales Volume Projection	Profit Margin	Failure Rate	Customer Complaints	Market Share	New Market Possibilities	Score	Importance Ratio	Ranking
Finance	Sales Volume Projection (A)	AA	AB	AC	AD	AE	AF			
	Profit Margin (B)	BA	BB	BC	BD	BE	BF			
Quality	Failure Rate (C)	CA	CB	CC	CD	CE	CF			
	Customer Complaints (D)	DA	DB	DC	DD	DE	DF			
Brand Performance	Market Share (E)	EA	EB	EC	ED	EE	EF			
	New Market Possibilities (F)	FA	FB	FC	FD	FE	FF			
							Total score			

With each pair of PI compared, its reverse comparison of the same PI will form a reciprocal value, as illustrated in equation (1).

$$BA = \frac{1}{AB}; EC = \frac{1}{CE}, \ldots \tag{1}$$

Once each comparison pair has been evaluated and given a value, a score representing indicators will be calculated by multiplying all values in the same row. For example, the score for indicator A will be calculated as shown in equation (2).

$$\text{Score A} = \text{AA} \times \text{AB} \times \text{AC} \times \text{AD} \times \text{AE} \tag{2}$$

The following equation (3) shows that the score ratio of indicator A to the total score represents the importance ratio of that indicator.

$$Importance\ of\ indicator\ A = (Score\ A)/(\Sigma\ (Score\ A, B, C, D, E)) \tag{3}$$

Prioritization of PI can then be performed by ranking each of them based on the respective importance ratios. The least important indicator which is related to the unsatisfactory PI will suggest a corrective area to investigate. With the suggestion obtained by utilizing the DSM, better decisions can be made with the support of quantifiable information and analysis. Section 4.2 describes the verification of the DSM by applying it into past R&D projects to be studied.

4.2 Case Study Validation

In-depth discussions were performed with four experienced project managers. The studies were done based on their respective ongoing projects, or those that were handled in the past. During the discussion, the project managers utilised the DSM to re-enact the project scenario, in order to identify the more important PI, and the interrelationships. These discussions aim to verify the decision-making flow and the relationships of PI in Figure 5 With reference of the decisions made by project managers on past issues, the applicability of the pairwise comparison prioritization calculation in Table 1 can be tested and verified.

Company A has an ongoing NPD project to venture into a new market in a different country. There were numerous difficulties as the project's sales volume projection was not achieved. In the discussion, the project manager attempted to apply the proposed DSM and selected the three most important criteria: finance, quality and brand performance. Referring to Figure 5, in order to rectify sales volume concerns, the direction of outward arrow shows that profit margin could be the PI to compromise. After performing pairwise comparison as shown in Table 2, the DSM analysis showed the important PI in descending order are profit margin, market share, sales volume projection, customer complaints, failure rate and new market possibilities. The outcome of the DSM analysis suggests that profit margin would be the PI to forgo. This outcome tallies with the action taken by the project team after several meetings. Therefore, this case study contributes to the verification of the relationship chart and the pairwise comparison model.

Table 2. Part II of DSM: Calculation of pairwise comparison and prioritization for company A.

Criteria	Indicators	Sales Volume Projection	Profit Margin	Failure Rate	Customer Complaints	Market Share	Market Growth Projection	Score	Importance Ratio	Ranking
Finance	Sales Volume Projection	1	3	1/3	1/3	3	1/5	0.20	0.00	4
	Profit Margin	1/3	1	1/5	1/3	1	1/5	0.00	0.00	5
Product Performance	Failure Rate	3	5	1	3	5	1	225.00	0.37	2
	Customer Complaints	3	3	1/3	1	3	1/3	3.00	0.01	3
Brand Performance	Market Share	1/3	1	1/5	1/3	1	1/5	0.00	0.000	5
	Market Growth Projection	5	5	1	3	5	1	375.00	0.62	1
								603.21		

The launch of one a new product by company B had many customer complaints, resulting in a recall of all product units in the market. Figure 6 shows the focused relations that could mitigate customer complaint issues.

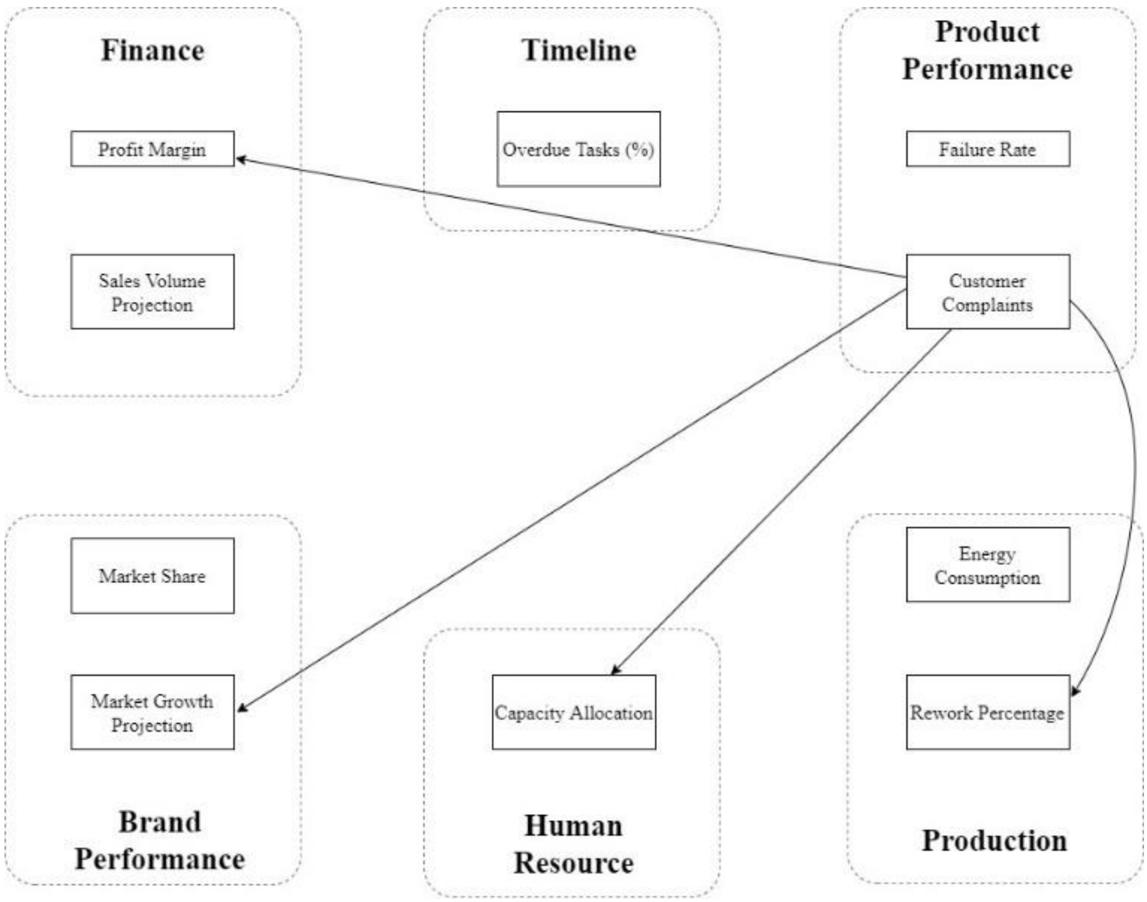

Figure 6. Part I of DSM: Key PI in mitigating customer complaint issue.

Referring to Figure 6, with human resource being a limiting factor of the company and production factor not considerable in this case, the considerations for solving this issue would be to sacrifice brand or finance performance. The pairwise comparison of PI under these aspects have shown that market growth potential, sales volume projection and profit margin are the three most important PI of the project, as shown in Table 3. Analysis by the interrelationship chart has shown that the complaint issue could be solved by considering the sacrifice of profit margin or the potential of market growth. However, since the DSM has shown that market growth potential ranked higher in terms of importance, the suggested solution is to compromise its profit margin. With both options being crucial to the project, it was a difficult decision for the stakeholders. The management have decided to sacrifice profit margin in this case, to the extent that it has resulted in a loss to the project.

Table 3. Part II of DSM: Calculation of pairwise comparison and prioritization for company B.

Criteria	Indicators	Sales Volume Projection	Profit Margin	Market Share	Market Growth Projection	Score	Importance Ratio	Ranking
Finance	Sales Volume Projection	1	3	1	1/3	1.00	0.04	2
	Profit Margin	1/3	1	3	1/4	0.25	0.01	3
Brand Performance	Market Share	1	1/3	1	1/2	0.17	0.01	4
	Market Growth Projection	3	4	2	1	24.00	0.94	1
						25.42		

Company C's product development and market share was challenged when a new technology emerged to compete in the market. Other than market share, timely completion of tasks and profit margin were the other key concerns of the project. Coincidentally, Figure 7 has shown that the available routes that could be considered to mitigate this issue are compromising the timeline and financial aspects.

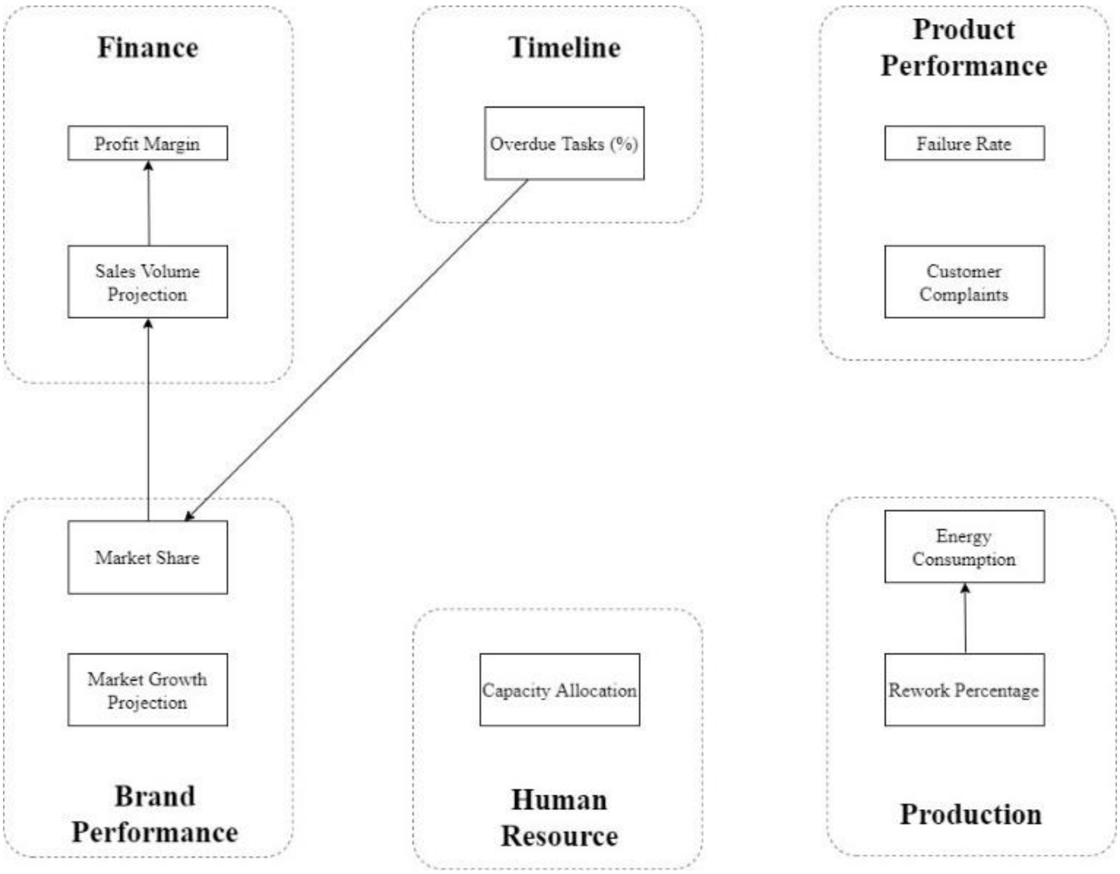

Figure 7. Part I of DSM: Key PI in mitigating market share issue.

With its goal to maintain its market share, PI analysis with the pairwise comparison has shown that the importance of timeline aspect comes before financial performance, as company C was competing in a timely manner. However, profit margin was also a crucial PI that could not be compromised, as continuation of this project would provide limited to no value to company C if profit margin were to be forgone. Hence, with no other options, company C adapted to this challenge with termination of project.

Discussions with the interviewed project managers have proven that the proposed DSM is able to provide decision guidance across the general R&D project managing scenarios. PI interrelationships representing project concerns of company A, B and C, as shown in Figure 6 and 7, have provided general options for solutions. The prioritization of PI in Table 2 and 3 shown that the rankings with suggested decisions was align with the actual decisions. The provided flexibility of choosing only the concerned criteria to be studied has also been proven to be useful in all cases. The DSM could have saved intensive communication efforts, crossing several levels of management. This verifies that the proposed DSM is able to reduce effort and additional resources in a decision-making process.

5. Conclusion

The main contribution from this research is the proposed DSM which displays interrelationships of R&D PI categorised according to different considering criteria, and a pairwise prioritization calculation to determine the importance of each considered indicators. The development of the proposed DSM is based on an extensive literature review which helped identify the most common PI measured in the R&D projects. In-depth interviews and case studies with experienced project managers in the engineering R&D field were crucial in achieving a deep understanding of decision-making flows and PI relationships. The finalised PI consist of profit margin, sales volume projection, market share, market growth projection, overdue tasks, capacity allocation, product failure rate, customer complaints, energy consumption and rework percentage. The finalised PI have been categorised into 6 main criteria, namely finance, brand performance, timeline, human resource, product performance and production. The proposed DSM included a method for pairwise comparison and prioritization of PI, in order to rank them based on their importance to the project. The least important indicator, if linked to the concerning PI, would be a suggested variable to be manipulated in resolving a problem that the project may be facing. This research has introduced a tangible and systematic decision-making plan for the engineering R&D project managing sector. The proposed DSM will be able to increase the efficiency of decision-making, in return reduce the time taken to respond to an encountered issue.

However, application of the DSM is limited to a few factors. The proposed DSM contains the prioritization part where numerical rating is required. The association of numerical value associated to each comparison might be subjected to biasness. In addition, the intervals between each rating may not be equidistant, therefore affecting the true measure of PI importance. The proposed DSM is developed based on a total of ten interview analysis only. Improvisation can be done by performing more case studies with the DSM and applying it in a real project scenario where ongoing decisions have to be made. The end goal of the DSM is to develop a practical DSS. Therefore, future research efforts may focus on integrating this DSM with information technology systems to develop a user-friendly software.

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