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RESEARCH ARTICLE

A Multi-Criteria Decision-Making for Legacy System Modernization With FUCOM-WSM Approach

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ABSTRACT Modernizing legacy software has always been a core concern of businesses and industries that strive to improve their performance. However, decision makers fail to address each criterion's concerns and provide precise solutions for how legacy software modernization can be implemented. This paper proposes a new Multi-Criteria Decision-Making (MCDM) method for legacy software modernization. The aim of the proposed method is to rank different software modernization solutions based on the predetermined evaluation criteria. The evaluation criteria considered in this work include Motivating Factors and Challenges criteria that possibly affect legacy software modernization. The method introduced is a combination of the Full Consistency Method (FUCOM) and Weighted Sum Method (WSM), in which FUCOM is used to maintain the reliability of the decision model and WSM to calculate overall importance or weight of each criterion in the decision-making process. This MCDM method is formulated to obtain the most optimal solution that satisfies the evaluation criteria defined by industrial stakeholders based on the survey conducted. A case study on modernizing legacy billing software for a telecommunication company is used to further illustrate the implementation of the proposed methodology in different situations.

INDEX TERMS Legacy software modernization, MCDM, FUCOM, WSM, software engineering.

I. INTRODUCTION

Legacy software modernization is an inevitable continuous practice within industries that relies on technology in their business execution. To avoid the risk of becoming obsolete and degrading the existing system architecture, modernization is a much-needed approach for the business to stay relevant in today's competitive market. Unfortunately, many companies still did not foresee the impact of retaining the legacy software, believing that it would last a long time. The risks of retaining old legacy systems go way beyond just dealing with slow processes or heavy maintenance. It could cause major security issues, lack of system support, brand or loyalty damage, low employee productivity, and many more. As legacy systems are considered the main core of an organization, failure of the system could have a severe impact on the organization's ability to perform its business [1].

Lehman [2] states that the performance and behavior of the system will degrade over time, and remedial action needs to be taken in order to keep the software running as intended [3]. Since most of the legacy systems are large at scale, it is hard to maintain and may cost a lot. The system typically consists of hundreds of thousands of lines of code, and it is hard to find the resources of experts in the programming language that has become obsolete. Furthermore, the cost of hiring these experts might be high since the skill is now rare and no longer in demand within the market. Thus, regardless of sectors, modernization is ultimately important to cope with the evolving software and technology once the current system is considered a legacy.

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However, modernizing legacy software is a complex scenario where the possibilities of failures and hiccups may affect various areas of implementation. Practitioners could face various issues in regards to the modernization, such as the size of required changes, system age, or the application area's maturity [4]. Therefore, improving decision making processes is necessary to minimize the risk of failure.

With the ongoing proliferation of decision methods and their variants, it is important to be aware of their significance. In order to help decision-makers opt for the best among a distinct set of alternative choices, each of the approaches uses numerical techniques. This is framed in terms of the impact on certain criteria of the alternatives and therefore on the judgment of their worth by the decision-maker. The challenge that often occurs when trying to compare decision methods and opt for the right one is to choose the best decision-making method.

Due to multiple criteria to be considered, it is difficult for decision-makers to determine the best and most suitable approach for modernizing their legacy software [5]. To overcome this problem, this paper conducts an extensive review of the existing MCDM method and application to pinpoint important and common approaches to modernizing legacy systems. Subsequently, this research aims to formulate a method for multi-criteria decision making (MCDM) in legacy software modernization by adapting a combination of FUCOM and WSM, followed by evaluating the efficacy of the devised approach according to the domain of the business industry. Both methods are often used together to ensure that the decision model is reliable and free from inconsistencies. The method contributes towards achieving traceability in decision-making processes by having the records of the criteria considered and deriving decisions based on the method's output. Hence, eliminating the intuition-based decision-making process faced by most organizations. Furthermore, it could serve as a reference for researchers to design new studies moving forward.

II. LITERATURES REVIEWS

A. LEGACY SYSTEM AND SOFTWARE MODERNIZATION

The topic of software modernization is influenced by various factors. To start off, in order for a system to be considered a legacy, the aspect of programming language is the main deciding factor, as it is the core component in building the software system. Conversely, Galinium and Shahbaz [6] emphasize five key success factors for modernization, particularly in the successful migration of existing legacy systems to service-oriented architecture (SOA). These factors encompass the company's business processes, the potential of legacy systems, legacy architecture, close monitoring, and SOA governance.

Strategic selection of criteria is vital in assisting decision makers to perform modernization decisions. Thus, all decisions should be based on systematically considering a comprehensive set of decision criteria. However, according to Koskinen, et al. [4], there are 20 important criteria in software modernization decisions and it is practically impossible to take into account all the stated criteria. Therefore, conducting a survey among professionals is one way to define which particular criteria should be focused on. Contrary to previous research, this study will be focusing more on performing research based on the Motivating Factors and Challenges of legacy software modernization criteria.

Substantial research alternatives have been proposed to address the issue of legacy modernization. Applying those tactics differs from one case to another, since they heavily rely on the modernization's goal or the organization's objectives. These solutions are categorized as follows:

1) Redevelopment/Reengineering [1]: involves the rewriting of the application. Reengineering usually adopts SOA to rebuild the old system with the same or added functionality. However, this method requires the old system to be shut down in the process of cut-over to the new system. This method is also the most costly approach since it will require more time and budget to develop a whole new system. These drawbacks are making some industries such as banking, which is critical in their downtime and data security, end up with using the old and outdated system as long as the legacy system could still run and serve the purpose.

2) Wrapping [1], [7]: is a solution that surrounds legacy systems with a software layer that hides the unwanted features of the old system and exports a modern interface. The main advantages of this method are that it requires low cost and needs the least amount of time to complete the modernization. However, this is more to a short-term solution, as the back end of the system will still comprise the old code of the legacy system, and it will still need to be modernized one way or another.

3) Migration [1], [8]: relocates the legacy system to a more versatile environment while preserving the data and functions. Migration usually consists of changing the programming language used, changing the database, and changing the platform. This method is more suitable as a long-term solution, mitigating the risk of system downtime and being more cost efficient as compared to redevelopment. Although this method might seem like the best option, it does pose several common challenges. These include target system development, testing, database model selection, database population, and cut over with mission critical support.

4) Re-hosting [7]: usually applicable to mainframe software, where the legacy applications and data is migrated to an open environment consisting of servers, and then replacing the middleware, operating system (OS) and the database with a similar open environment. With this approach, the system will keep running as it was running on the mainframe, with the benefits of the open environment and incorporation of new technologies.

5) Package Implementation [6]: is the replacement of the legacy system with commercial-off-the-shelf (COTS) software, such as Enterprise Resource Planning (ERP) or Customer Relationship Management (CRM). COTS can be purchased, leased, or even licensed to the general public. The main advantage of this method is that all of the standard functions are already included in the package, and modernizing the legacy system using this method will be straightforward. Yet, some level of reengineering or customization of packages and rewriting of business logic may be involved in this process as well.

Good number of research was conducted in the context of reviewing the legacy system modernization. For example, Abdellatif and his research collogue in [9] have worked to delves into reviewing the migration of legacy systems, striving to develop a versatile and flexible framework applicable to a broad spectrum of legacy applications. Their framework proves beneficial for four migration approaches: incremental migration, partial migration, complete migration, and wrapping.

Shahba, et al. [10] conduct a systematic mapping to explore the reengineering of legacy applications into Software Product Lines (SPLs), characterized by systems sharing common assets for disciplined reuse. SPLs typically evolve from existing systems that undergo a reengineering process rather than starting from scratch. Given the extensive interest in this research domain, a systematic mapping study was undertaken to offer an overview of the current research landscape concerning the reengineering of existing systems into SPLs.

Singh, et al. [11] on the other hand, focus on identifying community activity related to venues and publication frequency in the field of legacy system modularization. The aim is to highlight trends and unresolved issues that can guide future research. With a dataset of 119 pertinent publications, the primary sources were categorized along six dimensions: reengineering phases, applied strategies, types of systems in evaluation, input and output artefacts, and tool support. The analysis reveals a well-established community in this domain, showcasing a diverse range of strategies for various reengineering phases and tasks, along with the availability of tools. The study also pinpoints open issues and potential research areas, such as enhancing automation and tool support, utilizing different information sources, refining feature management, defining ways to integrate diverse strategies and methods, addressing the lack of sophisticated refactoring, and developing new metrics for more robust empirical evaluation.

A Systematic Literature Review (SLR), as documented in [12], has been conducted to explore the transition of legacy systems to Service-Oriented Architecture (SOA), incorporating findings from 121 primary studies. The assessment employs an evaluation framework derived from three prevalent methods in the software re-engineering domain. Meanwhile, in the work of Mažeika and Butleris [13], the research evaluation serves as an inventory of current research approaches, methods, and techniques employed in the evolution of legacy systems to SOA.

Given the extensive research of legacy software modernization encompassing various topics, it is crucial to understand the significance of this initiative as it able to assist in enhancing organizational efficiency, improving security, and technological adaptability [14].

B. MULTI-CRITERIA DECISION MAKING (MCDM)

MCDM is a well-known subset of the general category of operational research models that deal with decision-making problems in the production of a variety of decision-making criteria. As part of operations research, MCDM [15] has progressed to design computational and mathematical methods to support the subjective assessment by decision-makers of performance criteria [16]. In fact, MCDM has been applied to several domains, such as energy planning [17], [18], location planning [19], building information modeling [20], robotics [21], and even in COVID-19 risk factor [22]. The application of MCDM in legacy Software Modernization is fairly new. Nevertheless, the successful implementation in assisting previous decision-making processes in a variety of areas of research proves that MCDM is highly effective in easing the processing of legacy software modernization.

With multiple techniques offered, cracking solutions by resembling this process can give tolerance in uncertainty value, thus giving a unique solution. Compared to the traditional approach, the chances of maximizing goals using this exact solution are preferable. Currently, there are many different methods for MCDM. The following are some of the most popular and well-known methods for practical use: Weighted sum method (WSM) [23], [24], Weighted product method (WPM) [25], [26], Analytical hierarchy process (AHP) [27], Preference ranking organization method for enrichment evaluation (PROMETHEE) [28], [29], Elimination and choice translating reality (ELECTRE) [30], Technique for order preference by similarity to ideal solutions (TOPSIS) [31], Compromise programming (CP), and Multi-attribute utility theory (MAUT) [32].

Based on the eight different methods of MCDM reviewed, WSM seems to be the most appropriate measure for this research as it can be used easily in single-dimensional situations, in which all the units or elements are the same [33]. Hence, the implementation of the WSM method that offers high simplicity and performance is sufficient to see if the method is also applicable in the software modernization area of research.

A relatively newer approach for MCDM is the full consistency method (FUCOM) method that belongs to the subjective determination of weights of criteria [34]. It reduces the number of pairwise comparisons and offers validation through deviation from maximum consistency (DMC). Furthermore, it also allows for the flexibility of adoption of measurement scales as per expert preferences. It is used to calculate weight and that weight will be further utilized in the next phase of the MCDM method.

Thus, the current paper proposes a new approach on developing a method for multi-criteria decision making (MCDM) in legacy software modernization by adapting a combination of WSM and FUCOM methods, implemented using

MATLAB. By taking the most important criteria of each Motivating Factors and Challenges, the method would recommend the best approach for legacy software modernization based on the calculation of ranking of the listed approaches.

III. METHODOLOGY

A successful process of modernization for existing legacy software systems requires a holistic approach to analyze and evaluate the risks and benefits of available options versus the most suitable combination of modernization techniques. In this section, this study presents a proposed methodology framework to guide the process of selecting legacy modernization options in a systematic manner.

However, before going further on the method, another important structure that needs attention is expert selection and how the process of acquiring their responses happens. The flow of actions taken in order to recruit specialists with sufficient knowledge and trustworthy judgement on the topic is established through the following steps:

Step 1: Identify requirements for experts. The requirements for recruiting experts in this study include individuals with relevant expertise in software development, legacy systems, modernization techniques, and related domains. For example, software engineers, engineers, project managers, and those with experience and took part in legacy software modernization.

Step 2: Prepare materials. The survey form and material to facilitate expert review process is developed to obtain experts' opinions and responses on the subject matter.

Step 3: Approach and conduct survey. Approach experts that satisfied the requirements as in Step 1 and conduct the survey with targeted participants. Let the experts evaluate the criteria and express their opinion based on the Likert scale.

Step 4: Document responses. Gather and record all the responses of the experts. This step includes transforming all the answers into suitable forms of data for analysis and applying the chosen MCDM method.

The main goal of the study is to define criteria that inspire legacy software modernization and the challenges faced along the way, followed by developing a MCDM method appropriate for the topic at hand, and finally evaluating the method developed via the implementation through a case study. To achieve this goal, the methodology of this study is composed of the following steps as shown in Figure 1.

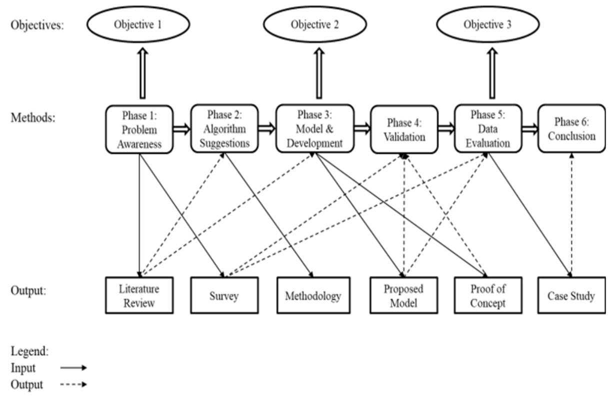

FIGURE 1. Proposed methodology framework.

A. PHASE 1: PROBLEM AWARENESS

Recognizing problems is a fundamental process in doing research. By reviewing previous research and literature related to Software Modernization of a Legacy System and Multi-Criteria Decision Models, research gaps and problems in the area of research are recognized and identified. Using comparative analysis, elements from the studies are compared in order to provide solutions for the problem faced in the modernization process and avoid redundant works.

B. PHASE 2: METHOD SUGGESTION

Subsequently, a survey was constructed based on the literature reviews to observe the real landscape of Software Modernization performed by companies as a preliminary study. All the methods, criteria, as well as drives that motivate the effort of modernizing an old system are carefully analyzed based on the survey responses from the perspectives of those that are involved in the process. In due course, eight different studies of the MCDM methods as a solution were examined through literature reviews to determine which is the most popular and preferred by those within the industries. The analysis and data obtained are used to support the results of the MCDM method by employing cross referencing analysis. A proven approach was required as the solution. As such, careful consideration of approaches by referring to previous studies is able to optimize the results produced by the method.

C. PHASE 3: MODEL & DEVELOPMENT

In this phase, a customized approach built upon the chosen MCDM method was introduced. This study combined the Weighted Sum Method (WSM) of the existing MCDM framework with the Full Consistency Method (FUCOM) for weightage determination. This is a modified approach proposed to cater to the data and environment of the study. Contemporary implementation of WSM typically set their weightage based only on expert reviews. Meanwhile, FUCOM took the common factors from the survey that has been conducted in calculating the weightage. Hence, the combination of WSM with FUCOM aims to enhance the approach based on statistical calculations. Development processes manifest the approach to be tested as a proof of concept. A simple application was built with the corresponding approach using MATLAB software tools, thus simplifying the process in verifying and validating the results produced.

D. PHASE 4: VALIDATION

The method developed was put into test to verify the effectiveness in solving the problem and assisting in facilitating the process of modernizing the legacy software. In this phase, a real-life case study involving an IT company that is undergoing legacy software modernization will be used to validate the findings of the preliminary study. The adoption of the developed method in actual situation showcases the applicability of the method to be used in real-world context. Additionally, the case study allows for comparison between the chosen method and another decision-making technique. The details of the case study can be found in chapter 4 of the research.

E. PHASE 5: DATA EVALUATION

In regard to this section, a case study on modernizing a legacy billing system of a Telecommunication Company was used in order to evaluate the effectiveness of the approach implementation at the actual business level. The structure of the research and analysis is similar to the initial preliminary study, which began with a survey of respondents involved in the modernization process for that specific company. However, the items and questions within the survey are limited to only the parts needed for the approach, including only the four topmost criteria and approaches listed. Besides achieving the research results, additional findings related to software modernization in Malaysia for telecommunication were also discovered. Though it is not as important as the intended research, these findings were hopefully able to help other researchers understand more about the condition of the legacy system in Malaysia. Details of the findings are shared in VI.

F. PHASE 6: CONCLUSION/OUTCOMES

Finally, the overall achievements of the research from the experiments and analysis that have been conducted were concluded. Fulfillment of research objectives was valued based on the accomplishment of the study, including its contribution to the study field. The limitations and weaknesses of the method developed were listed as a lesson learnt. Not only that, but any possible improvements for future works are recommended to ensure continuous enhancement on the approach and as a hint to others on areas that can be further improved to bring the method close to perfection.

In this research methodology, multiple stages with various processes were planned to fit the purpose of this research. It is important to achieve a trustworthy methodology to weigh this research's reliability. To validate the reliability and validity of the proposed approach, a survey-based experiment and case study, several steps are essential. Start by defining the constructs and ensuring that survey items accurately represent them. Verify content validity through expert review and pilot testing. Assess criterion-related, convergent, and discriminant validity by comparing survey results with established measures. Through these steps, researchers can confidently validate the quality of the proposed survey and its findings.

Careful procedures have therefore been planned to ensure that this study achieves its purpose and can be further taken advantage of as a reference by others in future studies that are centered on legacy software modernization. Besides, it makes it easier for others to replicate the decision criteria studies and methods implemented, eventually solidifying the existing knowledge.

IV. PRELIMINARY STUDY

The goal of this study was to determine criteria from both Motivating Factors and Challenges that may affect legacy software modernization. As such, this study is started through pilot study that conducts a survey addressed to 29 participants, covering 10 different domains of industries in Malaysia. The questionnaire is classified into three sections, in which Part A covers the respondents' overall demographic information. Part B consists of criteria designed based on options that adopt 7-pointer likert-type scales that comprise sets of evaluation criteria ranging from problems, motivating factors, commonly used approach for legacy system modernization, and up to obstacles in the migration approach of legacy system modernization. Lastly, Part C contains items related to rational decision making and improvement, where it highlighted issues of academic role in software modernization.

Table 1 shows the demographic profile of experts participating in this research. The majority of experts have approximately 5 to 10 years of working experience in the industry, with 13 individuals, representing 44.8% of the respondents. 9 (31%) experts have around 2 to 5 years of experience, 6 (20.7%) have 1 to 2 years of experience, and only 1 (3.5%) participant with more than 10 years of experience. Notably, with 12 (41.4%), respondents with the role as system analyst within the organization constitute a significant portion of the surveyed experts. Meanwhile, the rest are IT consultant (6.9%), developer (31%), IT executive (3.5%), IT manager (6.9%), system engineer (6.9%), and service support (3.5%).

Table 1 also presents the domain of organization the experts originated from, with 24.1% working with software company. The financial and manufacturing sectors trail closely behind, each with 17.2% of respondents. Followed by consulting (10.3%), government (3.5%), academic/IT research (6.5%), logistic (3.5%), power generations and utilities (3.5%), service provider (3.5%), and telecommunication (10.3%).

The survey is developed and instrumented based on Khadka, et al. [35] and Koskinen, et al. [4]. In order to determine the factors that affecting the practice of legacy software modernization and understand the perspective of those related to the subject of discussion, this research focus on 4 key issues, namely, problems, motivating factors, approaches for legacy software modernization and obstacles of most voted approach.

As the survey results are determined by adding up scores from a likert scale, a higher score indicates stronger agreement with the statement. Table 2 represents the scores of relevant problems and the concerns related to legacy software modernization.

TABLE 1. Demographic profile of experts.

Demographics	Description	Number	Percentage (%)
Working Experience	>10 Years	1	3.5
	5-10 Years	13	44.8
	2-5 Years	9	31.0
	1-2 Years	6	20.7
	Total	**29**	**100**
Role	IT Consultant	2	6.9
	Developer	9	31.0
	IT Executive	1	3.5
	IT Manager	2	6.9
	System Engineer	2	6.9
	Service Support	1	3.5
	System Analyst	12	41.4
	Total	**29**	**100**
Domain of Organization	Consulting	3	10.3
	Financial	5	17.2
	Government	1	3.5
	Academic/IT Research	2	6.9
	Logistic	1	3.5
	Manufacturing	5	17.2
	Power Generations and Utilities	1	3.5
	Service Provider	1	3.5
	Software Company	7	24.1
	Telecommunication	3	10.3
	Total	**29**	**100**

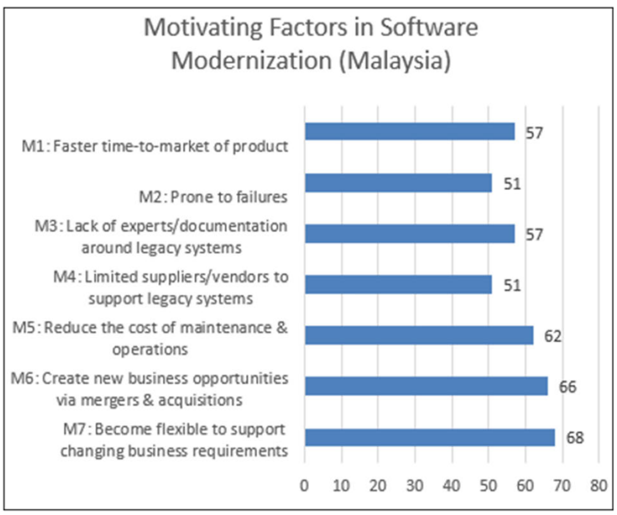

FIGURE 2. Motivating factors that may influence software modernization in Malaysia according to participants.

Based on the responses of the participants, Figure 2 highlights several motivating factors that drive the act of modernizing legacy software in an organization.

TABLE 2. Problems in legacy system modernization.

Problems	Results	Percentage (%)
P1: Lack of documentation	93	62.0%
P2: Lack of experienced manpower	99	66.0%
P3: Limited suppliers/vendors to support and maintain	87	58.0%
P4: Unable to adequately support, maintain, or enhance in house	85	56.7%
P5: Incompatible with current and/or future technological environments	94	62.7%
P6: Too rigid to comply with new business requirements	96	64.0%
P7: Monolithic architecture	84	56.0%
P8: High risk of failure	95	63.3%
P9: Poor user interface	92	61.3%
P10: Too costly to maintain	93	62.0%
P11: System correctness	89	59.3%
P12: System efficiency	97	64.7%
P13: Expected remaining system lifetime	98	65.3%
P14: Size of required changes	104	69.3%
P15: Delocalized system logic	91	60.7%
P16: System complexity	95	63.3%
P17: Application area's maturity	102	68.0%
P18: New technical opportunities	95	63.3%
P19: System age	103	68.7%

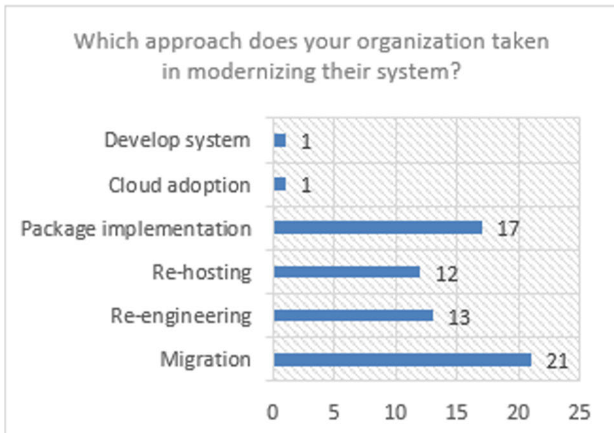

FIGURE 3. List of approaches in modernizing legacy systems and the preferred approach to be taken by the organization according to the participants.

Alternatively, Figure 3 illustrates several approaches taken by the organizations in modernizing their legacy systems, along with employee feedback on these actions. It presents a list of approaches in modernizing legacy systems and the preferred approach according to the participants' opinions.

According to Figure 3, the migration method has become the most popular choice among software practitioners in Malaysia. Thus, it is relevant for this study to get more details on the obstacles faced by the organization in carrying out the migration method, as these obstacles could also be challenges faced even with different approaches taken. Table 3 shows obstacles faced by software practitioners in the legacy system migration process.

TABLE 3. Percentage of challenges/obstacles in migration.

Challenges/Obstacles	Score	Percentage (%)
Data migration	81	67.5
Lack of resources (e.g., documentation, experts)	76	63.3
Poor system architecture or infrastructure (e.g., monolith, hardcoded)	76	63.3
Difficult to extract business rules/knowledge	85	70.8
Difficult to test	72	60.0
Resistance from the current users/maintainers in the organization	70	58.3
Cultural resistance in organization not to adapt new system	67	55.8
Difficult to effectively prioritize the functionality for modernization	73	60.8
Difficult to communicate the reasons/consequences of modernization	75	62.5
Funding legacy modernization project	83	69.2
Time constraints to finish legacy modernization	89	74.2
Predicting Return of Investment (ROI) of modernization	83	69.2

V. DESIGN AND IMPLEMENTATION

The proposed method of integrating WSM with FUCOM will be conducted via MATLAB software tool using criteria obtained from the survey.

A. SELECTING CRITERIA

Among all the criteria listed, only the four topmost Motivating Factors and Challenges will be further utilized in understanding the drives of software legacy modernization from the experts' perspectives. These criteria will be run in separate execution since Motivating Factors is the positive criteria that drive the modernization, and Challenges are bound to be the negative aspects that hold back the modernization in determining the legacy software modernization. These criteria will be examined further to determine their weightage and cross-referenced with the preferred approach.

The list of criteria in Table 4 and Table 5 is among the four highest responses from the survey and will be an input for the MCDM method to find the best approach in modernizing legacy software based on survey data for general practices. In assessing Motivating Factors, we consider responses marked as Strong (scored as 1) and Very Strong (scored as 2). For Challenges, responses labeled as Challenging (scored as 1) and Very Challenging (scored as 2) are taken into account. Hence, the top 4 criteria are listed as follows:

B. METHOD PROPOSED FOR MULTI-CRITERIA DECISION-MAKING METHOD

This study chose a combination of FUCOM and WSM method to calculate the weight of each criterion for both Motivating Factors and Challenges. Using MATLAB, these

TABLE 4. Motivating factors with the number of score.

	Motivating Factors	Score
C_1	Become flexible to support changing business requirements	65
C_2	Create new business opportunities via mergers & acquisitions	54
C_3	Reduce the cost of maintenance & operations	50
C_4	Lack of experts/documentation around legacy systems	44

TABLE 5. Challenges with the number of score.

	Challenges	Score
C_1	Time constraint	47
C_2	Difficult to extract business rules/knowledge	46
C_3	Funding legacy modernization projects	44
C_4	Predicting Return of Investment (ROI) of modernization	38

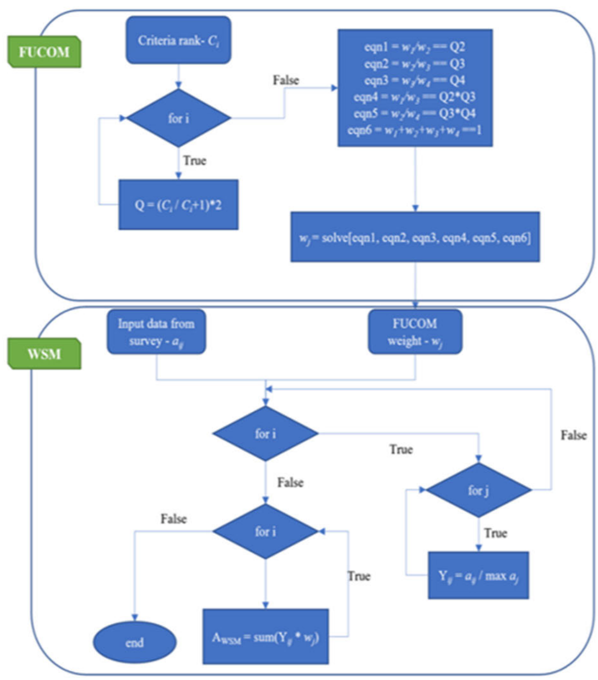

FIGURE 4. System flowchart for FUCOM and WSM in MATLAB.

two methods will be translated into series of codes to analyze and conduct calculation at each step for accurate results. The system developed will be proof of concept system that can be utilized by the decision-maker in the industry. Figure 4 below summarizes the flowchart of the system process for FUCOM and WSM within MATLAB

1) FULL CONSISTENCY METHOD (FUCOM)

According to the flowchart, this study initially implements the FUCOM method on the data obtained from the questionnaires to calculate the weight of each criterion for both

TABLE 6. Vector of comparative priorities of the evaluation criteria.

Criteria	C_1	C_2	C_3	C_4
$\phi k/(k+1)$	1.00	1.33	1.50	1.60

Motivating Factors and Challenges. Instead of relying on direct weight assignments based on expert opinions, this study opts to establish the approach's weightage through FUCOM calculations. Here, the criteria from a set of evaluation criteria are defined and ranked. The calculation process is detailed as below:

Motivating Factors:
$C_1 = 65, C_2 = 54, C_3 = 50, C_4 = 44$
Challenges:
$C_1 = 47, C_2 = 46, C_3 = 44, C_4 = 38$

The survey results indicate that $C_1 > C_2 > C_3 > C_4$. The criteria are then assigned with rank as $k = 1, 2, 3, 4$. Utilizing the k values, the $k/(k+1)$ is computed based on the various values of k, resulting in the following set of: [1/2, 2/3, 3/4, 4/5], as in (1).

$$\Phi = (\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{k/(k+1)}) \quad (1)$$

The results are then normalized, by 0.5 to 1, with the suppose scale of $\varpi Cj_{(k)} \in$ [1], [9], as in Table 6.

The weight calculations using the specific method resulted in the following given ratios:

1. w1/w2=1.33
2. w2/w3=1.50
3. w3/w4=1.60
4. w1/w3=1.33·1.50=1.995
5. w2/w4=1.50·1.60=2.40

This provides a hierarchical understanding on the relative importance of the criteria. These initial weight ratios will be further used in the technique to obtain the final values of the weight coefficient. In the next step of FUCOM, the computation is further computed following (2).

$$\begin{aligned} &\min \quad \chi \\ &s.t. \quad \left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)}\right| \leq \chi, \forall j \\ &\quad \left|\frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, \forall j \\ &\quad \sum_{j=1}^{n} w_j = 1, \forall j \\ &\quad w_j \geq 0, \forall j \end{aligned} \quad (2)$$

From there, the approach yielded the final values of the weight coefficient: 0.3896484375, 0.29296875, 0.1953125, and 0.1220703125. These values represent the relative importance or weights assigned to each criterion in the decision-making process. Apart from that, the technique achieved $x = 0.00$ for the result of deviation from full consistency (DFC). These obtained coefficients and the zero deviation from full consistency signify a robust and reliable decision-making model.

TABLE 7. Weightage of motivating factors with FUCOM.

	Motivating Factors	Weightage
w_1	Become flexible to support changing business requirements	0.3896484375
w_2	Create new business opportunities via mergers & acquisitions	0.29296875
w_3	Reduce the cost of maintenance & operations	0.1953125
w_4	Lack of experts/documentation around legacy systems	0.1220703125

TABLE 8. Weightage of challenges with FUCOM.

	Challenges	Weightage
w_1	Time constraint	0.3896484375
w_2	Difficult to extract business rules/knowledge	0.29296875
w_3	Funding legacy modernization projects	0.1953125
w_4	Predicting Return of Investment (ROI) of modernization	0.1220703125

Table 7 and Table 8 indicate the weightages attained using FUCOM for both Motivating Factors and Challenges criteria.

These results are further leveraged in the later part of the study where they will be segregated in the of WSM method to determine the ranking of the listed approaches.

2) WEIGHTED SUM METHOD (WSM)

Equation (3) will be carried out to compute WSM. In general, the actual computational process involved summing up the product of weights and corresponding values of each criterion.

$$A_i^{WSM} = \sum_{j=1}^{n} w_j x_{ij} \quad for\ i = 1, 2, 3 \ldots n \quad (3)$$

WSM method requires the process of normalizing the decision matrix to a scale that can be compared with all alternative ratings. In the above formula, A_i denotes the preference score according to the approach to select the best alternative. x_{ij} is the performance value extracted from the survey and cross-checked with the respondent preference approach. On the other hand, w_j are the weights of each criterion that has been calculated via FUCOM, previously.

Table 9 and Table 10 denote the WSM results obtained for each approach based on the criteria of Motivating Factors and Challenges that garnered the score of 1 and 2 in the survey. Using preference score, all approaches can be ranked accordingly and the higher the preference score, the better the rank, which indicates a better approach or alternative.

Within MATLAB, the system UI and calculations done can be referred to Figure 5 for FUCOM as well as WSM results.

VI. CASE STUDY

A simple case study was conducted with a telecommunication company located in Shah Alam, Malaysia. Using the

TABLE 9. WSM preference score and rank of approaches based on the motivating factors.

Approaches	Preference Score of WSM	WSM Rank
Develop system	0.028324	5
Cloud Adoption	0.024078	6
Package Implementation	0.95609	2
Re-hosting	0.55708	4
Re-engineering	0.79628	3
Migration	0.96232	1

TABLE 10. WSM preference score and rank of approaches based on the challenges.

Approaches	Preference Score of WSM	WSM Rank
Develop system	0.047853	5
Cloud Adoption	0.020376	6
Package Implementation	0.97738	2
Re-hosting	0.61984	4
Re-engineering	0.82715	3
Migration	1	1

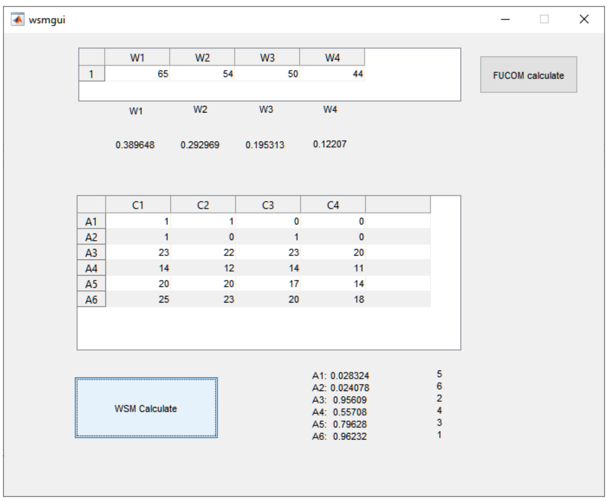

FIGURE 5. Proof of concept system UI for FUCOM and WSM in MATLAB.

previously developed approach, the study will be focusing on modernizing the legacy billing system of the telecommunication company. In conducting the survey, the target respondents are those that play a part in the process of modernizing the system. With a total of 5 respondents, each of them has different designations within the project, from a developer to project managers to an experienced legacy system user, where they are involved directly or indirectly with the modernization process.

Basically, the questions are the same as the previous study with some improvement and minimization of certain parts to only include items relevant to the current research. The current method utilizes the data of the preferred approach for modernization, motivating factors, and challenges. Moreover, the focus of approaches in modernization process of the billing systems will be only the top four highest ranks derived from previous result, namely, Package Implementation, Re-hosting, Re-engineering, and Migration.

TABLE 11. Input data from motivating factors.

Approaches	Criteria			
	Become flexible to support changing business requirements	Create new business opportunities via mergers & acquisitions	Reduce the cost of maintenance & operations	Lack of experts /documentation around legacy systems
Package Implementation	5	5	3	2
Re-hosting	0	0	0	0
Re-engineering	6	1	3	4
Migration	4	1	2	2

TABLE 12. Input data from challenges.

Approaches	Criteria			
	Time Constraint	Difficult to extract business rules/ knowledge	Funding legacy modernization projects	Predicting Return of Investment (ROI) of modernization
Package Implementation	5	2	3	4
Re-hosting	0	0	0	0
Re-engineering	4	2	3	3
Migration	4	2	1	1

TABLE 13. Comparison of preference score and rank of approaches based on the motivating factors.

Approaches	Preference Score of WSM	WSM Rank	Preference Score of WPM	WPM Rank
Package Implementation	0.87402	1	0.85586	1
Re-hosting	0	4	0	4
Re-engineering	0.76563	2	0.62406	2
Migration	0.5096	3	0.45235	3

TABLE 14. Comparison of preference score and rank of approaches based on the challenges.

Approaches	Preference Score of WSM	WSM Rank	Preference Score of WPM	WPM Rank
Package Implementation	1	1	1	1
Re-hosting	0	4	0	4
Re-engineering	0.89155	2	0.88509	2
Migration	0.70031	3	0.62454	3

The survey results are then organized in Table 11 and Table 12 representing criteria from each, motivating factors and challenges, that serve as inputs for the development of suggested MCDM method.

Following that, a series of FUCOM-WSM method is conducted via MATLAB using the input data to rank the approaches accordingly based on the predetermined criteria. The results from the integrated method are displayed in Table 13 and Table 14.

Furthermore, both preference scores as well as rank achieved via WSM are being compared with the results obtained via Weighted Product Model (WPM), for benchmarking purposes. The input of motivating factors and challenges for both methods, WSM and WPM, are the same.

WPM is similar to WSM but, instead of addition, WPM utilized multiplication as the main mathematical operation. Equation (4) can be referred to for calculating preference score using WPM.

$$A_i^{WPM} = \prod_{j=1}^{m} (x_{ij})^{w_j} \tag{4}$$

A_i represents the preference score for each alternative i. x_{ij} is the performance of alternative i on criterion j. w_j is the weight assigned to criterion j and m is the total number of criteria.

The required modification occurs at the final step in MATLAB in which WPM will be used to multiply all the values. These multiplied values are subsequently raised to the corresponding weightage. The calculated WPM preference scores can be found in Table 13 and Table 14. To facilitate comparison, the results from both the WSM and WPM are consolidated into a single table, allowing for a side-by-side comparison.

VII. DISCUSSION

In this section, we present a comprehensive analysis of our findings from the case study. The application of the FUCOM-WSM method in the context of legacy software modernization for the billing system of a Telecommunication company resulting in insightful findings.

As our study focused on identifying the top-ranked approaches for modernizing the billing system, four highest ranking approaches derived from previous research were included, namely Package Implementation, Re-hosting, Re-engineering, and Migration. Through the utilization of FUCOM-WSM approach, we were able to effectively evaluate and prioritize modernization strategies of these four approaches based on another top four motivating factors and challenges criteria.

The data obtained from the survey (Table 11 and Table 12) were plotted in MATLAB to generate preference scores of the developed approach. Based on Table 13 and Table 14, both inputs, motivating factors, and challenges, produce different preference scores but reflect the same ranking of approaches. The scores revealed that Package Implementation ranked highest among the motivating factors with a score of 0.87402, followed by Re-engineering (0.76563), Migration (0.5096) and Re-hosting that received a score of 0 as no respondents preferred this approach. Similarly, for challenges, Package Implementation ranked highest with a score of 1, followed by Re-engineering (0.89155), Migration (0.70031), and Re-hosting (0).

To ensure a comprehensive understanding of decision-making processes, WPM, a widely used methodology in MCDM, is included for comparison with WSM performance. From Table 13 and Table 14, WPM preference scores show that Package Implementation emerged as the top choice with a score of 0.85586 and 1 for motivating factors and challenges, respectively. This is followed by Re-engineering that generates 0.62406 from motivating factor and 0.88509 for challenges. Migration on the other hand, obtained 0.45235 for motivating factors and 0.62454 for challenges. Lastly, Re-hosting, that produces 0 score for both motivating factors and challenges.

The comparison of two methods, WSM and WPM, yielded similar rankings for the modernization approaches. Despite minor variations in preference scores, the overall outcome remains consistent. Since two different methods, WSM and WPM, achieved the same ranking through the utilization of the same weightage (determined through FUCOM), it indicates that the decision-making process is robust. It suggests that the criteria chosen, and their weights accurately represent the important factors affecting the decision.

Comparing these results with the approach adopted by the current Telecommunication company, we observed that the company is implementing the modernization project with Package Implementation, which ranked first in both motivating factors and challenges criteria. This is aligned with the action taken by the company that is transitioning their legacy billing system from Kenan Arbor platform to another platform known as Srun 4k Convergent Billing Solution software.

Thus, our findings support the effectiveness of the proposed FUCOM-WSM methodology in guiding modernization decisions for legacy software systems. By prioritizing approaches based on the defined criteria, organizations can make informed decisions that align with their goals and priorities.

In this study, the proposed MCDM approach was used to compare only the top four strategies for modernization, Package Implementation, Re-hosting, Re-engineering, and Migration. By narrowing the scope and focusing on these selected approaches, researchers can conduct an in-depth analysis and provide recommendations tailored to these approaches, leading to more actionable findings.

However, it is important to note that there are other additional approaches for modernizing a system, such as Cloud Adoption, Hybrid Solution, or Componentization. Excluding other approaches may reduce the applicability to a broader range of modernization scenarios. This is because aside from the top four ranked approaches, there could be other approaches that are more relevant to certain organizations or contexts.

To address this, incorporating additional approaches into the study's framework should be considered. By expanding the scope, researchers can provide a more comprehensive analysis of modernization strategies.

VIII. CONCLUSION AND FUTURE WORKS

The continuous advancement of technology calls for improvement of legacy software systems in an effort for the business process to remain up to date, enhance technical services, increase usage value, and most of all, avoid the systems from becoming obsolete. By adapting to the combination of FUCOM-WSM, the study developed a MCDM method for legacy software modernization based on the criteria determined by Motivating Factors and Challenges.

However, there are several limitations to the proposed methodology. One of them is the procedure did not account for any methods other than the combination of FUCOM with WSM, and comparison with WPM in determining the best approach. Another limitation of the proposed methodology is the reliance on expert opinions for identifying evaluation criteria affecting legacy software modernization. While expert input is valuable, it may be exposed to subjectivity and bias. Thus, some mitigation method should be explored to prevent this, such as incorporating user feedback.

For future research, it would be relevant to consider and explore the incorporation of other techniques within the field of MCDM, such as AHP, TOPSIS, ELECTRE, PROMETHEE, or even different hybrid approaches. Such comparisons will not only enhance the robustness of the analysis but also provide valuable insights into the effectiveness of different modernization strategies. Moreover, future research should focus on extending the applicability of the developed MCDM approach to diverse legacy software systems across various industries and organizational settings. Investigating the adaptability of the method to different legacy software environments will help to determine the method's versatility and effectiveness in guiding decision-making processes related to modernizing different types of legacy software.

In summary, the proposed methodology framework and approach presents the following contributions: 1) identifying a set of evaluation criteria affecting legacy software modernization based on experts' opinions, which resulted in Motivating Factors and Challenges criteria, 2) developing a MCDM method for legacy software modernization that implements an integration of FUCOM-WSM method via MATLAB software, and 3) applying the concept into an actual business domain that plan for legacy software modernization to test the applicability in assisting the decision maker in choosing the best evolution approach.

Following this research, others will be able to replicate independent empirical decision criterion investigations based on this foundation, strengthening the existing information. Understanding the behavior of decision makers in charge of selecting modernization and software evolution strategies is critical for successful process improvement and method development. As a result, it is believed that this paper has made a significant contribution to the discipline.

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