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MULTICRITERIA DECISION-MAKING MODEL FOR LEGACY SYSTEM MODERNISATION: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Rapid development of information technology and communication (ICT) has increased the use of information systems in companies. At the same time, many organizations are still using old systems to support their business (legacy systems). Even though these systems cause technical problems, but they are still used to support service delivery to the customer. These systems are also essential to organizations as they have been operated for many years and possess high business value Legacy system modernization (LSM) decision is very challenging and problematic issues in many organisations. In this Systematic Literature Review (SLR) paper, we describe the problem from a theoretical perspective, followed by models and approaches for its effectiveness. We present trends in decision-models and approaches and the resulting implications on practicality strategies. We then review the multicriteria decision-making (MCDM) application in LSM. Additionally, we present all relevant works classified by the year of publication, MCDM techniques, journals, and conferences in which they appeared. We discuss significant criteria identified to support researchers and industry practitioners by adopting the MCDM techniques to their LSM and providing insights into the state-of-the-art approaches or models, respectively. The study successfully managed to answer the three presented research questions.

Keywords: *SLR, Legacy System Modernisation, MCDM, Approaches, Models, Software Engineering.*

1. INTRODUCTION

1.1 Legacy System and Maintenance

A legacy information system [80] represents a massive long-term business investment, and such systems are mostly stiff [74]. These systems are resistant to change, slow, and non-extensible when faced with new technologies. In [75] [48] recommend that such systems need to be evolved to either match the continuously evolving business or cope with the continuous evolution of the other systems around them. Legacy system evolution, according to [14], [74] and [45] is a broad term that can range from adding a new field in the system screens to a complete replacement of the system. This evolution can be categorised into three: maintenance, modernisation, and replacement. In terms of maintenance, its business value, costs, and life expectancy should be the determining factors whether the system is worth to be redeveloped [46]. Now, this will relate to the modernisation process, where the potentially reusable components will be identified, and the outcome will determine the components that should be rewritten completely and replaced (replacement) with new components. According to [6], these three categories are rather staged such that the system initially does not need any support at all until some business needs start to deviate from its initial intended usage. They agree with [21] who also focus on approaches that include redeveloping, wrapping, and migration. The modernisation project might evolve; however, when time passes by, the organisation might need a total system replacement to cope with the new technologies.

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To improve the legacy system, several criteria lead the selection of modernisation techniques [35], [71], [68], [41]. The first and foremost is cost-effectiveness. This factor will evaluate the cost adequacy of a certain model in a way that can be effectively contrasted with different models [35]. The cost also covers the whole process of modernisation [39] where it begins with problem analysis, development model, system evaluation, and system maintenance, which can also be easily understood based on experiences, risks, methods that were used, and resources [7]. The second factor involved in is technology integration. Technology integration will assist in the integration process of legacy systems. It empowers the existing property unreservedly used from the new condition through adaptable associations with the conveyed technology [71]. Using this technology, the current project and development can be utilised independently with no critical change. The other considered factor is the organisational factor. The perplexities of the organisations originate from the way that the accompanying variables ought to be considered in the technique determination choices, which are the inspirations driving the implementation of this modernisation and the cost of applying every methodology in the framework [68]. The variables consist of top management support, organisational readiness, and the ability of human resources. Next, the legacy system technical attribute is also one of the factors in improving legacy systems [27]. This factor consists of several attributes to achieve technical value such as maintainability, which can be achieved by the process of *simplification,* where reducing the size of the system will eliminate any bad code [31] that is obsolete as well as unusable function and data. Second, *decomposability* should be determined before migrating the legacy system with a few other things such as proper documentation and source code. This process can be explained as either the main components of the system can be independent of any other components and identifiable. Next, *deterioration* is an expression in which the system has been through a lot of constant changes throughout the process of rebuilding the system according to the business requirements that can be changed. The last attributes are *obsolescence* where the state of the components that the software had is no longer current and cater to the needs of the user, which is no longer useful and is also not manufactured any more [41]. The *quality attributes* of the system are the attributes of the legacy systems, which are a vital point that governs the amount of work needed to modernise the current legacy system [26] towards the target of business value. This factor involves several quality attributes such as economic value, data value, utility, and specialisation [41]. In terms of usability, the legacy system sometimes has been through several changes which result in a complicated system. These will certainly affect the system performance and will hinder the organisation from constantly changing its business requirements, which are related to the flexibility of the system. Having knowledgeable system experts (knowledge/skill) is necessary because they are the ones that will prepare the organisation for the legacy modernisation. System experts not only solve difficult problems in terms of database scheming and prevent data redundancy but also evaluate a suitable framework and a proper plan. Next, having a long development time (time effectiveness) could potentially increase the maintenance cost [22] and also jeopardise the lifespan of the technology itself (e.g., when the system finishes, the technology may be obsolete and needs to be re-engineered). Lastly, the system should accommodate business needs (flexibility) and not otherwise. For the system to be flexible, robust is needed. The system that has been legacy modernised should be able to maintain and cope with future business requirements [16]. To sum up, any legacy system with these nine criteria need to lead the procedure for LSM.

MCDM is a subdiscipline [13] of operation research that is used to evaluate multiple conflicting criteria in decision-making. MCDM is classified into two categories, namely discrete MCDM or discrete multiple attribute decision-making (MADM) and continuous multi-objective decision-making (MODM) methods. There are a few types of MCDM methods [55] that are discussed, each type of MCDM is formulated based on the needs of the expected results. MCDM method helps us to analyse problems and identify the best criteria that can influence decision-making. For every decision made, there must be some choices that need to be evaluated, hence MCDM helps evaluate the available decision choices [54]. The application of the MCDM method covers every aspect of everyday life in which it can influence the decision-making process in the public and private sectors in terms of evaluating the process, providing in-line support in managing business strategies as well as identifying the appropriate policies [53][52] for an organisation. MCDM based on a collection of methodologies to compare, select, or rank multiple alternatives that typically involve incommensurate attributes [76]. The approach deals mainly with different classes of

decision problems such as classification, sorting, and ranking to support experts and decision-makers in finding consistent and robust solutions to multicriteria problems.

1.2 LSM Models

We have reviewed the software modernisation decision model in several domains such as private and public sectors, environments, manufacturing, transportation, and health care systems. From the reviews, some approaches are based on a single approach and some approaches use integrated and hybrid model. Among the decision models used include analytical hierarchy process (AHP), elimination and choice expressing reality (ELECTRE), technique for order of preference by similarity to ideal solution (TOPSIS), analytic network process (ANP), decision-making trial and evaluation laboratory (DEMATEL), service-oriented architecture (SOA), interpretive structural modeling (ISM) or total interpretive structural modelling (TISM), and fuzzy matrices d' impacts croisés multiplication appliquée á un Classement (MICMAC) analysis approach [51][59]. In this paper, we focus on MCDM for LSM. Several approaches have been provided for this in the literature but no effort on the overall analysis [62] of the studies in the literature. This work provides a systematic literature review (SLR) to identify, analyse, and describe the state-of-the-art advances in MCDM for legacy systems. There are several well-known MCDM methods for alternative analysis and prioritisation. According to [73], MCDM approaches vary in complexity and possible solutions. Each MCDM method has its privileges, strengths, and weaknesses in certain applications. In this review, the most important and widely used MCDM approaches such as AHP [58], ELECTRE [57], TOPSIS [34], ANP [58], and SOA [29]. MCDM is also applied to select product-service system (PSS) concepts by considering the concepts of sustainability and value assessment as one of the decision attributes and focusing more on the sustainability of the ecosystem [12] [10].

1.3 Contribution of This Work To LSM

Up to date, various research works have been produced in legacy system focusing on the reengineering such as method and tools for software evolution [77] [24]], code reuse [78], business process, assessment framework development [43] and modernisation process [44] [60]. However, only few studies in-depth on the LSM approach and its transformation factor. A framework that analyses these factors would benefit more parties in preparation of LSM.

A multiphase study selection process is used in this SLR which published literature in major software engineering journals and conference proceedings are studied. 41 of them are assessed as primary studies related to our research questions. Based on the analysis of the data extraction process, we discuss the key criteria for all identified approaches. For researchers, this SLR gives a report of MCDM for LSM with empirical evidence of criteria from the identified approaches. Practitioners may benefit from the SLR by identifying the strengths and weaknesses of the approaches as well as the remaining important challenges. The main research problem is of this research is identify the main criteria and main MCDM methods which can be used by discussion makers to come up with the right decision regarding LSM.

2.0 RELATED WORKS

While conducting this review, we have also encountered other review related to areas that are close to LSM. This section provides a summary of the related studies.

2.1 Systematic Review of Legacy System Migration

In [84] conducts review in the area of migration of legacy system. It aims to have a generic and adaptable framework that can be used fully or partially for the widest number of legacy applications. The framework is typically useful for four migration approaches which include incremental migration, partial migration, complete migration, and wrapping. No specific method of review nor a specific number of articles involved are mentioned in the article.

2.2 Reengineering legacy applications into software product lines: a systematic mapping

In [61] conducts systematic mapping on reengineering legacy applications into Software Product Lines (SPLs), which are families of systems that share common assets allowing disciplined reuse. Rarely SPLs start from scratch, instead, they usually start from a set of existing systems that undergo a reengineering process. Due to wide interest in this research area, they conducted a systematic mapping study to provide an overview of the current research

on reengineering of existing systems to SPLs [63], identify the community activity in regarding of venues and frequency of publications in this field, and point out trends and open issues that could serve as references for future research. Based on 119 relevant publications, these primary sources were classified in six different dimensions related to reengineering phases, strategies applied, types of systems used in the evaluation, input artefacts, output artefacts, and tool support. The analysis of the results points out the existence of a consolidated community on this topic and a wide range of strategies to deal with different phases and tasks of the reengineering process, besides the availability of some tools. They also identify some open issues and areas for future research such as the implementation of automation and tool support, the use of different sources of information, need for improvements in the feature management, the definition of ways to combine different strategies and methods, lack of sophisticated refactoring, need for new metrics and measures and more robust empirical evaluation.

2.3 Legacy to SOA Evolution: A Systematic Literature Review

In [78] conducts SLR on legacy to SOA evolution involving 121 primary studies and evaluated using an evaluation framework, which was developed from three evolution and modernization methods widely used in the software re-engineering domain [81]. The evaluation constitutes the inventory of current research approaches and methods and techniques used in legacy to SOA evolution.

3.0 REVIEW METHOD

SLR focuses on the aggregate primary studies of the results and investigates if the results are consistent, or any contradiction happens that can potentially come up from the investigation. SLR synthesises the evidence. The SLR has three main phases: planning, pre-reviewing activities, and establishing a review protocol for the pilot test. The second phase searches and selects relevant studies based on the keyword search. This phase examines and validates selected studies based on quality assessment criteria [25] [49]. The third phase reports the results obtained from the literature review study. We carried out the SLR to provide an overview of existing research directions regarding the multicriteria decision model for LSM by following the guidelines and process proposed.

3.1. Literature Review and Methodology steps

In conducting a review process as shown in Figure 1 on previous academic studies, this study has referred to the reporting items for systematic method [85]. This method emphasises systematic review techniques, a review method based on the formulation of clear research questions that use explicit methods.

3.2. Research Questions

To examine the evidence of MCDM for legacy software modernisation, we ask the right questions to derive relevant findings. The questions need to be meaningful and important. Hence, we define the following research questions as shown in Table 1.

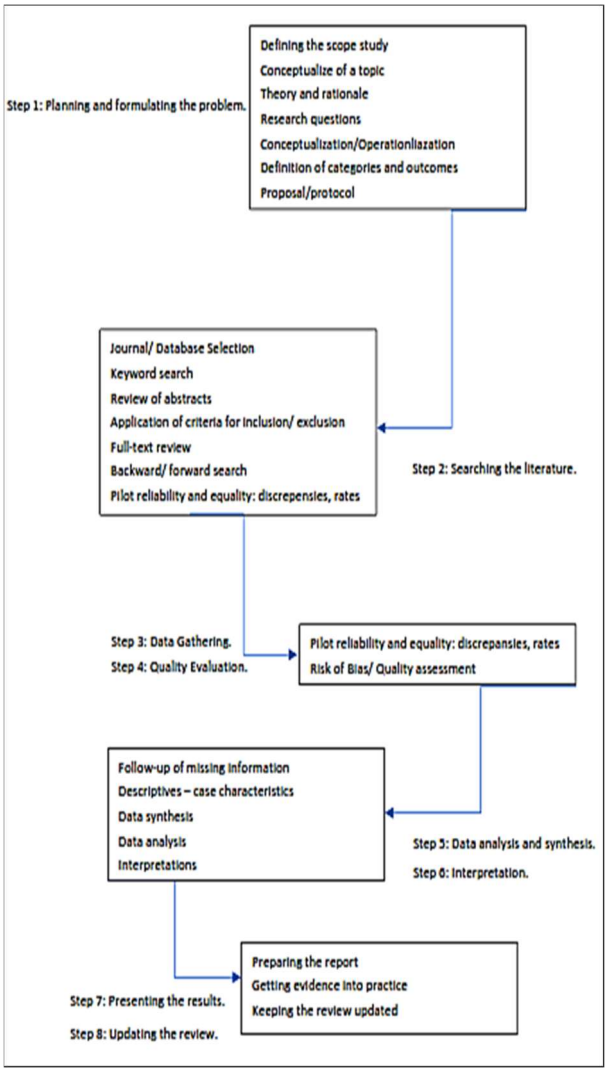

Figure 1: Literature review study protocol

Table 1: Research Questions

RQ1:	What is the current research of MCDM for LSM? We aim to know the distribution of articles on MCDM for LSM in journals and proceedings.
RQ2:	What are the available MCDM approaches and categories for LSM? With this research question, we aim to identify the different categories of MCDM approaches. This will highlight the current scope and applicability of MCDM for LSM.
RQ3:	What are the significant criteria for each particular approach considered in the existing research? A considerable number of criteria for modernising legacy systems that have been proposed will be identified and summarised.

3.3. Search Strategy

In this stage, five electronic databases were chosen to provide a comprehensive application of MCDM in LSM. These databases were ScienceDirect, Taylor & Francis, IEEE, Springer, and Emerald. Papers published in academic journals and international conferences by these five databases were considered to be worthy of comment and reliable. The literature search was performed according to the following descriptors: "MCDM, AHP, ANP, TOPSIS, DEMATEL, ELECTRE, SOA, ISM/TISM, legacy systems, software modernisation [62], modernising legacy system" and their combinations. In summary, a total of 183 academic papers were extracted based on the above-mentioned search strategies. After the removal of duplicated papers with redundant information, 121 potentially relevant articles remained. Indicative titles and structured abstracts were then screened, and irrelevant studies were removed. A total of 62 potentially relevant studies.

3.4. Study Selection and Eligible Papers

In this phase, the full text of the papers extracted from the previous stage was reviewed independently by the authors for eligibility. A careful step was identified for paper selection to reach a consensus. Papers which had applied MCDM methods in legacy systems [82] were chosen. Another 88 papers that did not explicitly mention the use of MCDM methods in their content were identified among the review of those selected papers. Master's and doctoral dissertations, textbooks, book chapters, unpublished working papers, non-English papers, and abstract-only papers were excluded. During the data extraction phase, we also had to exclude any studies that failed to provide a multicriteria analysis in legacy systems even though they had employed methods such as genetic algorithm (GA) and data envelopment analysis (DEA) [63].

Eventually, we selected 41 academic papers on MCDM application in legacy systems from 41 academic journals and international conferences which met our inclusion criteria. In addition to general inclusion/exclusion criteria, we also considered eligibility criteria as shown in Table 2.

Table 2: Eligibility criteria (PICOS)

Participants	Five major research databases were selected (IEEE, ScienceDirect, Emerald, Springer, and Taylor & Francis). From 759 articles, only 191 academic papers were extracted using keywords. There were 128 potentially relevant articles left in which only 41 published papers appeared to be fit.
Interventions	Journals and conference proceedings were selected based on their year of publication between 2007 and 2021. The literature search was based on "MCDM, AHP, ANP, TOPSIS, DEMATEL, ISM/TISM, ELECTRE, SOA, legacy systems, software obsolescence, software modernisation, modernising legacy system" and their keyword combinations.
Comparators	Reporting the comparator (control) group intervention(s), such as the year of publication for papers, MCDM techniques used, type of publishers and language used is essential for the readers to fully understand the selection criteria of the primary studies, which were included in the systematic reviews.

Outcomes	For researchers, SLR should give them a report of MCDM for a legacy system with strong empirical evidence and the practitioners may benefit from SLR by identifying the strengths and weaknesses.
Study design	By using the systematic methodology, SLR plan would be the main practice in SLR to investigate relatively broad topics and would aim to identify, analyse, and structure the goals, methods, and contents of previous studies. The review techniques systematically refer to a review method based on the formulation of clear research questions that use explicit methods.

3.4.1. Identification Of Relevant Literature

The identification of any relevant literature is a major step to start generating any search strategy in identifying any potential literature. This initial process was taken through an online search. To compensate for any of the challenges that could arise while doing the normal database search is to consider making a complementary manual citation-based (snowballing) search, which is to minimise any missing important pieces of information. Through this step, we considered the article search process that was proposed by Bakar [7], which separates the strategies into three phases. The first phase used an online database search, the second phase applied any complimentary citation-based search, and the third and last phase utilised a manual target search.

3.4.2. Inclusion (Practical Screen) And Exclusion Criteria (Quality Appraisal)

After collecting the candidate articles, we then screened for inclusion of the articles based on our set of criteria that we needed to include and exclude from the list. These candidate articles needed to satisfy at least one of the inclusion criteria and vice versa for the exclusion. We based our criteria on the quality checklist for the inclusion criteria. The practical screen is a step which requires the reviewer to be explicit about what type of studies are to be considered for the review and articles that are not related to the study are excluded without further examination. For the inclusion criteria, the aim is to include such articles that would have a similar approach to our extraction approach for our criteria.

For the exclusion screening, the main exclusion criteria were excluded because the main focus was not on MCDM, and the criteria did not mention using MCDM explicitly as well as did not have any insufficient quality to be included in the review synthesis. Any articles that fulfilled the criteria below certainly needed to be excluded. All the included articles needed to be scored for their quality and depended on the research methodologies that were employed by the articles. The screening of the exclusion is as follows:

- Articles that did not use any MCDM method in the legacy system and did not mention using MCDM in their content explicitly were not included.
- Any unpublished papers and short papers, master's and doctoral proposals, lecture notes or textbooks, summary of conference keynotes, book chapters, work-in-progress reports, doctoral symposium papers, abstract-only papers and posters: articles describing the concepts of MCDM which appeared in short papers, work-in-progress papers, or business model proposal for MCDM that were not empirically validated were excluded.
- During the data extraction phase, we also had to exclude any studies that failed to provide a multicriteria analysis in the legacy systems even though the studies had used methods such as GA and DEA.
- Papers not written in English.

3.5. Study Quality Assessment

In addition to the general inclusion/exclusion criteria, we also considered assessing the quality of primary studies. The main goals of the quality assessment step are providing more detailed inclusion/exclusion criteria, determining the importance of individual studies once the results are synthesised, guiding the interpretation of findings, and leading recommendations for further research. We considered the quality assessment as part of our data extraction process and used the result of the assessment while providing an answer to RQ3.

We applied quality instruments defined by Brereton [17] and went through all checklist of factors that need to be assessed for each study. The quality checklist was derived by considering the factors that could bias the study results. Table 3 presents the quality checklist. Since the aim is ranking studies according to an overall quality score, we deployed the items in the quality checklist on a numeric scale. We used the three-point scale and assigned scores (yes = 1, somewhat = 0.5, no = 0) to each criterion.

Table 3: Quality checklist.

#	Assessment category	Question
Q1 Q2 Q3	Quality of reporting	Are the aims of the study clearly stated? Are the scope and context of the study clearly defined? Is the proposed solution clearly explained and validated by an empirical study?
Q4 Q5 Q6	Rigour	Are the variables used in the study likely to be valid and reliable? Is the research process documented adequately? Are all the study questions answered?
Q7 Q8	Credibility	Are the negative findings presented? Are the main findings stated clearly in terms of creditability, validity, and reliability?
Q9 Q10	Relevance	Do the conclusions relate to the aim of the study? Does the report have implications in practice and results for multicriteria decision model for legacy systems?

3.6. Data Extraction and Summarising

In the final stage of methodology, necessary data were gathered and any disagreement between authors was discussed and solved. Then, these 41 papers were summarised, and significant factors were found (Sections 4). Next, academic papers were classified into different categories, including publication year, MCDM techniques, and journal and conferences in which they appeared (Section 6). The action of summarising and categorising papers enabled us to obtain several critical and impressive hints. As a result, several potential future work and recommendations were proposed. It is worth mentioning that the research investigation was performed carefully, and it provided a comprehensive basis concerning MCDM application in LSM.

4. RESULTS

In this section, we present the synthesis of evidence from our SLR. First, we present the analysis of the results from article searches, followed by the quality assessment results. Next, we present the answers to the main research questions from Section 3.2.

4.1 Results of Article Search

As mentioned in section 3, we performed our search in three phases. In this section, we will present the results of the search process.

4.1.1 Phase 1: Online Database Search

By using an online database search, we need to formulate our search string which derived from our Table 1. We used a string to link the major terms from the participants, interventions, and study design. Therefore, the complete search string derived is in Figure 2:

(("MCDM" AND "AHP" AND" ANP" AND" TOPSIS" AND "DEMATEL" AND" "ISM/TISM" AND "ELECTRE" AND "Software obsolescence" AND "SOA" AND "legacy systems" AND "software modernisation" OR "modernising legacy system"))

Figure 2: Search strings

These strings were deployed to the Computer Sciences and Software Engineering articles. The selected databases were IEEE, ScienceDirect, Emerald, Springer, and Taylor & Francis. We applied inclusion and exclusion criteria and also removed irrelevant studies.

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4.1.2 Phase 2: Complementary Citation-Based Search

During phase 2, the citation-based search was used to find out any citations made to the papers that were selected previously from phase 1. We also looked at the references of each paper that were identified (backward snowballing). Next, we listed down the selected papers that could be relevant to our objectives. Then we would find out any citations that were cited by other researchers to do forward snowballing and make a list. These two lists were compiled with duplications being removed. Any papers that were identified to be poorly written were excluded. Because we used abstracts and titles as one of our search bases, we applied the inclusion and exclusion technique.

4.1.3 Phase 3: Manual Target Search

Although manual target search was proven to be difficult and time-consuming to skim through all of the papers, it often brings a high chance of getting a high-quality result in terms of finding the right papers from the digital library. Throughout this research, we used five leading journals which are IEEE, ScienceDirect, Emerald, Springer, and Taylor & Francis. These journals were hand-picked for their frequency of being cited by researchers. A similar condition was used for conferences. Our search was also limited to any papers published between January 2007 and April 2019.

In total, we have collected 62 articles from the three phases of article searches. However, after removing duplicates, we are only left with 41 studies. Duplicate entries are either articles that are already retrieved by the earlier searches or work from the same group of authors being published at different venues. For the second duplicate condition, we only include the most recent publication Figure 3 shows completed Data flow diagram of the systematic process.

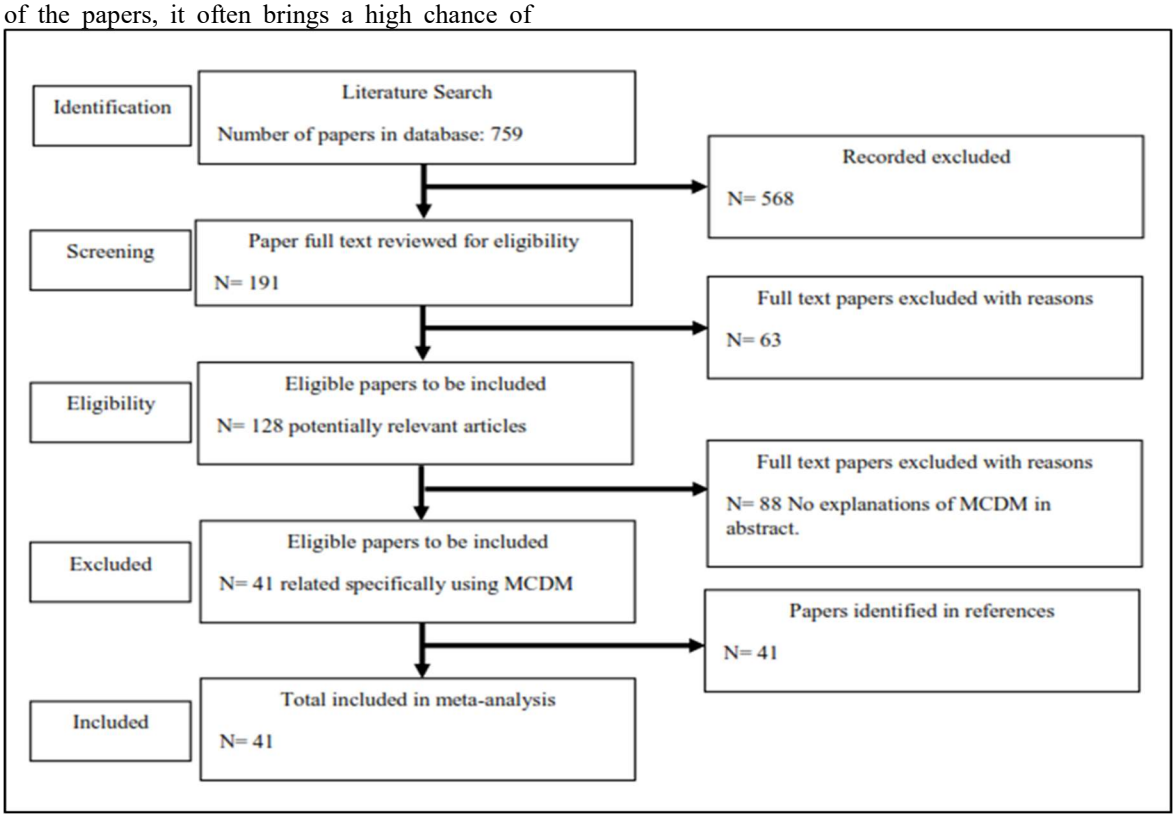

Figure 3: Flow Diagram Of The Systematic Process

4.2 Quality Assessment Results

We used a score scale of 0–2: very poor (score<3), poor (score of 3 to <5), fair (score of 5 to < 7), good (score of 7 to < 9), and very good (score of 9–10). Most studies (36 studies) achieved score 9 and above, which are deemed to be of very good quality. Five studies (12.2%) scored 8 and 8.5 that are deemed to be of good quality. The results of

the assessment are given in Appendix B study quality assessment form. These results are used to support the data extraction step.

4.3 Answering the research questions

4.3.1 Classification of academic papers

RQ1: What is the current research of MCDM for LSM? We aim to know the distribution of articles on MCDM for LSM in journals and proceedings.

a) Distribution of academic papers by publication year (Figure 4)

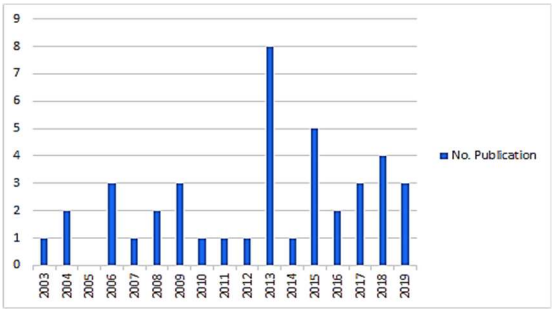

Figure 4: Distribution of research papers by publication year.

The distribution of MCDM approaches applied in LSM is displayed by publication year between 2003 and 2019 (see Fig. 4). It is clear from the chart that MCDM usage in LSM has allocated a greater number of papers over the last 10 years, 29 papers in comparison with that of the first seven years, 12 papers (71% and 29% respectively). The frequency of MCDM usage in legacy systems remained almost constant throughout the first seven years, followed by a gradual increase in 2013 and 2015. In 2006, the frequency of research papers rose to three compared to 2005, which is null. It has gradually increased from 2007 until 2009; however, it becomes stagnant in 2010 until 2012. The usage of MCDM in legacy systems experienced a dramatic rose, reaching a peak of eight papers in 2013. Over the next six years, the number of MCDM usage for LSM went through up and down scoring.

b) Distribution of academic papers by MCDM approach (Figure 5)

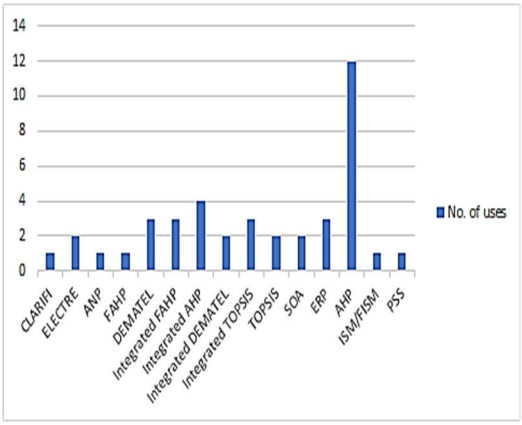

Figure 5: Distribution of papers based on the application of MCDM techniques.

The distribution of papers based on the usage of MCDM approaches is presented in Figure 5. From the chart, it is clear that AHP has been the most popular MCDM approach to modernising the legacy system about others. This approach is followed by integrated TOPSIS to take advantage of a hybrid technique in LSM. Also, 11 out of 41 academic papers utilised an integrated approach to overcome the shortage of individual MCDM approaches. However, the related numbers belonging to CLARIFI, ELECTRE, ANP, Fuzzy-AHP (FAHP), and DEMATEL methods were far less than any other MCDM approaches, standing at 1 similarly.

In general, there is no specific pattern in MCDM usage for LSM between 2003 and 2019. Even though the AHP method usage in modernising legacy systems is the most popular with the highest frequency, when it comes to the hybrid method, the integrated TOPSIS method is more popular than the integrated AHP method.

c) Distribution of academic papers by journals and conferences

The research papers were selected from a total of 41 different journals and conferences. The distribution of academic papers by journals and conferences is shown in Table 4. As can be seen, "Expert Systems with Applications" has the most contributions in publishing the academic papers on the application of MCDM approaches for LSM (7.3%). It is followed by "Computer Networks", "International Journal Production Economics", and "Journal of Environmental Management"

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with 4.9% contribution each. Other journals and conferences have contributed 2.4% each in the publication of our data set papers.

d) Distribution of academic papers by MCDM approach and publication year

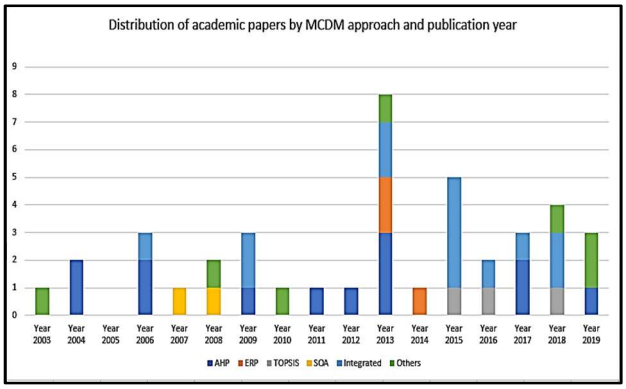

Figure 6: Distribution of academic papers by MCDM approach and publication year.

Figure 6 illustrates the distribution of 41 academic papers by MCDM approach and publication year. The study shows that the AHP approach in modernising legacy systems has a consistent trend between 2003 and 2019 with either one or two publications for every two or three years. The reason why AHP has become the most popular modernising approach even though there are other new approaches and new integrated approaches is due to user confidence in the reliability of the AHP approach based on previous results. From the chart, it can also be observed that the integrated MCDM approaches have become more popular from 2009 until 2019 even though they have been applied since 2006. Utilising the MCDM integrated approaches in recent years can indicate the urge of researchers to come up with more reliable methodologies and accurate results. The implementation of integrated MCDM approach recently demonstrates the inclination of the academics and software professionals to think of more solid techniques and precise outcomes.

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Table 4: Distribution Of Academic Papers By Journals And Conferences.

Journal and conference	Type	Freq	%
27th CIRP Design 2017 Procedia	P	1	2.4%
Computers & Industrial Engineering	J	1	2.4%
Expert Systems with Applications	J	3	7.3%
Computer Networks	J	2	4.9%
Applied Mathematics and Computation	J	1	2.4%
Energy Conversion and Management	J	1	2.4%
Resources Policy (Elsevier)	J	1	2.4%
International Journal of Production Economics	J	2	4.9%
Business System Research	J	1	2.4%
Applied Mechanics and Materials	J	1	2.4%
International Journal of Software Engineering and Its Applications	J	1	2.4%
Annales Univ. Sci. Budapest	J	1	2.4%
ResearchGate	J	1	2.4%
ICEIS 15 (International Conference on Enterprise Information Systems)	P	1	2.4%
IEEE Conference and Service Computing	P	1	2.4%
The Journal of Transport and Land Use, 4(3)	J	1	2.4%
17th European Conference on Software Maintenance and Reengineering (IEEE)	P	1	2.4%
Proceedings of 6th International Conference on. IEEE	P	1	2.4%
Applied Soft Computing, 13(2013), 590–599	J	1	2.4%
The Journal of Systems and Software	J	1	2.4%
Journal of Biomedical Informatics, 53(2015), 390–404	J	1	2.4%
International Journal Production Economics, 103(2006), 726–741	J	1	2.4%
Applied Geography, 42(2013), 34–47	J	1	2.4%
Procedia Computer Science, 122(2017), 315–322	P	1	2.4%
Journal of Environmental Management, (2008) 970–983	J	2	4.9%
Procedia Engineering, 148(2016), 1043–1050	P	1	2.4%
Journal of Manufacturing Systems, 31(2012), 240–252	J	1	2.4%
Environmental Modelling & Software, 46(2013), 129–141	J	1	2.4%
A Publication of the Defense Acquisition University	J	1	2.4%
Applied Economics, 51(32), 1–21	J	1	2.4%
Benchmarking: An International Journal, 26(2)	J	1	2.4%
Proceedings of the 2018 IEEE IEEM	P	1	2.4%
Sustainability, 2019, 11, 1952, DOI:10.3390/su11071952	J	1	2.4%
Systems Engineering, 2018, 1–11	J	1	2.4%
International Journal of Information Technology & Decision Making,18(2),(March 2019)	J	1	2.4%
Journal of Quality in Maintenance Engineering, 24(2)	J	1	2.4%

4.3.2 RQ2: What are the available MCDM approaches and categories for LSM? With this research question, we aim to identify the different categories of MCDM approaches. This will highlight the current scope and applicability of MCDM for LSM

Based on the analysis, the 41 papers are classified into three main categories, namely individual, integrated, and other MCDM techniques.

a) Individual MCDM approach

Analytical hierarchy process (AHP)

AHP method proposed by [58] is a comprehensive framework designed to be applied to certain, uncertain, rational, and irrational multiple criteria decision problems. This method serves the evaluation, ranking, and criteria selection, which results in optimised and predicted decisions. Commonly expressed by a unidirectional hierarchy, AHP shows the relationship between goal and criterion levels. AHP utilises the concept of hierarchy to simplify complex decision problems into elements that the highest level represents decision goals and the lower level represents decision criteria [64] [65]. Sub criterion elements are constructed under each relevant criterion. AHP is also used to evaluate the impact of multiple obsolescence elements over the life cycle of a software application [16]. Based on the analysis of our data set papers, 12 out of 41 (29.3%) papers have implemented AHP as an individual approach for modernising legacy systems. These academic papers that applied the AHP method for LSM are summarised next.

Darwish [25] [26] adopted AHP to elicit relationships between quality attribute trade-offs and architectural characteristics quantitatively. Despite that, it also helps in giving weight alternatives using the pairwise technique. This technique aims to achieve continuity and interoperability across legacy engineering systems and modern commercial ones to face ever-growing engineering challenges. In [39] established a set of criteria to prioritise the traveller preferences to modernise the travel planning system during peak season. The decision process used the MCDM approach to extract the best alternative in decision matrices and to reserve it as a tentative plan. Hence, the decision is used to meet the technical requirements including travel integration of the legacy system, information recovery, and monitoring of post plans. In [60] implemented the AHP method's basic theory analysis to handle a lot of characteristics that control the selection of modernisation strategy altogether using decision theory to come up with the most optimal strategy to be used in modernising the legacy systems in question. In [5] proposed the AHP method to provide a knowledge-based decision support model and took into account five factors identified from the secondary research as covering all aspects of cloud migration decision-making. In [8] applied the AHP technique to make MCDM accessible and useful from both the top-down and bottom-up perspectives on transportation planning. The proposed framework utilises rankings as inputs instead of pairwise comparisons for factors and attributes according to different hierarchical levels. It is also designed to simplify the decision-making processes in modernising legacy systems. AHP was used by [33] to compare the differences between scale functions and drive commendation for the application of the scales. The simple analytic functions were used and the number of criteria for the decision problems was also taken into consideration.

Enterprise resource planning (ERP)

Three out of 41 (7.3%) papers have implemented ERP as an individual approach for modernising legacy systems. These academic papers that applied the ERP method for LSM are summarised next. In [15] implemented the SOA method by representing the central element of future e-governance architecture. It has actively contributed to the development of new collaborative instruments and better efficiency of all the specific activities to improve integration between public research and development strategy. [50] introduced the ERP method to investigate system criteria within selection process system. The purpose of this method is to analyse which criteria are made in identifying certain businesses whether at the multinational enterprises or small and medium enterprises (SMEs). In [50] implemented the ERP method in 2014 to discover the most recent trend in the applied method of selection processes and to identify the related set of criteria in practice, and a qualitative analysis of the impact and frequency of use in practice in order to consider replacing the operational legacy systems fully or partially with the new information system.

Service-oriented architecture (SOA)

SOA is an approach to building distributed systems that deliver application functionality as a set of self-

contained business-aligned services. These services communicate with each other. The communication can involve either simple data passing or two or more services coordinating some activities. Two out of 41 (4.9%) papers have implemented SOA. Salama and Aly (2008) implemented SOA [69] as a decision-making tool for the selection of service-oriented based LSM strategies. The tool takes into consideration choosing key migrating evaluation factors, rating the relative importance of such factors, inputting the organisational significance of each factor, and operating on individual system components. Erradi [30] introduced SOA for building distributed systems that deliver application functionality as a set of self-contained business-aligned services. It promises lower integration costs, increased reusability, and improved enterprise agility and adaptability. In their work, they applied the SOA method to integrate or transform legacy applications into services to participate in an enterprise-wide SOA. It also presents a decision framework to guide architects in selecting the optimal combination of legacy modernisation options.

The technique for order of preference by similarity to ideal solution (TOPSIS)

The TOPSIS was introduced by [34] and further explained by [9]. According to Behzadian [9], TOPSIS applies a simple concept of maximising distance from the negative-ideal solution and minimising the distance from the positive-ideal solution. The chosen alternative must be as close as possible to the ideal solution and as far as possible from the negative ideal solution. The ideal solution represents the maximal benefit solution determined from a composite of best performance values. The negative-ideal solution represents the minimal benefit solution, which is also a composite of the worst values. TOPSIS makes full use of attribute information, provides a cardinal ranking of alternatives, and does not require attribute preferences to be independent and to apply this technique, attribute values must be numeric, monotonically increasing or decreasing, and have commensurable units [3]. The model has also been employed by system designers and other decision-makers to conduct a trade study in obsolescence management [2].

Three out of 41 (7.3%) papers have implemented TOPSIS. In [36] implemented the TOPSIS method to rank alternatives in terms of their desirability concerning multiple criteria that can influence the decision. In [1] Zainal implemented the TOPSIS-entropy method as a decision-making tool to evaluate the trade-off of inherently safer design (ISD) alternatives.

b) Integrated MCDM approach

Integrated TOPSIS

Three out of 41 (7.3%) papers have implemented integrated TOPSIS. In [38] presented a hybrid technique by combining two MCDM methods, TOPSIS and FAHP, to quantify the importance of agility criterion in the process of evaluating suppliers and estimating the business impact of resulting supply chains. They used fuzzy AHP to calculate prior weights of decision criteria while the TOPSIS method was used to determine the rankings of candidate suppliers. By using this method, they were able to present approximated Pareto fronts of the resulting supplier chains for varying priority weights of the agility criterion and its sub criteria. They also compared business costs of agile and non-agile supply chains before and after reconfigurations of original supply chains in response to unexpected disruptions under two order allocation strategies, a skewed order allocation (SOA) strategy and an even order allocation (EOA) strategy.

Integrated DEMATEL

Kusi-Sarpong [37] combined fuzzy DEMATEL and ANP methods. Their work focused on adopting a previously developed comprehensive and integrative green supply chain management (GSCM) in the mining industry. Fuzzy DEMATEL is applied to develop interrelations or interdependencies amongst GSCM practices and sub practices to identify which interdependencies are most influential while the ANP method is used for weight measurements to rank the best criteria [83] on the overall goal. Titiyal [66] implemented the hybrid DEMATEL with ANP (DANP) method and used the multicriteria optimisation and compromise solution (VIKOR) method. These methods are employed in the hybrid MCDM method.

Integrated AHP

Bergmayr [11] presented a hybrid approach in the MCDM method, which is a combination of AHP method and goal programming method for migrating legacy systems. They proposed a comprehensive software modernisation approach covering business and technical aspects. In particular, the workers employed the AHP techniques to automate the reverse engineering of legacy software and goal

programming, which aims at forwarding engineering of cloud-based software in a way that modernises software that truly benefits from targeted cloud environments. Therewith, this method can reduce the risks, time, and costs of software modernisation and lowers the barriers to exploit cloud computing capabilities and new business models.

c) Other MCDM Approach

Decision-making trial and evaluation laboratory (DEMATEL)

The DEMATEL method originated from the Geneva Research Centre, Battelle Memorial Institute [32]. This method has been successfully applied in many fields by analysing complex scientific, political, and economic problems. DEMATEL is especially practical and useful for visualising the structure of complicated causal relation using matrices or digraphs [4]. According to Ahmadi et al, the matrices or digraphs portray a contextual relationship between the elements of the system in which a number represents the strength of influence. Hence, the DEMATEL method can convert the relationship between the causes and effects of criteria into an intelligible structural model.

Lu [40] implemented DEMATEL to analyse the interrelationships between the 13 criteria summarised from their literature. In their work, they developed a general evaluation framework for industry evaluation, improvement, and adoption of radio frequency identification (RFID). They used MCDM methods known as DEMATEL, DANP (DEMATEL-based ANP), and VIKOR to evaluate the factors that influence the adoption of RFID. Specifically, they studied the adoption of RFID in Taiwan's health care industry and they found that technology integration is the most influential criterion and the strongest driver in the adoption of RFID of Taiwan's health care industry. This approach was also used by India for their e-tailer study to identify the distribution strategy selection [66].

Fuzzy analytic hierarchy process (FAHP)

Chu and Khosla in [23] utilised the fuzzy MCDM method to analyse various index priorities and strategy preferences of communities of practice (CoPs) by undertaking empirical studies of the Industrial Technology Research Institute in Taiwan. The fuzzy MCDM method [79] was used to measure the weight and average utility value of four groups while the AHP method was applied to conduct a pairwise comparison and evaluate related hierarchy system, to weight dimensions and criteria. The findings of this work can promote performance value of implementing knowledge management systems and modelling of competitive strategies for CoPs.

Elimination and choice expressing reality (ELECTRE)

The origin of the ELECTRE method began with [57] and was continued by Buchanan [20] went ahead to publish two other articles that also talked about ELECTRE [18] [19]. According to [42] [43] ELECTRE is capable of handling the discrete criteria of both the quantitative and qualitative methods to provide a complete order of alternatives. This technique used a concordance, discordance indices, and threshold values. Based on these indices, graphs for strong and weak relationships are developed to obtain the ranking of alternatives. The index is defined in the range of 0–1 to provide judgement on the degree of credibility of each outranking relation. This method is employed based on uncertainty through the pseudo-criterion concept and outranking relations and also by developing a dynamic way to determine the weights as used by [72]. Mastalerz [47] ELECTRE to deal with the problem of categorising what criteria refer to a legacy system. The proposed ELECTRE method started with defining a set of criteria and determining their family. Next, based on the preference analysis made, the equivalence and preference thresholds were determined. The author indicated that ELECTRE uses quantitative and qualitative data, which highly expand its range of usage. He argued that this approach is a reliable and effective method for modernising legacy systems.

Analytic network process (ANP)

The theory of ANP was introduced by [58] as a new essential phase in decision-making theory. According to [28], ANP is a special case of AHP, which changes problems to a network shape in which, goals and alternatives are interconnected. As compared to AHP that aims at modelling problems into a hierarchy structure, ANP enables feedback connections and loops between nodes to illustrate interdependence. The similarity between AHP and ANP lies in the use of pairwise comparisons to measure the weights of alternatives and finally to rank those in the decision process. However, the

main difference between AHP and ANP is that ANP approaches decision problems more holistically by considering the dependence and feedback among the criteria. Tuzkaya [67] addressed the problem of undesirable facility location selection using the ANP, an MCDM technique. The ANP method is used for decision-making based on four main factors, namely benefits, costs, opportunities, and risks, to help companies to evaluate and select suitable undesirable facility locations successfully. The ANP method is capable of taking into consideration both tangible and intangible criteria without sacrificing their relationships and it can deal with all kinds of dependencies systematically. Unlike traditional MCDM methods which are generally based on the independence assumption, the ANP is a relatively new MCDM methodology, incorporating feedback and interdependent relationships between decision attributes and alternatives.

Interpretive structural modelling (ISM)/Total interpretive structural modelling (TISM)

ISM is an interactive learning process that interprets based on the decision of a group of judges, which could be the key persons in industry [56]. ISM is a computer-aided method for developing graphical representations of system composition and structure. The concept of relatedness in the context of a particular relationship distinguishes a system from a mere aggregation of components. ISM methods help by defining a contextual relation which describes the interelement relationship to be explored, after that defining a decision rule by which the group (majority rule) will decide its response to the ISM queries. So ISM has systematically explored a pattern of relationship between elements as technology assessment's set of tools. In [56] studied the non-performing assets (NPAs) of the Indian banking sector on the interaction and interplay of the determinants. The hierarchical model that was developed illustrates the driving and dependence relationships among different factors. Economical-political environment was the main driver of the NPAs to adopt international best practices, affect the ownership patterns, and help identify three crucial paths that need to be focused on.

TISM is derived from ISM and is used to model and structure factors that are identified based on the opinions of the expert group that determine how the different elements are connected and why these elements are supposed to connect that way [56]. TISM is a model technique as it provides interpretation for both links and nodes in the structural model in order to identify any factors and examine the structure of an ecosystem (e.g., TISM is used to examine the structure of the mobile ecosystem in Korea due to the enhanced mutual alliance between service industries and mobile manufacturing, and find out that decision-makers should consider dynamic patterns for examining new mobile ecosystems by emphasising the sociotechnical aspects). According to [56], TISM incorporates interpretations of each relation; it does not only gives direct relation but also gives transitive relation, which can also contribute to creating a knowledge base of the interpretive logic of all the relations. TISM process starts with identifying the relevant variables related to the problems and issues. After identifying a variable that is related to the problems and issues, the next step is to use problem-solving techniques against this variable, for example, fuzzy MICMAC method was used to determine the non-performing assets in banks of India [56].

4.3.3 Significant Factors in LSM

RQ3: *What are the significant criteria for each particular approach considered in the existing research*? A considerable number of criteria for modernising legacy systems that have been proposed will be identified and summarised

Table 5 shows the paper identification of the reviewed articles to identify the criteria that are concerned in each particular approach. A considerable number of criteria for modernising legacy systems have been proposed and summarised. Detailed information about the method of each paper and its common selected criteria are also presented. It should be noted that the criteria evaluated in this study came from various fields such as software development, manufacturing, academic as well as the financial institutions. Therefore, this study focuses on finding the significance of these criteria by calculating the frequency of their usage. The wide fields also lead to the identification of different terms to elaborate on major criteria.

Table 5: List of paper identifications and authors.

ID	AUTHOR	ID	AUTHOR
1	Clark et al. (2004)	2	Yim, Ahn, Kim, & Park (2004)
3	Bigham, Cuthbert, Yang, Lu, & Ryan (2004)	4	Regan, Colyvan, & Markovchick-Nicholls(2006)
5	Doerr, Gates, & Mutty (2006)	6	Erradi, Anand, & Kulkarni (2006)
7	Buchanan & Vanderpooten (2007)	8	Salama & Aly (2008)
9	Saaty (2008)	10	Chu & Khosla (2009)
11	Azani (2009)	12	Tuzkaya & Önüt (2008)
13	Mastalerz (2010)	14	Soroor, Tarokh, Khoshalhan, & Sajjadi (2012)
15	Behzadian, Otaghsara, Yazdani, & Ignatius(2012)	16	Macary, Almeida-Dias, Uny, & Probst (2013)
17	Ahmadi, Rad, Nilashi, Ibrahim, & Almaee (2013)	18	Boscoianu & Boscoianu (2013)
19	Molnár, Szabó, & Benczúr (2013)	20	Lu, Lin, & Tzeng (2013)
21	Cano, Garzón, & Sánchez-Soto (2013)	22	Sahin & Mohamed (2013)
23	Mehrjerdi (2013)	24	Barfod & Steen (2014)
25	Zavadskas, Antucheviciene, & Kaplinski (2015)	26	Ahmadi, Nilashi, & Ibrahim (2015)
27	Alhammadi, Stanier, & Eardley (2015)	28	Kim, Kim, & Kim (2015)
29	Lee, Cho, & Kim (2015)	30	Kala & Kumar (2017)
31	Shamseer et al., (2015)	32	Darwish & Shehab (2017)
33	Singh, Verma, & Koul (2017)	34	Srinivas, Ramakrishna, Rao, & Babu (2016)
35	Bowlds, Fossaceca, & Iammartino (2018)	36	Titiyal, Bhattacharya, & Thakkar (2019)
37	Zaabar, Beauregard, & Paquet (2018)	38	Adetunji, Bischoff, & Willy (2018)
39	Rizvi, Kashiramka, Singh, & Sushil (2019)	40	Bertoni (2019)
41	Goepel (2019)		

Table 6 presents the significant criteria obtained in many MCDM approaches for modernising legacy systems. From the results, the most important criteria in LSM is cost-effectiveness (obtained 43.9% of the selected papers), followed by technology integration with 29.2% and organisational factors with 19.5%. The other criteria that have also been of prior concerns in the selected papers are technical attributes (17%), usability (12.2%), knowledge/skill (17%), and time effectiveness (14.6%).

Table 6: Main criteria and relevant terms.

Key criteria	Relevant terms
Cost-effectiveness	"reduce cost", "cost dimension", "integration cost", "solution cost", "system cost", and "financial parameters"
Technology integration	"technology dimension", "technology competence", and "enhance integration"
Organisation	"top management support", "firm size", and "organisation readiness"
Usability	"easy implementation", "service availability", and "service quality"
Knowledge and skill	"lack of application knowledge" and "legacy skill shortage"
Time effectiveness	"duration" and "migration duration
Flexibility	"easy change", "company business changes", and "modification effect"

5. RESULTS AND DISCUSSIONS

5.1 Implication of This Study

A summary of implication from this study is tabulated in Table 7. thirteen criteria are investigated further as shown in Table 7. The significant criteria are consistent with the previous studies, which cost-effectiveness leading the list. The step-by-step process in LSM must be cost-effective for the company is very important. Technology integration follows next, which existing property unreservedly used from the new condition through adaptable associations with the conveyed technology. The third is the organization factor, which is the source of the accompanying variables to be considered in the technique determination choices. Technical attributes such as maintainability, simplification, for instance, will ensure new change is viable. The rest are as shown in the table makes the top 13 criteria from all 30 criteria identified in the review.

Table 7: Criteria of LSM

#	Criteria	#	Criteria	#	Criteria
1	cost-effectiveness	2	technology integration	3	organization factor
4	technical attributes	5	knowledge skill	6	time effectiveness
7	functionality	8	supplier/vendor	9	business area
10	maintainability	11	reliability	12	usability
13	availability				

Table 8 depicts classification dimensions for single AHP and its variation LSM approach and criteria from 13 studies. The top approach used for LSM in this review is AHP and its variations. Cost-effectiveness and technical attributes are the main criteria in the selected studies. All criteria except reliability are considered important. Five is the maximum number of criteria considered as in S8, S9 and S10 do not consider these 13 criteria but the

Table 9 depicts classification dimensions for integrated AHP and its variation LSM approach and criteria from 12 studies. Cost-effectiveness and technology integration are the main criteria considered in the selected studies. All criteria except time effectiveness are considered important. S31 considered six criteria which include cost-effectiveness and technology integration.

Table 10 depicts classification dimensions for LSM other single approaches and criteria. Similar to Table 8 and 9, cost-effectiveness is also the main criteria considered in other single approaches for LSM. S8 considered 6 criteria, which indicate the highest use of criteria in the approach used. Meanwhile, S16 and S37 considered 4 and 5 criteria, respectively.

Table 11 depicts classification dimensions for LSM other integrated approaches and criteria. As shown in the table, different criterion is identified randomly in recent LSM integrated approaches.

5.1.1 The Preferred Single MCDM Approach

This study has also identified an interesting finding where the most popular MCDM approach used for LSM is the individual approach, where it represents more than half of academic studies with a score of 58.5% (24 out of 41 papers). This is followed by integrated approaches with 26.8% (11 out of 41 papers) while other approaches get a score of 14.6% (6 out of 41 papers). 13 studies as shown in Table 7 showed the highest AHP and its variation single approach used. Ultimately, we can conclude that individual MCDM approach is more popular than any other approaches when it comes to LSM.

5.1.2 The Integrated MCDM Approaches Is No Preference

When comparing the individual to integrated approaches, it is learnt that the integrated approaches are less preferred, looking at their 31.8% lesser score than the individual approaches, making them only 26.9% from the overall studies. A relatively low score for an integrated approach is due to the nature that it needs to be integrated with other methods, making them more complex and requiring a comprehensive adaptation. As shown in Table 6, the integrated approach is dominated by AHP and TOPSIS, there is also research that uses a combination of DEMATEL and FAHP. MCDM is expected to be focusing more unto a more integrated and hybrid approach in the coming years. As shown in Table 6, recent research applied more on integrated approaches rather than a single approach. As expected, more criteria will be taken into consideration in integrated approach since the existing single approach has some limitations.

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Table 8: Criteria Of LSM For Single AHP And Its Variation Approach

Selected studies		Approach	Criteria												
			1	2	3	4	5	6	7	8	9	10	11	12	13
S4	Regan, Colyvan, & Markovchick-Nicholls (2006)	AHP							/			/		/	
S5	Doerr, Gates, & Mutty (2006)	AHP			/			/							
S6	Erradi, Anand, & Kulkarni (2006)	AHP	/	/			/								
S7	Buchanan & Vanderpooten (2007)	AHP	/					/							
S8	Salama & Aly (2008)	AHP	/			/				/	/			/	
S9	Saaty (2008)	AHP													
S10	Chu & Khosla (2009)	AHP													
S11	Azani (2009)	AHP		/	/		/								
S12	Tuzkaya & Önüt (2008	AHP				/									/
S13	Mastalerz (2010)	AHP	/												
S14	Soroor, Tarokh, Khoshalhan, & Sajjadi (2012)	AHP	/		/										
S20	Lu, Lin, & Tzeng (2013)	FAHP			/										
S41	Goepel (2019	AHP	/		/										

Table 9: Criteria Of LSM For Integrated AHP And Its Variation Approach

Selected studies		Approach	Criteria												
			1	2	3	4	5	6	7	8	9	10	11	12	13
S24	Barfod & Steen (2014)	DEMATEL-FAHP				/									
S25	Zavadskas, Antucheviciene, & Kaplinski (2015)	DEMATEL-FAHP	/	/	/										
S26	Ahmadi, Nilashi, & Ibrahim (2015)	TOPSIS-FAHP													
S27	Alhammadi, Stanier, & Eardley (2015)	TOPSIS-FAHP			/	/									
S28	Kim, Kim, & Kim (2015)	TOPSIS-FAHP	/												
S29	Lee, Cho, & Kim (2015)	TOPSIS-AHP	/												/
S30	Kala & Kumar (2017)	TOPSIS-AHP				/			/						/
S31	Shamseer et al., (2015)	TOPSIS-AHP	/	/						/	/	/		/	
S32	Darwish & Shehab (2017	AHP-GP		/			/								
S33	Singh, Verma, & Koul (2017)	AHP-GP	/	/									/		
S34	Srinivas, Ramakrishna, Rao, & Babu (2016)	FAHP-QFD													
S40	Bertoni (2019)	AHP-TOPSIS		/		/							/		

Table 10: Criteria Of LSM For Other Single Approaches

Selected studies		Approach	Criteria												
		Single	1	2	3	4	5	6	7	8	9	10	11	12	13
S1	Clark et al. (2004)	DEMATEL	/	/	/										
S2	Yim, Ahn, Kim, & Park (2004)	TOPSIS				/									
S3	Bigham, Cuthbert, Yang, Lu, & Ryan (2004)	TOPSIS													
S16	Macary, Almeida-Dias, Uny, & Probst (2013)	ERP		/				/	/					/	
S17	Ahmadi, Rad, Nilashi, Ibrahim, & Almaee (2013)	ERP	/								/				
S18	Boscoianu & Boscoianu (2013)	SOA	/				/								/
S19	Molnár, Szabó, & Benczúr (2013)	SOA	/				/								
S21	Cano, Garzón, & Sánchez-Soto (2013)	ELECTRA	/			/									
S22	Sahin & Mohamed (2013)	CLARIFI								/				/	
S23	Mehrjerdi (2013)	ANP	/												
S37	Zaabar, Beauregard, & Paquet (2018)	ELECTRA-III	/	/				/	/	/					
S38	Adetunji, Bischoff, & Willy (2018)	TOPSIS	/				/		/			/	/		/

Table 11: Criteria Of LSM For Other Integrated Approaches

Selected studies		Approach	Criteria												
		Integrated	1	2	3	4	5	6	7	8	9	10	11	12	13
S35	Bowlds, Fossaceca, & Iammartino (2018)	ISM/TISM			/		/				/	/	/		
S36	Titiyal, Bhattacharya, & Thakkar (2019)	DEMATEL-VIKOR						/		/			/		
S39	Rizvi, Kashiramka, Singh, & Sushil (2019)	PSS-MCDM									/	/			

5.1.3 Criteria In Modernising Legacy Systems

Another accomplishment of this study is finding the main criteria used in modernising legacy systems. A countless number of criteria were proposed by our informational index papers, and they were outlined in Appendix A. As indicated by our exploration findings, it has been discovered that the 13 most important criteria are considered for modernising legacy systems which carried more than 10%. They were cost-effectiveness, technology integration, organisational factors, technical attributes, knowledge/skill, time-effectiveness, functionality, supplier and vendor, business area, maintainability, reliability, and usability and availability.

As shown in Table 6 four important criteria are used in single AHP and integrated of AHP with another approach are 1) cost-effectiveness (10), 2) technology integration (7) 3) organization factor (6) 4) technical attributes (6). Overall, these four are still the most important criteria considered in the reviewed approaches. Hence, new MCDM should consider cost-effectiveness, technology integration, organization factor and technical attributes. Also, six criteria is the maximum considered criteria in the selected studies. Hence, besides those four, two other criteria could be chosen from knowledge skill, usability or availability.

Finally, we find that this study is quite significant as the sources of this study came from 41 different academic articles including papers presented at international seminars. All of these selected studies have highlighted the usage of the MCDM method in the process of LSM and inscribed the criteria used in applying this method.

5.2 The Use of MCDM In Legacy System Modernization Is Trendy

In recent years, MCDM approaches have been under considerations and become options among researchers and professionals. This study has identified 41 academic studies that have been published between 2003 and 2021. The selected academic studies are those that have applied the MCDM approaches into LSM. Thus, this study was conducted to identify the importance of MCDM for LSM. The main contribution provided by this study is to present the types of MCDM approaches and the criteria used in modernising legacy systems by researchers and professionals.

The results obtained from this study found that there were significant implications; from the observations, the adoption of MCDM approach in modernising legacy systems has increased from year to year where it is evidenced through academic studies published between 2003 and 2021. In the first seven years (2003–2009), 12 academic studies successfully published on MCDM usage for LSM where it represents 29%. While for the next 10 years (2010–2019), the significant increase was double that with 29 published academic studies, representing 71%. Hence, this study believes that the increase is due to the researchers' and professional software awareness of the importance of the MCDM approaches in assisting the process of LSM.

The most popularly used MCDM technique is AHP, which was proposed by [58]. Even though AHP is widely used, it cannot handle complex problems. AHP fundamental scale of absolute number is derived from the psychophysical law of Weber-Fechner and uses absolute number 1, 2, 3 …., 9. AHP works is in a hierarchal structure no matter how many levels, but it does not mean that it can consider complex scenarios since AHP ignores reality. What we had found is that in reality, there are a lot of alternatives for many different scenarios and with perhaps hundreds of criteria. These problems will be unique towards many industries such as industrial location, infrastructure works, and political influences that are considered forbidden territory for AHP because of the complexity and the necessary pairwise comparison that had to be observed. AHP practitioners mostly work with no more than 10 criteria. The model does not work well with resources, and it also does not take into an account any of the correlation between the criteria and ignores the dependencies between any of the alternatives. AHP is also probably the best chance when the decision-maker or analyst deals with problems that may benefit the company directly in an instant. Another popular selection that was found is TOPSIS, which is becoming more popular. It does not work with subjectivities but with facts. The same can be said about PROMETHEE and ELECTRE in which even if they use subjectivity, their conclusions are based on facts or in mathematical procedures, for instance, PROMETHEE uses different types of distributions to represent uncertainty.

5.3. Threats to Validity

The results of this SLR might have been affected by certain limitations such as inaccuracy in data extractions, bias in the selection of primary studies, and in accuracy in assigning scoring to each study for the quality assessment criteria. To minimise the bias in data extraction and QA assessment, the third author filled in the appropriate data collection forms and the first and second authors reviewed it. The accuracy of assigning scores to the selected studies on quality assessment criteria was very subjective. For example, some of the studies did not explicitly mention the strategy employed and required a very subjective judgement from the researchers. Any discrepancies found were discussed among the authors until a consensus is met. Our SLR might have also missed out other modernisation approach for legacy system that have been patented and commercialised but have not been published in literature, possibly due to privacy or copyright reasons. We address the issue of bias in study selection through multiphase search approaches (on-line database, snowballing, and manual search on targeted journals and conferences) that help to minimise the possibility of missing evidence.

6. CONCLUSION AND FUTURE WORK

Although many research works have been carried out in LSM, practitioners are not provided with advice on important factors to consider in the selection of particular LSM approach. An LSM framework that covers those factors and approaches for LSM would be useful for them since incorrect chosen of LSM approach not only delay the modernisation but importantly some operations in the organisation might have to be stopped and in turn, it would give stress experience to many customers.

We have answered the main research questions, and importantly the result is presented in Section 4.3. Our main findings from this SLR include the following:

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i) AHP method has become the top choice among researchers and practitioners in the process of modernising legacy systems. However, its use is still inadequate as there are still weaknesses in the method that causes its percentage score not to exceed 70% of the overall academic study. By not denying some of the advantages and the strengths in this method among them, it is based on a mathematical theory that has produced a simple and convenient perspective of the user. In the meantime, this study has also identified that the criteria contained in AHP are independent although not entirely. Therefore, this study also wishes to suggest that future studies on MCDM usage for the modernisation process of legacy systems also take into account other approaches such as ANP to address the issues of independent criteria within the AHP since it can link between one criterion with another criterion despite being in the different level of the hierarchy.

ii) TOPSIS integrated approach was utilised more than some other MCDM integrated approaches. Be that as it may, the yield of TOPSIS is centred only on weighting the relative significance of criteria and thus conditions among criteria are ignored. Despite that, there are times when criteria for heritage modernisation frameworks are interwoven, and the reliant relations of criteria should be resolved with a specific end goal to get solid and unequivocal outcomes. Therefore, the coordinated MCDM approach, for example, the DEMATEL-ANP approach is profoundly prescribed for modernising inheritance frameworks. This is because of the way that DEMATEL is fit for ascertaining the interdependency among the criteria and ANP weights criteria in light of those interdependency found by DEMATEL.

Most important criterion for LSM is cost effectiveness where it was used in 46.3% of selected papers. This is followed by technology integration (29.2%), organisational factors (21.2%), technical attributes (17%), knowledge/skill (17%), time-effectiveness (14.6%), functionality (12.2%), supplier and vendor (12.2%), business area (12.2%), maintainability (12.2%), reliability (12.2%), and usability (12.2%) and availability (12.2%).

We believe the findings of this study can supply an important contribution to the practitioners and researchers as it provides them with useful information about the different legacy systems modernisation approaches and key criteria for the LSM framework. The framework will furnish the software professionals and researchers with a rule and knowledge into future powerful research on the MCDM usage for LSM. Be that as it may, this study has the accompanying impediment: due to limited time, manpower, and resources, this study only covers research papers from five online databases. In this manner, extra academic papers can be pulled over to cover other imperative databases for broader research findings. We trust that continuous research activities will explore and depict wider ideas on these issues.

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