

MCDM for Engineering Education: Literature Review and Research Issues

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Abstract. The Multi-Criteria Decision Making (MCDM) methodology had been widely applied and accepted in businesses, industries and manufacturing sectors. However, there is a limitation of resources available on discussing the way of MCDM may applied in engineering education decision problems within university setting. The current economic crisis as well as the changes in the way Ministry of Higher Education providing funding to higher education institution had created a major shift in emphasis. Both public and private higher education institutions are facing increasing cost and declining revenue streams. The purpose of this paper is to review the literature which focused in seven majors engineering education decision problems: resources allocation, performance measurement, budgeting, scheduling, planning, obtaining resources, and evaluation. The paper carried out review of articles in international scientific journals and well known international conferences related to MCDM applications published within 2000 and 2016 inclusive. Related articles are reviewed and analyzed for the types of decision problems that were paid most attention to, MCDM approaches adopted, and inadequacies of those approaches. Some improvements and possible future works are recommended based on those inadequacies. The reviewed result will create an interest to university management as it is presented in an effective way to academic process improvement, resources allocation and achieving greater satisfaction among students.

Keywords: Engineering education · Multi-criteria decision making · Decision analysis

1 Introduction

Engineering education is one of the components in higher education and its quality tends to be the assurance of the level of educational quality at Higher Education Institution (HEI). This occurrence has led to high demand of engineers with excellent abilities and skills in applying their knowledge creatively and innovatively to solve real life problems. Hence, it is a need for engineering education institution to produce graduates who will fulfil the high standard requirement as needed by industry,

government and other sectors of society. However, the quality of engineering education faces the challenges from persistent worldwide economic with major restructuring of business and industry and advent of the information technology era that will affect the culture and method of engineering education [1, 2]. These phenomena causing universities have to manage their system optimally and keep improving their performance so that enough funding can be raised to cover necessary expenses [3].

Traditional activities such as teaching, research and service were increasing committed to the need of society [4] and universities have been assuming play a crucial responsibilities within development of economy [5]. Furthermore, there have been major transformations in the legal and institutional setting of most universities [6]. As a result of these developments, there was an opportunity and challenge for aligning each institution of higher engineering education (IHEE) system to activity of its faculty members with its objectives and strategic plans. Therefore, IHEE needs to manage each of them through process which include resources allocation, performance measurement, budgeting, scheduling, obtaining resources, and evaluation, so that the performance in term of teaching and research can be improved. Aligning those academic administrations with policies and objectives which comprised numerous conflicting interest groups involve decision making. Management science concepts and techniques have long been applied to academic administration.

MCDM was introduced in the early 1970's. MCDM methodological had been adopted by most researchers and academician for dealing with complex academic administration problems. In general, MCDM is a modeling and methodological tool which used by most universities for dealing with the real situation involved handling multiple conflicting objectives simultaneously.

In 1996, Mustafa and Goh [7] reported that 62 higher education administrations had proposed to apply the MCDM techniques in university settings. Within the MCDM, Multiple-Objective Decision Making (MODM) techniques (such as Goal Programming) were 60% more prevalent to be applied as compare to Multi-Attributes Decision Making (MADM) techniques (such as Analytic Hierarchy Process). However, the report did not emphasize on the application of other quantitative techniques such as mathematical modeling in operation research. Quantitative analysis is crucial to decision makers especially if the decision makers have little experience with similar problems, or problems are very sophisticated [8]. Although Ho *et al.* [9] had considered quantitative techniques in their paper; they did not focus on other applications of MCDM techniques in academic administration such as scheduling, planning, obtaining resources, evaluation and planning.

In addition, White [10] had classified that the primary purpose of application of management science techniques in academic administration are based on resource allocation, budgeting, scheduling, planning, obtaining resource, performance measure and evaluation. Mardani *et al.* [11] also reviewed a total of 393 articles related to MCDM and its applications published from 2000 to 2014. However, there is less specific attention was paid on the application of MCDM in engineering education.

Hence, this paper focused on providing an overview of the published application of MCDM methodology in IHEE. Once completion of this review, which MCDM techniques and management process were prevalent applied in engineering education and inadequacies of approaches adopted by previous researchers could be known.

This report was organized as follows. Section 2 explained which database and what searching criteria were used for finding the relevant journal articles. Section 3 described the categories of MCDM techniques including MODM and MADM, and distinguished their differences. Section 4 involved analyses the result of the finding by figuring out the trend of researchers, discussed some improvements on approach proposed by previous researchers and possible future work. Section 5 concluded the paper.

2 Review Methodology

The present study was aimed to investigate the application of MCDM approach to IHEE management process through reviewing previous work done by researchers and classification of international journal articles within 2000 and 2016 inclusive. The main purpose for sorting out articles within this period was that most of the studies relevant to IHEE using MCDM had gained much attention from researchers after some researchers [7, 8] had reported a detail of its advantages.

The review methodology of this paper was carried out through the used of internet and database to analyse the different aspect of topic related to MCDM application. Initially, the application of MCDM techniques to higher engineering education management process was seek through a literature review and classification of international journal articles from 2000 to 2016 inclusive. The relevancy of the journal papers found in databases were filtered based on title, abstract and keyword fields. In addition to the query of “higher engineering education”, the keywords such as resources allocation, performance measurement; budgeting, scheduling, planning, obtaining resources; evaluation; MCDM; MODM; MADM; AHP; operation research and mathematical modeling were searched simultaneously.

After topic filtering, twenty-two papers were selected and studied to understand various research issues and techniques of MCDM being explored by researchers applying MCDM approach to solve the decision problem found in the higher engineering educational settings. On the other hand, there were many limitations to the search methodology. One important limitation was the availability of the papers to the authors. Primary databases searched for paper were Emerald, Elsevier, IEEE and Springer publishing groups. Many papers were reviewed from cross references because it contained the required information.

3 Multiple Criteria Decision Making (MCDM)

MCDM was one of the most widely applied decision methodologies in engineering, management science, and business. The MCDM approaches have gained much attention from practitioners and researchers, particularly among academia due to its ability to improve the quality of decisions by creating the policy development more effective, rational and explicit. A large number of approaches and techniques have been introduced in this area of study. Previous literature consisted of numbers of classification of MCDM tools with fuzzy theory sets [11]. The developed of MCDM

approaches was mostly based on various real academia problems that require the consideration of multiple criteria.

Generally, MCDM techniques can be divided into two categories which are Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM). MODM techniques are the extension of linear programming. Linear programming model was defined as involvement of linear expressions in single objective function and constraints, where decision variables are continuous [12]. However, MODM techniques involved multi-objective functions that were incorporated into the model simultaneously. While, MADM techniques aimed at selecting from a population of feasible alternatives which characterized by multiple attributes. Both techniques were widely being adopted compared to other MCDM techniques as they possess unique advantages.

3.1 Multiple Objective Decision Making (MODM)

Goal Programming (GP) invented by Charnes and Cooper [13] is the most highly developed and tested techniques of linear programming, particularly a programmatic method for MODM. The concept of this technique has similarity to the linear programming model except it involves the incorporated of all goals (objective) into a single model. The goals as well as their priority level are identified by the decision makers.

Basically, the target of the most important goal had to be attained to the fullest extent before target of the second goal was considered in solution generating process. This procedure was followed within the given system constraints until the targets of all goals are fulfilled to the fullest extent. The other approach of MODM methods was the vector optimization algorithm. These methods required the generation of the entire efficient solution of a set of a multiple objective problems. However, this method had been criticized for their computation burden in generating the entire efficient set in selecting a solution from an infinite number of alternatives [7].

3.2 Multiple Attribute Decision Making (MADM)

The multiple attribute utility theory (MAUT), outranking methods, and Analytic Hierarchy Process (AHP) are the widely methods of MADM. However, the AHP method developed by Saaty [14] was found to be the most prevalent MADM techniques for dealing with the decision problems in higher education [7]. Saaty [14] defines AHP was a general method for structuring complex ill-structured multi-attribute problems and comprised of three main operations including hierarchy construction, priority analysis and consistency verification.

Basically, the approaches of the AHP methods can be characterized by the following procedure:

- Complex multiple criteria decision problems break down into its components parts where every possible attributes are arranged into multiple hierarchical levels.
- Compare each component in the same level in pairwise fashion based on decision maker's own experience and judgment.

However, some degree of inconsistencies may be occurred since the comparisons were carried out through personal or subjective judgments. The final operation named consistency verification should be carried out to ensure the judgments were consistent. This verification was regarded as one of the most advantages of the AHP as the degree of consistency was measured among the pairwise comparison by computing consistency ratio [8]. Lastly, the judgments can then be synthesized to figure out the priority ranking of each criterion and its attributes.

AHP approach thereby providing a feedback mechanism for the decision makers to review and revise their judgments. In some multiple criteria decision problems like resource allocation in higher education, the decision makers would like to know how much should be allocated to which area (e.g., number of administrative staff employed) [7]. For this reason, the GP can be incorporated with the AHP because the decision variables are used to determine the amount of allocation. It can definitely provide more and useful information for the decision makers. Based on the above analysis, it was believed that it must be beneficial to the decision making process if the AHP and the GP are integrated together.

4 Result Analysis

There are 22 journal articles which appeared in the period 2000 to 2016 studying the resource allocation, performance measurement, budgeting, scheduling, planning, obtaining resources and evaluation in higher engineering education setting. In IHEE, the involved resources were basically students, faculties, staffs, facilities, equipment, financial, scheduling time and some external assistance form government, community or industries.

In this context, resource allocation can be defined as levels of certain resources to be determined and allocated among competing members or activities. Budgeting is concerned on dealing with financial allocation and scheduling related to allocation of time slot for course, examination and classroom. Performance measure was referred to evaluate and analysis of efficiency and/or effectiveness used of certain resources. Whilst, planning concerns on the process of preparing a set of information based on alternative in managing policy formation or any relevant administrative action. Furthermore, obtaining resources were related to availability levels of certain resources and effects of certain actions was performed on its. Lastly, the evaluation may refer to the comparative analysis on efficiency or performance of the available resources. Relevant journal articles were classified according to the above mentioned categories in IHEE administration.

The classification of these journal articles and techniques used in each decision problems are summarized in Table 1. Three issues related to these relevant journal articles are examined including:

- (1) What kind of decision problems was paid most attention to?
- (2) What types of MCDM techniques commonly applied and implemented?
- (3) What are the possible future works after a detailed analyze of the approaches?

Table 1. Summary techniques used in focus major higher education decision problems

Decision problem	Researches	MCDM techniques used
Resources allocation	[15]	MCDM
	[16]	Qualitative
	[17]	MCDM
	[18]	Qualitative
Performance measurement	[19]	Quantitative
	[20]	Quantitative
	[21]	Qualitative
	[22]	Quantitative
	[23]	Qualitative
	[24]	Qualitative
Budgeting	[25]	MCDM
Scheduling	[26]	MCDM
Planning	[27]	MCDM
	[28]	MCDM
	[29]	Quantitative
Obtaining resources	[30]	MCDM
	[31]	Quantitative
	[32]	Quantitative
Evaluation	[33]	Quantitative
	[34]	Quantitative
	[35]	Quantitative
	[6]	MCDM

4.1 Higher Education Decision Problems

Regarding the various decision problems in higher educational setting, performance measure was the most commonly studied as shown in Table 2. Most of the subjects of performance measure conducted by researcher were generally in performance of IHEE [21, 22], and faculty or department members or students [19, 22, 23].

Table 2. Number of articles in each higher education decision problems

Decision problem	Number of articles	%
Resources allocation	4	18
Performance measurement	6	27
Budgeting	1	5
Scheduling	1	5
Planning	3	14
Obtaining resources	3	14
Evaluation	4	18

The number of articles studying evaluation and resources were both four articles respectively. Among the five articles related to evaluation, the focus from most of researchers [6, 33, 35] was mainly on developing evaluation model in analyzing the decision problems. For example, Costa *et al.* [6] had proposed a new faculty evaluation model that addressed the whole range of academic activities and adopted by engineering school of the Technical University of Lisbon. Other researchers [34] studied on the comprehensive evaluation of students' vocational ability based on AHP approach.

For the resource allocation, the focused of the articles was mainly on allocating resources to students or faculty members. Datta *et al.* [15] had applied the MCDM approach with the used of comprise ranking method in allocating an appropriate supervisor to students. While, Rouyendegh *et al.* [17] suggested MCDM approach to solve decision problem by allocating good working area for industrial engineering students.

It was then followed by the three decision problems regarding planning and obtaining resources respectively that had conducted by researchers. Among the three articles related to obtaining resources, the focuses of researchers were diverse. Banerjee *et al.* [31] studied the use of MCDM approach to solve the decision problems involvement recruitment of faculty members in engineering organization. On the other hand, Isik *et al.* [32] used the AHP approach to obtain the learning management system that best suited students. Focus areas involving planning decision problem conducted by researchers also diverse. Lopez *et al.* [22] conducted a study on the web based learning object selection in engineering education using AHP process. While Erkan *et al.* [28] were conducted a study on determining industrial engineering curriculum change parameters for Bachelor's Degree students in Turkey by MCDM.

Comparatively, decision problems involved budgeting and scheduling had attracted less attention. Each of these categories only consists of one researcher carry on this study. Only Awingo [25] was focused on budget decision problem and developed a goal programming model for budgeting in IHEE. While, for scheduling problem, Parthiban *et al.* [26] solved assignment problem for faculty course by decision making models.

Unlike the findings of Mustafa and Goh [7], performance measurement was paid most attention rather than resources allocation. This occurrence was due to funds provided to most IHEE was performance related. Therefore, it was crucial for decision makers to conduct performance measure including academic activities such as teaching and research, so that continuous improvement on quality of engineering education can be proceed based on bench-marking results. However, performance of all individual members from IHEE was highly related to available resources allocated and budget to them. Thereby, it was crucial to study this issue in the immediate future.

4.2 Techniques Used

Techniques used to solve those problems as stated in Table 1 can be classified into three categories: MCDM, quantitative and qualitative. As shown in Table 3, the quantitative approach was mostly adopted by researchers as there are nine articles applying this approach, which is slightly more than application of MCDM approach, that is eight articles.

On the other hand, qualitative approach had attracted much less attention and applied to the resource allocation [16, 18] and performance measurement [23, 24] decision problem in IHEE setting. It was interesting to find that most of the researchers will apply quantitative and qualitative approach in solving problem regarding performance measure in university rather than adopting MCDM as suggested by Ho *et al.* [9]. However, this finding was similar with Ho and his colleagues [9] that MCDM approach techniques can be applied to resources allocation [15, 17], budgeting [25] and scheduling [26]. Furthermore, both qualitative and quantitative had gained much attention than MCDM techniques, 23%, 41% and 36% respectively. Most of researchers such as Ho and his colleagues [9] and Janis [36] claimed that the MCDM was a practical and applicable technique coincided with real world problem as decision problem normally comprised of multiple criteria rather than single objective. It was, therefore, worth investigating the application of MCDM techniques to IHEE decision problems in the immediate future.

Table 3. Numbers of articles in each technique

Techniques/Tools	Number of articles	%
Qualitative	5	23
Quantitative	9	41
MCDM	8	36

4.3 Possible Future Work

After the detailed description of the approaches in the previous section, two major possible future research areas can be recommended. First, it was noticed that nearly most of the journal articles studied performance measurement. Only a few journal articles, however, investigated resource allocation. Resource allocation was definitely a dominant attribute of performance. A system's performance can be enhanced by providing that sufficient resource is allocated to it. Due to gradual cuts in higher education budgeting, resource allocation should be optimized so that the performance of a university can be at least maintained or even superior to its competitors. Furthermore, resource assignment is closely related to budgeting problems. In present study, it was found that only one reported budget decision problem using MCDM by IHEE. Thus, developing MCDM models for usage at solving budget decision problems in IHEE where future work is critically needed.

Second, quantitative, particularly AHP approach [18–20, 27, 28, 31, 33, 34] were found to be the most prevalent techniques in dealing the decision problem with multiple criteria. It had applied to all major decision problems. This situation was due to most judgment made by decision maker is determined subjectively and may induce some inconsistencies. This condition had encouraged most of the researchers to adopt AHP approaches since it involves the consistency test to examine whether the judgment made is consistent. However, this approach may not suitable for other decision problems, particularly for evaluating performance of each criterion. It was suggested to incorporate the GP to formulate the goal equation and objective function once

consistency test is satisfied. Since some knowledge-based agents are hybridized in the original GP technique, we called this as knowledge-based goal programming (KBGP) technique which normally used to tackle the resource allocation problem or model [9]. For example, since Erkan *et al.* [28] found that there was a gap of reaching a uniform group decision in curriculum design and planning, they proposed MCDM approach that identifies relevant and essential criteria in changing curriculum parameters. They had adopted AHP to prioritize the criteria. The criteria comprised of two alternatives of curriculum. In each criterion, there were multiple attributes. The higher the scores, the higher the possibility of the curriculum to be adopted. Undoubtedly, their approach can be well applied to plan and develop the curriculum. However, this approach may not suitable for other decision problems, particularly for evaluating performance of each criterion.

4.4 Implementation of MCDM Techniques

Recently, MCDM has gradually made some significant impact on IHEE administration based on gathered articles. Regarding to this evidence, most of studies or gathered articles (approximately 60%) indicated post implementation compared than a proposed work or pilot implementation. The implementation rate was relatively high may due to MCDM approach allow a greater improvement for decision makers in obtaining the best solutions in solving complex problems involving several factors. Furthermore, a hybrid MCDM approach have gained much attention from various researchers [16, 30], which allow greatest improvement on the part of the decision maker of IHEE in the modeling stages. Thereby, the MCDM would become easier to be used and implemented.

The reviewed of work relevant application of MCDM in IHEE is aimed to encourages readers who involved in the IHEE administration to apply MCDM approach in decision making process, particularly solving complex problem or obtaining the best alternatives. Applying MCDM methodological would allow modelers or decision makers to have a systematic and efficient in searching for optimum solution by considering all the objectives or factors in the problems modeled.

5 Conclusion

This paper mainly reviewed the application of the MCDM techniques to seven major higher engineering education decision problems, namely resource allocation, performance measurement, budgeting, scheduling, planning, obtaining resources and evaluation. It was found that nine out of 20 journal articles collected in the 2000 to 2016 studied performance measurement. The previous researchers preferred measuring performance of universities, department or faculty members. Resource allocation also gained much attention from researchers as most of the universities currently facing gradual decrease in higher engineering education funding. This study has some major limitation that can be considered as recommendations for future work. First, this review paper is focused on the use of MCDM techniques. Articles published in earlier than 2000 and late 2016, if any, are not included in present study due to limited reporting

time. It was suggested that a future review can be expanded further in decision making scope. Furthermore, there are also some qualities papers on MCDM application may have been left out of this review due to limitation in the search methodology. The data collected is excluding textbooks, doctoral and master dissertations, PhD thesis and unpublished articles in the MCDM issues. Thereby, data collected from these scholarly journals and obtained results can be compared with this paper. However, authors believe that there is comprehensively review on papers from high reputable publishers although some of relevant outlets may have remained outside the scope of this study. Thereby, future studies can review those articles which are not discussed in this review paper.

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