Research Article

A Decision Support Framework for Curriculum Planning in Undergraduate Supply Chain Management Program: An Integrated Approach

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Curriculum planning is an important but complex and challenging decision-making problem at universities. There is a growing interest in curriculum planning problem. However, the body of research on curriculum planning process using analytical methods is still small. Additionally, prior research focused on planning of an individual curriculum or making study plan for students. Curriculum planning at the program level is an under-researched topic. A robust model has not been constructed to address curriculum selection and credit allocation problems simultaneously. To help educational leaders make the most appropriate curriculum plan corresponding to their goals with the highest level of utility achieved, this study presents a new decision support framework with integrated approach. In the proposed framework, based on the competency weights derived from the analytical hierarchy process method, the importance of each potential curriculum is evaluated using the fuzzy comprehensive evaluation method. An exploratory estimation is made to calculate the contribution values of competency development by each curriculum taught at different levels. Finally, multichoice goal programming with utility function determines the curriculum to be provided and corresponding credits to minimize the aggregate deviations from predefined goals with multiple aspirations. An application to curriculum planning of an undergraduate supply chain management program is presented to validate the flexibility and practicality of the proposed approach. The implications of the study are not restricted to curriculum planning of supply chain management program.

1. Introduction

As a cross-functional approach that involves planning, implementing, and controlling the flow of products and services from demand forecasting and procurement to production and distribution, supply chain management (SCM) is a vital foundation of business success and customer satisfaction [1]. In today's global economy and digital world, a well-designed system of SCM can help business become more efficient and significantly reduce a company's operating expenses, therefore driving up profits and improving its competitive advantage [2]. The importance of a robust SCM system has been further strengthened due to the COVID-19 pandemic situation [3]. However, the SCM profession is facing a global talent shortage crisis, which has attracted a tremendous amount of attention from both scholars and practitioners [4, 5]. Talent development is an integral part of university’s mission, and a university education is essential for SCM professionals [6, 7]. Nowadays, due to the fulfilling and prosperous career path after graduation, SCM has become a hot, sought-after major on undergraduate campuses.

Curriculum planning is a key element in the higher education system and is the core of academic work. Curriculum planning in this study is specified at the program level. It is a decision process in which the purpose, sequence, module, credits, examination type, and schedule of the program curriculum are defined by considering available
resources and stakeholders’ preferences [8]. New degree programs must plan curriculum from scratch. It is also necessary for existing academic programs to reform and update curriculum plan regularly (e.g., annual review and revision) to deal with the changes in industrial demand and educational practice. For instance, China’s Ministry of Education published the National Standards for Teaching Quality of Higher Education Institutions (henceforth, National Standards) in 2018. Covering 587 undergraduate majors, it is the first national standard of its kind aimed at improving the quality of teaching and training in China’s colleges and universities. Thereby, higher education institutions need to adjust their curriculum plans to comply with the criteria and requirements proposed by the National Standards. A successful curriculum planning could ensure program quality and greatly improve learning environment and student experience [9]. Effective planning of curriculum for education programs, prioritization of curriculum, and allocation of resources to the curriculum to be delivered are important in terms of effective use of faculty and efficient use of economic resources. Therefore, for a degree program with a wide range of potential curricula, it is critical to choose the most important ones by comparing the materiality of each, direct the teaching activity to these curricula to meet public expectation, and determine appropriate teaching hours to accomplish learning outcomes.

On the other hand, academic program design has been criticized for not responding to rapid social and technological development [10]. Gaps have also been identified between the designed curriculum plan and the needs of supply chain hiring managers [4, 11]. Despite these concerns, there has not been major progress in changing the curriculum planning process [9]. To study and address the important curriculum planning problem of academic programs and enhance the quality of SCM education program, a research question is raised: how should the curriculum planning process be managed for credit-bearing undergraduate SCM program? In particular, we focus on studying the following two essential areas in the curriculum planning process: how to select the right curriculum to be provided by the degree program? How to determine the number of credits for the selected curriculum? In other words, which level of breadth and depth of learning is reasonable for a curriculum (e.g., introductory level, intermediate level, and advanced level)? Curriculum scheduling considering the prerequisite courses is not included in the scope of this study.

Curriculum planning is a challenging decision process that needs to deal with many complex factors and conflicting objectives and consider multiple aspiration levels and preference of decision-makers (DMs). As a branch of operational research (OR), multi-criteria decision-making (MCDM) supports DMs to find the best feasible solution according to the established criteria and objectives [12]. Selection of curriculum portfolio and allocation of credits in curriculum planning can be considered as an MCDM type of problem. A manually designed curriculum plan based on personnel experience could result in errors and have a negative effect on education quality. Motivated by the needs of higher education institutions, a new unique method combining analytic hierarchy process (AHP), fuzzy comprehensive evaluation (FCE), and multichoice goal programming with utility function (MCGP-U) is proposed with an application to the curriculum planning of an undergraduate SCM program in the context of a Chinese university. In the proposed approach, AHP is used to calculate the relative weight of each selection criterion, the FCE method is used to obtain an importance degree of each alternative curriculum, and finally the MCGP-U model is adopted to simultaneously determine the optimal combination of curriculum and corresponding credits. The aim of the integrated approach is to help educators make better decisions when developing a curriculum plan.

The major contributions of this study are summarized as follows:

(i) This is the first study presenting fuzzy MCDM methodology for developing curriculum planning in undergraduate SCM program and utilizes China’s National Standards for this purpose. Group decision-making incorporates different perspectives and ideas and thus makes better decisions than individuals. We fill a substantial knowledge gap regarding reaching a uniform group decision in curriculum planning of credit-bearing academic programs. By illustrating the implementation of OR techniques through a real-life case, this study contributes to better understanding of SCM curriculum planning process. The newly proposed curriculum planning methodology also can be applied to any academic programs.

(ii) To the best of our knowledge, this is the first research to explore and estimate the relationship between the curriculum credits and the competency development values. The credits assigned to the same curriculum can vary significantly among different higher education institutions. For example, the credits of logistics and distribution range from 1 to 3 among different schools in reality. How to determine the credits via a scientific method is a meaningful research topic. The research endeavor in this study focuses on learning the contribution of credits to competency increment and thereby expands the knowledge base in credit determination.

(iii) The results of this study will also be of interest to education policymakers, educational software company, and DMs of training and continuing education programs. This study sheds light on prioritizing and selecting compulsory and elective courses while determining corresponding credits. Educational software company can develop new functions of the software based on the proposed method, which helps to enhance customer satisfaction. The proposed method may be useful for solving various MCDM problems in practice in education and other fields.

The rest of this study is organized as follows: Section 2 conducts literature reviews on curriculum planning,
2. Literature Review

2.1. Curriculum Planning. Operational research is an interdisciplinary subject dealing with the development and application of advanced analytical techniques (e.g., computer simulation, optimization, and mathematical modeling) to better understand complex scenarios and make more informed decisions [13]. OR techniques can be used to solve a variety of managerial and administrative problems, including resource allocation, production and service planning and scheduling, and evaluation and selection of alternatives. Education is one of the fields in which OR techniques have been widely applied. The state-of-the-art surveys on the use of OR in education can be found in Ho et al. [14]; Johnes [15]; Sinuany-Stern [16]; and Smilowitz and Keppler [17]. Many educational decision problems, such as budgeting and resource allocation, efficiency and performance measurement, and assignment and scheduling, have been resolved by OR methods. Previous OR studies related to curriculum planning focused on planning for an individual curriculum (e.g., content-based curriculum development) [18–20], or assisting students in planning their curricula towards graduation, including course recommendation and determination of the semester to take courses [21–23]. Among numerous OR methods, the stand-alone methods or integrated methods of the following techniques are most commonly used: techniques for order preference by similarity to ideal solution (TOPSIS) [24], goal programming (GP) [25], data envelopment analysis (DEA) [26], decision trees (DT) [27], analytic hierarchy process [28], analytic network process (ANP) [29], genetic algorithm (GA) [30], and linear programming (LP) [31].

Research on planning academic program-level curriculum, however, has had limited exposure in the literature and thus needs further discussion and development [32, 33]. Gonzalez et al. [34] used quality function deployment (QFD) and benchmarking to design a customer-oriented undergraduate SCM program. Hsieh [35] applied fuzzy Delphi technique and AHP to develop curriculum frameworks to provide systematic planning for MICE (meeting, incentive travel, convention and exhibition, event) program in continuing education. To plan the curriculum of an industrial engineering undergraduate program, Kirıç [8] firstly utilized AHP and simple additive weighting (SAW) methods to classify available courses into compulsory courses and elective courses based on the rank of scores of the courses and then applied multichoice goal programming (MCGP) techniques for assigning these courses to related semesters. Kristiansen et al. [36] proposed mixed-integer programming (MIP) model to obtain an optimal solution to the elective course planning problem for high schools. Based on the professional competency requirements and the importance degree of relevant courses, Lin et al. [37] ranked the curriculum of industrial design education with AHP and QFD methods. Barnhart et al. [38] handled course scheduling problem for a Master of Business Administration program with integer programming (IP) method. Siew et al. [39] analysed the learning method (e.g., face-to-face, e-learning, distance learning, blended learning) using AHP and VIsekriterijumska optimizacija i Kompromisno Resenje (VIKOR) model, providing a guidance for educational institutions to determine appropriate teaching methods of a curriculum. To facilitate students' timely graduation, Khamechian and Petering [40] applied an integer programming model to assist an academic department in deciding which courses to offer during which semester.

The following gaps are identified based on the performed review: (1) there is no previous research that handles the problem of curriculum selection and credit determination when developing the curriculum plan of an academic program; (2) competency-based education is a norm in practice-oriented disciplines [41]. Competency refers to the knowledge, skills, and capabilities to perform jobs. However, nothing has been done to estimate appropriate competency contribution values of the curriculum by possible teaching scopes although it is a difficult work; (3) uncertainty is not uncommon in the planning problem. However, existing studies in the literature have not addressed the uncertainty in the curriculum planning; (4) while the Bologna process, an intergovernmental higher education reform process that includes 48 European countries, has been discussed broadly, very little research has been done on the adaptation of the China's National Standards. This study aimed to fill these research gaps through the proposed methods.

2.2. Curriculum Evaluation Criteria. In the era of knowledge economy, education has become a key component of sustainable development and a source of power of any society. Education is also expected to meet the growing needs of society for various occupations through the quality teaching process [42]. Employers look for well-rounded graduates and expect educational curriculum to be relevant to contemporary techniques and business issues [4]. Empirical studies also suggest that SCM competencies are positively related to SCM performance and competitiveness [43]. Therefore, curriculum should be designed based on competencies to meet industry requirement [44]. Competency-based curriculum planning is an effective and sustainable approach in education [45]. To this end, SCM competency is used as the curriculum evaluation criteria in this study. We list the SCM competency framework, as shown in Table 1, based on the works of Jordan and Bak [46]; Derwik and Hellström [47]; and Birou et al. [4].

2.3. AHP, FCE, and MCGP-U. The MCDM is the science, which considers different criteria with varying degrees of importance to search out the most suitable option/plan [3].
In this study, the AHP method is used to assign the relative weight of each defined professional competency (i.e., curriculum evaluation criteria). Then, the FCE method is used to obtain the overall assessment on curriculum based on the AHP results. Finally, the MCGP-U method is used to select curriculum and determine credits.

The combined AHP-FCE method is an effective evaluation approach under imprecise condition. AHP, originally proposed by Saaty [48], is one of the main MCDM methods to solve complex multilevel decision-making problems [49]. It has been recognized as the most popular method to determine a numerical weight for each element in a hierarchical structure. Therefore, it is suitable for obtaining the weights of SCM competencies that the academic program aims to develop. In addition, the relevance degree between the competency and the curriculum is vague and needs to be evaluated with linguistic terms. In such case, fuzzy systems provide suitable techniques to transform qualitative evaluation of DMs into quantitative evaluation and handle the uncertainty [50]. FCE uses fuzzy transformation to make a comprehensive evaluation of an alternative considering all relevant factors. Integrated with the weight derived from the AHP method, FCE makes a synthetic assessment in a fuzzy decision environment with multiple criteria and can determine the importance level of each curriculum based on DMs’ judgements.

MCGP-U enables DM to set multiple aspiration levels on the target and take DM’s expected utility values into account, resulting in better decisions. Due to the incompleteness of available information, an underestimation may occur when DMs only define one specific aspiration level on the competency goal. For instance, when determining the production quantity of different products, DMs set the profit goal at 1 million dollars. However, this amount might be underestimated, resulting in losing the opportunity for better performance. In real situation, DMs would like to increase their preference value as much as possible. As an improved method to traditional GP, the MCGP model [51] addresses multi-aspiration level (i.e., “the more the better” and “the less the better”) of an objective. To consider DM’s preference in making decisions, Chang [52] proposed MCGP-U, which is an effective MCDM method to respond real-world problem [53, 54]. MCGP-U provides an effective way to formulate multiple objective problems considering DM’s preference mapping with utility functions.

The proposed integrated MCDM approach helps to achieve desirable goals that cannot be solved by a single method. Table 2 shows a comparison of the proposed analytical method with other classical MCDM methods. One of the key advantages in using the proposed AHP, FCE, and MCGP-U models is to offer a systematic procedure for selecting curriculum portfolio, which most contributes to the desired competency, and allocating credits to each curriculum according to the requirements of the curriculum module. Consequently, higher education institutions can develop a solid and optimal program-level curriculum plan within reasonable time according to their preferences and goals, leading to the efficient use of academic resources.

### 3. The Proposed Framework

#### 3.1. An Overview of the Process. As mentioned earlier, the purpose of this study is to provide a structured framework to evaluate and select curriculum with allotted credits by integrating three methods of AHP, FCE, and MCGP-U. The procedure and methods of this integration are shown in Figure 1.

A general depiction of the structured three-phase curriculum planning framework is stated as follows. The proposed framework is applicable to any degree programs.

1. **Identification of Potential Curricula**
   - Identify a list of potential curricula. The candidate curricula are proposed based on various inputs, such as curriculum required by the National Standards, current version of curriculum plan, student feedback, and faculty brainstorming. Recommended curriculum can also come from a variety of external sources, including referring to top-ranked undergraduate programs, nationally recognized researchers, and industrial experts. In addition, a program’s overall curriculum map can be created to pair each objective with curriculum. Mapping the curriculum of a degree to the associated competency ensures graduates are equipped with comprehensive competence to act as qualified professionals [55].

### Table 1: SCM competency.

| Criteria             | Subcriteria                          |
|----------------------|--------------------------------------|
| Functional (C₁)      | Boundary spanning management (c₁₁)   |
|                      | Company and industry experience (c₁₂) |
|                      | Customer service and markets (c₁₃)   |
|                      | Ethics and integrity (c₁₄)           |
| Process management (C₂) | Project management (c₂₁)               |
|                      | Professional qualifications/ certification (c₂₂) |
|                      | Compliance with regulations (c₂₃)     |
| Relationship management (C₃) | People management (c₃₁)                   |
|                      | Leadership skills (c₃₂)               |
|                      | Collaborative learning (c₃₃)           |
| Decision analysis (C₄) | Oral and written communication (c₄₁)   |
|                      | Time management (c₄₂)                 |
|                      | Motivation and enthusiasm (c₄₃)        |
|                      | Stress management (c₄₄)               |
| Behavioral (C₅)      | Finance and economics (c₅₁)           |
|                      | Information technology (c₅₂)          |
|                      | Data analytics and statistic skills (c₅₃) |
| Conflict management (C₆) | Management of complexity and change (c₆₁) |
|                      | Influence and negotiation (c₆₂)        |

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Curriculum map is a valuable tool to reveal gaps between the curriculum and the competency. Table 3 presents an example of curriculum map, in which the check (X) indicates that a curriculum can contribute to corresponding competency. In the illustrated matrix, competency #2 has not been covered by any curriculum, and thus, additional curriculum should be proposed.

(2) Evaluate curriculum (AHP-FCE application phase).

A competency model should be developed according to the program’s strategic objectives (e.g., SCM competency in Table 1). However, with the development of the society, the competency model also should be updated as necessary to align with job qualification. Of all the competencies, some knowledge and skills might be more important than others, and the AHP method can be utilized to measure the importance of each competency. Based on the curriculum map, experts rate each potential curriculum in terms of the relevance degree between the curriculum and corresponding competency. Combining with the obtained competency weight, experts’ opinions are then synthesized using the FCE method to compute an overall importance level of the candidate curriculum. In addition, the number of assigned credits will impact the level that a curriculum could contribute to improving student competency. Thereby, a contribution value of curriculum should be estimated by possible credits. In this study, we propose an exploratory formula in Subsection 3.2.3 to estimate the contribution to competency development based on different curriculum credits.

(3) Curriculum planning decision-making (MCGP-U application phase).

Before making decision on curriculum selection and credit allocation, multiple objectives and expected utility are defined by DMs. According to the predefined goals, MCGP-U model is then applied to make an optimal decision to increase the level of utility achieved. Finally, the proposed curriculum plan needs to be approved by the undergraduate academic affairs office or other responsible departments in the higher education institution.

3.2. Mathematical Formulation

3.2.1. AHP-FCE Method.

The key principle of AHP method is to perform pairwise comparison of alternatives with respect to upper-level criteria. Typically, the comparison is
conducted using Saaty’s [48] nine-point (1–9) scale. Consistency ratio (CR) is calculated to verify the consistency of judgement summarized in the comparison matrix. If CR is below 0.1, then the importance weight of criteria is determined. If CR > 0.1, then the importance weight of criteria should be re-computed using Saaty’s [48] nine-point (1–9) scale. In the decision problem, the consistency ratio (CR) is calculated to verify the consistency of the decision-makers’ preferences [52]. In this study, the left linear utility function (LLUF) and right linear utility function (RLUF) are introduced, respectively, as follows:

$$u_k(y_k) = \begin{cases} 1, & \text{if } y_k \leq g_{k,\min} \\ \frac{g_{k,\max} - y_k}{g_{k,\max} - g_{k,\min}}, & \text{if } g_{k,\min} \leq y_k \leq g_{k,\max} \\ 0, & \text{if } y_k > g_{k,\max} \end{cases}$$  \tag{3}$$

$$u_k(y_k) = \begin{cases} 1, & \text{if } y_k \leq g_{k,\min} \\ \frac{y_k - g_{k,\min}}{g_{k,\max} - g_{k,\min}}, & \text{if } g_{k,\min} \leq y_k \leq g_{k,\max} \\ 0, & \text{if } y_k \geq g_{k,\min} \end{cases}$$  \tag{4}$$

where $u_k(y_k)$ is the utility function, $y_k$ is the aspiration value of the $k$th goal, and $g_{k,\min}$ and $g_{k,\max}$ are the lower bound and upper bound of the $k$th goal. As shown in Figures 2 and 3, lower (higher) values are preferred in terms of LLUF (RLUF). To increase the utility value, a DM should make $y_k$ close to $g_{k,\min}$ ($g_{k,\max}$) as much as possible.

The MCGP-U model considering LLUF and RLUF is presented in the following equations:

$$\min \sum_{k=1}^{K} \left[ w_k(d_{k}^+ + d_{k}^-) + \beta_k f_k \right],$$  \tag{5}$$

s.t. \begin{align*}
\lambda_k & \leq \frac{g_{k,\max} - y_k}{g_{k,\max} - g_{k,\min}} & k = 1, 2, \ldots, K, & \text{(for LLUF)}, \\
\lambda_k & \leq \frac{y_k - g_{k,\min}}{g_{k,\max} - g_{k,\min}} & k = 1, 2, \ldots, K, & \text{(for RLUF)}, \\
f_k(x) - d_k^- & = y_k & k = 1, 2, \ldots, K, \\
\lambda_k & + f_k^- & = 1 & k = 1, 2, \ldots, K, \\
g_{k,\min} & \leq y_k & k = 1, 2, \ldots, K, \\
d_k^+, d_k^-, f_k, \lambda_k & \geq 0 & k = 1, 2, \ldots, K,
\end{align*}$$  \tag{6}$$

$$\text{Table 3: A sample of curriculum map.}$$

| Degree program courses | Competency # 1 | Competency # 2 | Competency # 3 | \ldots | Competency # Q |
|------------------------|---------------|---------------|---------------|--------|---------------|
| Curriculum # 1         | X             | X             | X             | \ldots | X             |
| Curriculum # 2         | X             | X             | X             | \ldots | X             |
| \ldots                 | X             | X             | X             | \ldots | X             |
| Curriculum # P         | X             | X             | X             | \ldots | X             |
where \( u_k \) and \( \beta_k \) are weights attached to the deviations \( d_k^+ \), \( d_k^- \), and \( f_k \). \( f_k \) is the normalized deviation of \( g_{k,\text{min}} \), \( \lambda_k \) is the utility value, and \( f_k(x) \) is the function of the \( k \)-th objective. The other variables are previously defined.

3.2.3. Contribution Estimation by Credits. A curriculum can be delivered at the basic level, which takes fewer teaching hours. Instead, faculty members need to spend longer teaching hours in order to cover extensive content in the class, and thus, more credits are required for the curriculum. However, there is a lack of research on the relationship between curriculum’s contribution to students’ competency development and curriculum credits. Inspired by the classic learning curve developed by Wright [58], we propose a subjectively assessed formula as follows to obtain the contribution value. It is an exploratory estimation, and more investigation is needed.

\[
S_{mn} = \frac{H_{mn}}{T_m} \times D_m, \tag{13}
\]

where \( S_{mn} \) denotes the competency contribution value of \( m \)-th curriculum under \( n \)-th teaching scope. \( D_m \) denotes the full contribution value (or importance score) of \( m \)-th curriculum obtained based on the AHP-FCE method. \( H_{mn} \) denotes the credits of \( m \)-th curriculum under \( n \)-th teaching scope. \( T_m \) indicates the credits necessary for teaching \( m \)-th curriculum thoroughly or achieving the full contribution value of \( D_m \). \( B_m \) indicates the learning factor of \( m \)-th curriculum. In fact, the values of \( T_m \) and \( B_m \) depend on the characteristic of the curriculum as the learning difficulty of each curriculum and breadth of the topics on the subject may vary.

In the meantime, the relationship between the competency contribution value and curriculum credits should satisfy the law of diminishing marginal utility as (14). In other words, for each curriculum, the more the credits are assigned, the higher the competency contribution value should be. However, competency contribution per unit of credit decreases.

\[
\frac{\Delta S_{mn}}{\Delta H_m} > \frac{\Delta S_{m(n+1)}}{\Delta H_{m(n+1)}}, \tag{14}
\]

where \( \Delta S_{mn} \) means the additional competency contribution obtained by delivering \( m \)-th curriculum at one level higher than \( n \)-th scope; \( \Delta S_{m(n+1)} \) means the additional competency contribution obtained by delivering \( m \)-th curriculum at one level higher than \( (n+1) \)-th scope; \( \Delta H_m \) means the additional credits needed to teach \( m \)-th curriculum at one level higher than \( n \)-th scope; and \( \Delta H_{m(n+1)} \) means the additional credits needed to teach \( m \)-th curriculum at one level higher than \( (n+1) \)-th scope.

4. An Illustrative Case

4.1. Background. To illustrate the reasonableness of the proposed integrated approach in the curriculum planning process, the designed framework is applied to an undergraduate SCM program of a Chinese university. A distinguishing characteristic of the program is the implementation of interdisciplinary learning based on economics and management. Focusing on students’ comprehensive quality, the program pays attention to the combination of theory and practice, which not only cultivates students’ solid theoretical foundation but also trains students’ practical skills. All the students are required to complete 150 credits to graduate from the program, and the current curriculum structure is listed in Table 4.

Currently, the curriculum plan of the undergraduate SCM program is reviewed annually. However, there is a lack of standard process, and the revisions on the plan are merely based on intuitive decisions. The curriculum has not been linked with desired competency. The department head often hesitates to replace or add a suitable curriculum and assign proper credits to the curriculum. The business school plans to apply for AASCB (Association to Advance Collegiate Schools of Business) accreditation and look for a way to improve the curriculum planning process. To overcome the drawbacks of the manual and intuitive process and address the dilemma, both scholars and practitioners are interviewed to generate the research model and questionnaire.
Table 4: Curriculum structure.

| Type               | Nature | Module                                           | Credits |
|--------------------|--------|--------------------------------------------------|---------|
| General education  | Compulsory | Ideological and political education | 16      |
|                    |         | College English                                 | 12      |
|                    |         | College physical education                      | 4       |
|                    |         | Computer basics                                 | 2       |
|                    |         | Military education                              | 2       |
|                    | Elective | Innovation and entrepreneurship education        | 4       |
|                    |         | Generic modules                                 | 5       |
| Program specific   | Compulsory | Preparatory curriculum                         | 15      |
|                    |         | Core curriculum                                 | 30      |
|                    |         | Practice-oriented                               | 18      |
|                    |         | Thesis                                          | 8       |
|                    |         | Major-related                                   | 24      |
|                    | Elective | Interdisciplinary                               | 10      |

4.2. Implementation of the Proposed Framework

4.2.1. Competency Prioritization Using AHP. The importance of competency identified in Table 1 can be obtained using the AHP method. The expert panel is composed of 1 department head, 2 professors from SCM program, and 2 SCM professionals from a multinational company. Meshcade software (Nanjing Meshcade Software, Nanjing, China), an AHP software, is used to process the collected AHP questionnaire. Table 5 shows the result, which is the weight set of fuzzy comprehensive evaluation. According to experts’ opinion, problem-solving (c41), communication (c51), and time management (c52) are the top three competencies in driving professional performance.

4.2.2. Curriculum Evaluation Using FCE. In this study, general education curricula are not considered since they are determined at the university level. We focus on mandatory and elective curriculum that is specifically for the undergraduate SCM program. Based on the existing curriculum plan of the studied program and the input from expert panel, a total of 55 curricula are proposed. \(A_m\) \((m = 1, 2, \ldots, M)\) is used to denote the curriculum. Then, the expert panel is asked to rate the relevance between the curriculum and the competency. We classify the relevance degree into weak correlation, medium correlation, and strong correlation [37]. Table 6 uses principles of management \((A_i)\) as an example to illustrate interviewers’ opinions.

By normalizing the above table, a fuzzy relationship matrix \(R\) can be obtained. For instance, in terms of the relevance between the curriculum and the boundary spanning management \((c_{11})\), three interviewees (60% of DMs) rate this curriculum as "weak correlation," while the rest (40% of DMs) rate this curriculum as "medium correlation." None of the experts rate this curriculum as "strong correlation." Combining the weight set with the fuzzy relationship matrix, a final comprehensive evaluation set for the assessed curriculum can be obtained, as shown as follows:

\[
E = W \ast R = \begin{bmatrix}
0.0349^T & 0.6 & 0.4 & 0 \\
0.0596 & 1 & 0 & 0 \\
0.0148 & 0.6 & 0.4 & 0 \\
0.0435 & 0.8 & 0.2 & 0 \\
0.0505 & 0.2 & 0.6 & 0.2 \\
0.0222 & 1 & 0 & 0 \\
0.0145 & 1 & 0 & 0 \\
0.0101 & 0 & 0.2 & 0.8 \\
0.0525 & 0 & 1 & 0 \\
0.0189 & 0 & 0 & 1 \\
0.0435 & 0.2 & 0.4 & 0.4 \\
0.1098 & 0.4 & 0.2 & 0.4 \\
0.0347 & 0 & 0.2 & 0.8 \\
0.0181 & 0 & 0 & 1 \\
0.0377 & 0.6 & 0.4 & 0 \\
0.0392 & 0.4 & 0.4 & 0.2 \\
0.0769 & 0 & 0 & 1 \\
0.0746 & 0.4 & 0.6 & 0 \\
0.0512 & 0.6 & 0.4 & 0 \\
0.0396 & 0.2 & 0.8 & 0 \\
0.0126 & 1 & 0 & 0 \\
0.0663 & 1 & 0 & 0 \\
0.0349 & 0.8 & 0.2 & 0 \\
0.0317 & 0.6 & 0.2 & 0.2 \\
0.0078 & 0.6 & 0.4 & 0 \\
\end{bmatrix}
\]
The result is calculated by multiplying the two matrices, which means that the membership value (or probability) of the curriculum’s importance/contribution to the competency development as “weak,” “medium,” and “strong” is, respectively, 0.4609, 0.3038, and 0.2353. The defuzzification process is then applied to calculate a crisp number of the fuzzy concept. Let $V = \{\text{weak, medium, strong}\} = \{1, 3, 9\}$ [37]. In this study, we use the weighted average method for defuzzification [59]. After defuzzification, the curriculum’s overall importance/contribution score $(D_1)$ is 3.4901. In other words, the importance level of this curriculum is between “medium” and “strong.” By repeating the same process, the importance score of all curriculacan be computed. The resultsarereferred to Table 7. It canbeseenthat the top 5 curriculain terms of importance levell are all from practice-based and research-based module, highlighting the application nature of the SCM program.

In addition, based on the discussion with expert panel members, we classify the curriculum scope into three levels: introductory, intermediate, and advanced. For each curriculum, the credits under each scope $(H_{mn})$, credits needed to achieve the full contribution value $(T_m)$, and learning factor $(B_m)$ are given by the department head. A learning factor represents the difficulty of the curriculum. Each $B_m$ is assessed on a five-point scale ranging from 1 (very easy) to 5 (very difficult) with 2, 3, and 4 as intermediate values.

According to (13), the competency contribution value of each curriculum under each scope is calculated $(S_{mn})$ as Table 7. Principles of management $(A_1)$ is taken as an example, assume that it takes 6 credits to deliver the curriculum thoroughly to achieve the full contribution value (i.e., 3.4901), and the learning factor is evaluated at 2 as the

| Competency | Area weight | Subcriteria | CR | Item weight | Combined weight |
|------------|-------------|-------------|----|------------|----------------|
| C1         | 0.1529      | $c_{11}$    | 0.229 | 0.0349     |
|            |             | $c_{12}$    | 0.39  | 0.0596     |
|            |             | $c_{13}$    | 0.097 | 0.0148     |
|            |             | $c_{14}$    | 0.285 | 0.0435     |
| C2         | 0.0872      | $c_{21}$    | 0.579 | 0.0505     |
|            |             | $c_{22}$    | 0.255 | 0.0222     |
|            |             | $c_{23}$    | 0.166 | 0.0145     |
| C3         | 0.1249      | $c_{31}$    | 0.081 | 0.0101     |
|            |             | $c_{32}$    | 0.42  | 0.0525     |
|            |             | $c_{33}$    | 0.151 | 0.0189     |
|            |             | $c_{34}$    | 0.348 | 0.0435     |
| C4         | 0.2396      | $c_{41}$    | 0.459 | 0.1098     |
|            |             | $c_{42}$    | 0.145 | 0.0347     |
|            |             | $c_{43}$    | 0.076 | 0.0181     |
|            |             | $c_{44}$    | 0.157 | 0.0377     |
|            |             | $c_{45}$    | 0.164 | 0.0392     |
| C5         | 0.2422      | $c_{51}$    | 0.317 | 0.0769     |
|            |             | $c_{52}$    | 0.308 | 0.0746     |
|            |             | $c_{53}$    | 0.211 | 0.0512     |
|            |             | $c_{54}$    | 0.163 | 0.0396     |
| C6         | 0.1138      | $c_{61}$    | 0.11  | 0.0126     |
|            |             | $c_{62}$    | 0.583 | 0.0663     |
|            |             | $c_{63}$    | 0.307 | 0.0349     |
| C7         | 0.0395      | $c_{71}$    | 0.803 | 0.0317     |
|            |             | $c_{72}$    | 0.197 | 0.0078     |

| Table 5: Weights of curriculum evaluation criteria. |
|--------------------------------------------------|
| Competency | Area weight | Subcriteria | CR | Item weight | Combined weight |
|------------|-------------|-------------|----|------------|----------------|
| C1         | 0.1529      | $c_{11}$    | 0.229 | 0.0349     |
|            |             | $c_{12}$    | 0.39  | 0.0596     |
|            |             | $c_{13}$    | 0.097 | 0.0148     |
|            |             | $c_{14}$    | 0.285 | 0.0435     |
| C2         | 0.0872      | $c_{21}$    | 0.579 | 0.0505     |
|            |             | $c_{22}$    | 0.255 | 0.0222     |
|            |             | $c_{23}$    | 0.166 | 0.0145     |
| C3         | 0.1249      | $c_{31}$    | 0.081 | 0.0101     |
|            |             | $c_{32}$    | 0.42  | 0.0525     |
|            |             | $c_{33}$    | 0.151 | 0.0189     |
|            |             | $c_{34}$    | 0.348 | 0.0435     |
| C4         | 0.2396      | $c_{41}$    | 0.459 | 0.1098     |
|            |             | $c_{42}$    | 0.145 | 0.0347     |
|            |             | $c_{43}$    | 0.076 | 0.0181     |
|            |             | $c_{44}$    | 0.157 | 0.0377     |
|            |             | $c_{45}$    | 0.164 | 0.0392     |
| C5         | 0.2422      | $c_{51}$    | 0.317 | 0.0769     |
|            |             | $c_{52}$    | 0.308 | 0.0746     |
|            |             | $c_{53}$    | 0.211 | 0.0512     |
|            |             | $c_{54}$    | 0.163 | 0.0396     |
| C6         | 0.1138      | $c_{61}$    | 0.11  | 0.0126     |
|            |             | $c_{62}$    | 0.583 | 0.0663     |
|            |             | $c_{63}$    | 0.307 | 0.0349     |
| C7         | 0.0395      | $c_{71}$    | 0.803 | 0.0317     |
|            |             | $c_{72}$    | 0.197 | 0.0078     |

The table 5 shows the weights of curriculum evaluation criteria.

| Table 6: Experts’ judgements on the curriculum’s relevance with competency. |
|--------------------------------------------------|
| Main criteria | Sub-criteria | Number of DMs for each relevance grading |
|----------------|---------------|-----------------------------------------|
|                |               | Weak | Medium | Strong |
| C1             | $c_{11}$      | 3    | 2      | 0      |
| $c_{12}$       | 5              | 0    | 0      |        |
| $c_{13}$       | 3              | 2    | 0      |        |
| $c_{14}$       | 4              | 1    | 1      | 0      |
| C2             | $c_{21}$      | 1    | 3      | 1      |
| $c_{22}$       | 5              | 0    | 0      |        |
| $c_{23}$       | 5              | 0    | 0      |        |
| C3             | $c_{31}$      | 0    | 1      | 4      |
| $c_{32}$       | 0              | 5    | 0      |        |
| $c_{33}$       | 0              | 0    | 5      |        |
| $c_{34}$       | 1              | 2    | 2      |        |
| C4             | $c_{41}$      | 2    | 1      | 5      |
| $c_{42}$       | 0              | 1    | 4      |        |
| $c_{43}$       | 0              | 0    | 5      |        |
| $c_{44}$       | 3              | 2    | 0      |        |
| $c_{45}$       | 2              | 2    | 1      |        |
| C5             | $c_{51}$      | 0    | 0      | 5      |
| $c_{52}$       | 2              | 3    | 0      |        |
| $c_{53}$       | 3              | 2    | 0      |        |
| $c_{54}$       | 1              | 4    | 0      |        |
| C6             | $c_{61}$      | 5    | 0      | 0      |
| $c_{62}$       | 5              | 0    | 0      |        |
| $c_{63}$       | 4              | 1    | 0      |        |
| C7             | $c_{71}$      | 3    | 1      | 1      |
| $c_{72}$       | 3              | 2    | 0      |        |
| Module                        | #     | Curriculum (\(A_m\))                      | \(D_m\) | \(S_{m1}\) | \(H_{m1}\) | \(S_{m2}\) | \(H_{m2}\) | \(S_{m3}\) | \(H_{m3}\) | \(T_m\) | \(B_m\) |
|------------------------------|-------|-------------------------------------------|---------|------------|------------|------------|------------|------------|------------|--------|--------|
| Compulsory-preparatory       |       |                                           |         |            |            |            |            |            |            |        |        |
| 1                            | Principles of management    | 3.4901 | 2.0150 | 2          | 2.4679     | 3          | 2.8497     | 4          | 6        | 2      |        |
| 2                            | Economic mathematics I      | 2.3010 | 1.8911 | 3          | 2.0031     | 4          | 2.0946     | 5          | 8        | 5      |        |
| 3                            | Economic mathematics II     | 2.3010 | 1.7484 | 2          | 1.9349     | 3          | 2.0792     | 4          | 6        | 4      |        |
| 4                            | Economic mathematics III    | 2.4406 | 1.8545 | 2          | 2.0523     | 3          | 2.2053     | 4          | 6        | 6      |        |
| 5                            | Principles of statistics    | 2.7950 | 2.1237 | 2          | 2.3503     | 3          | 2.5256     | 4          | 6        | 4      |        |
| 6                            | Economic law                | 3.0110 | 1.7384 | 2          | 2.1291     | 3          | 2.4585     | 4          | 6        | 2      |        |
| 7                            | Principles of microeconomics| 2.8156 | 1.9522 | 2          | 2.2347     | 3          | 2.4597     | 4          | 6        | 3      |        |
| 8                            | Principles of macroeconomics| 2.8156 | 1.9522 | 2          | 2.2347     | 3          | 2.4597     | 4          | 6        | 3      |        |
| 9                            | Quantitative analysis       | 2.3343 | 1.7199 | 2          | 1.8527     | 3          | 1.9688     | 5          | 3        | 3      |        |
| Compulsory-core              |       |                                           |         |            |            |            |            |            |            |        |        |
| 10                           | Business communication      | 1.9065 | 0.6740 | 0.5        | 0.9533     | 1          | 1.1675     | 1.5        | 4        | 2      |        |
| 11                           | Organizational behavior     | 1.6984 | 1.2010 | 2          | 1.3427     | 2.5        | 1.4709     | 3          | 4        | 2      |        |
| 12                           | Information technology for business | 2.3184 | 1.7082 | 2          | 1.9554     | 3          | 2.1522     | 4          | 5        | 3      |        |
| 13                           | Business ethics             | 2.6118 | 1.5079 | 1          | 1.8468     | 1.5        | 2.1325     | 2          | 3        | 2      |        |
| Compulsory-practice-based and research-based |       |                                           |         |            |            |            |            |            |            |        |        |
| 14                           | Introduction to logistics   | 3.0982 | 2.1908 | 3          | 2.3663     | 3.5        | 2.5297     | 4          | 6        | 2      |        |
| 15                           | Warehouse management and inventory control | 2.6131 | 1.8477 | 3          | 1.9958     | 3.5        | 2.1336     | 4          | 6        | 2      |        |
| 16                           | Purchasing management       | 2.9753 | 1.8817 | 2          | 2.1039     | 2.5        | 2.3047     | 3          | 5        | 2      |        |
| 17                           | Distribution management     | 2.4789 | 1.5678 | 2          | 1.7528     | 2.5        | 1.9201     | 3          | 5        | 2      |        |
| 18                           | Introduction to global supply chain management | 3.2730 | 2.4677 | 3          | 2.7160     | 4          | 2.9257     | 5          | 7        | 3      |        |
| 19                           | Customer relationship management | 2.6627 | 1.6840 | 2          | 1.8828     | 2.5        | 2.0625     | 3          | 5        | 2      |        |
| 20                           | Operation management        | 2.4009 | 1.6977 | 3          | 1.8337     | 3.5        | 1.9603     | 4          | 6        | 2      |        |
| 21                           | Introduction to electronic commerce | 2.5088 | 1.5867 | 2          | 1.7740     | 2.5        | 1.9433     | 3          | 5        | 2      |        |
| 22                           | Lean and six sigma processes| 3.6292 | 2.2863 | 2          | 2.6171     | 3          | 2.8805     | 4          | 8        | 3      |        |
| 23                           | Demand planning and fulfillment | 2.4337 | 1.9316 | 3          | 2.0335     | 3.5        | 2.1260     | 4          | 6        | 3      |        |
| 24                           | Transnational issues in supply chain | 3.7083 | 2.4277 | 3          | 2.8032     | 4          | 3.1341     | 5          | 7        | 2      |        |
| 25                           | Quality management          | 2.2048 | 1.2729 | 2          | 1.5590     | 3          | 1.8002     | 4          | 6        | 2      |        |
| 26                           | Supply chain management strategy | 2.9094 | 2.1935 | 3          | 2.3092     | 3.5        | 2.4143     | 4          | 7        | 3      |        |
| 27                           | Cost management in supply chain | 2.6186 | 1.7247 | 2          | 1.8579     | 2.5        | 1.9743     | 3          | 7        | 3      |        |
| Compulsory-practice-based and research-based |       |                                           |         |            |            |            |            |            |            |        |        |
| 28                           | Training on the technology of Internet of things | 2.8380 | 1.5618 | 1          | 1.7878     | 1.5        | 1.9678     | 2          | 6        | 3      |        |
| 29                           | Training of SCM software    | 3.8874 | 2.8421 | 2          | 3.1453     | 3          | 3.3799     | 4          | 7        | 4      |        |
| 30                           | Training of the intelligent supply chain technology | 4.1748 | 2.6300 | 2          | 3.0106     | 3          | 3.3135     | 4          | 8        | 3      |        |
| 31                           | ERP sand table simulation training | 4.4325 | 3.3592 | 2          | 3.6430     | 3          | 3.8587     | 4          | 8        | 5      |        |
| 32                           | Capstone projects in supply chain management | 6.3750 | 5.0108 | 3          | 5.3075     | 4          | 5.5498     | 5          | 10       | 5      |        |
| 33                           | Seminar in professionalism  | 4.0542 | 2.0271 | 1          | 2.4827     | 1.5        | 2.8668     | 2          | 4        | 2      |        |
| 34                           | SCM simulation technology   | 4.6264 | 3.4881 | 3          | 3.6720     | 3.5        | 3.8391     | 4          | 7        | 3      |        |
| 35                           | Social practice             | 5.0341 | 3.5596 | 2          | 3.9394     | 3          | 4.2332     | 4          | 8        | 4      |        |
| 36                           | Graduation internship       | 6.0297 | 4.5816 | 4          | 4.8444     | 5          | 5.0704     | 6          | 12       | 4      |        |
| 37                           | Scholarly research in SCM   | 5.0423 | 3.4620 | 2          | 3.8313     | 3          | 4.1170     | 4          | 9        | 4      |        |
| 38                           | The graduation thesis       | 5.3813 | 4.3198 | 4          | 4.5169     | 5          | 4.6847     | 6          | 12       | 5      |        |
| Module | #  | Curriculum ($A_m$)                                      | $D_m$ | $S_{m1}$ | $H_{m1}$ | $S_{m2}$ | $H_{m2}$ | $S_{m3}$ | $H_{m3}$ | $T_m$ | $B_m$ |
|--------|----|--------------------------------------------------------|-------|----------|----------|----------|----------|----------|----------|-------|-------|
|        | 39 | Planning and design of supply chain system             | 3.2099| 2.5119   | 3        | 2.6922   | 4        | 2.8540   | 5        | 8     | 4     |
|        | 40 | Bar code technology and application                    | 4.0721| 3.2320   | 3        | 3.4024   | 3.5      | 3.5573   | 4        | 6     | 3     |
|        | 41 | Application of Internet of things and electronic tag technology | 3.2357| 2.0464   | 2        | 2.2880   | 2.5      | 2.5064   | 3        | 5     | 2     |
|        | 42 | Supply chain optimization                              | 3.7090| 3.0010   | 3        | 3.2248   | 4        | 3.4098   | 5        | 7     | 4     |
|        | 43 | Project management                                     | 4.9459| 3.7289   | 3        | 4.1042   | 4        | 4.4212   | 5        | 7     | 3     |
|        | 44 | Case study of SCM                                      | 4.6725| 2.4976   | 2        | 3.0589   | 3        | 3.5321   | 4        | 7     | 2     |
|        | 45 | Logistics facilities and equipment management          | 2.9677| 1.7134   | 2        | 2.0985   | 3        | 2.2666   | 3.5      | 6     | 2     |
|        | 46 | Supply chain information system                        | 4.6264| 3.6204   | 3        | 3.7626   | 3.5      | 3.8903   | 4        | 8     | 4     |
|        | 47 | Production logistics management                        | 2.7743| 1.9236   | 2        | 2.2020   | 3        | 2.4236   | 4        | 6     | 3     |
|        | 48 | Spreadsheet modeling and analytics                     | 4.0103| 2.3153   | 2        | 2.8357   | 3        | 3.2744   | 4        | 6     | 2     |
|        | 49 | Systems dynamics and supply chains                     | 2.6302| 2.1281   | 3        | 2.2868   | 4        | 2.4180   | 5        | 7     | 4     |
|        | 50 | Transportation and packaging management                | 2.2900| 1.3221   | 2        | 1.6193   | 3        | 1.8698   | 4        | 6     | 2     |
|        | 51 | Introduction to entrepreneurship                       | 3.9004| 3.0957   | 3        | 3.2590   | 3.5      | 3.4073   | 4        | 6     | 3     |
|        | 52 | Introductory financial accounting                      | 2.5565| 2.0685   | 3        | 2.1498   | 3.5      | 2.2227   | 4        | 7     | 4     |
|        | 53 | Introductory management accounting                     | 2.5565| 2.0685   | 3        | 2.1498   | 3.5      | 2.2227   | 4        | 7     | 4     |
|        | 54 | Principles of finance                                  | 2.3689| 1.9920   | 3        | 2.0703   | 3.5      | 2.1405   | 4        | 6     | 4     |
|        | 55 | Principles of marketing                               | 2.2096| 1.5624   | 3        | 1.6876   | 3.5      | 1.8041   | 4        | 6     | 2     |
subject is relatively easy. Based on expert’s judgement, it requires 2 credits, 3 credits, and 4 credits, respectively, to teach the subject at the basic level, intermediate level, and advanced level. According to equation (13), the contribution value can be calculated as 2.0150, 2.4679, and 2.8497 for the three levels. All the results are verified by marginal analysis as per equation (14). Following the same methodology, competency contribution values by different credits can be obtained for all candidate curricula.

4.2.3. Curriculum Planning Using MCGP-U. In the category of compulsory curriculum, the candidate curriculum that is finally not selected can be still considered as the potential elective curriculum. Therefore, the problem considered in this study involves a two-stage sequential selection and allocation process. Accordingly, it is solved in two stages in which the curriculum selection and credit allocation are performed for compulsory curriculum and elective curriculum, respectively. The steps are elaborated in the following subsections.

(1) Stage 1: determine compulsory curriculum and corresponding credits.

The goal in this stage is to contribute to the student competency development of at least 60 with a linear and right triangular utility function, in which the level of utility achieved is the higher the better and the upper bound of the competency contribution value goal is 80. According to the MCGP-U model considering RLUF, the problem is formulated as follows:

\[
\begin{align*}
\min & \quad d_1^* + d_1, \\
\text{s.t.} & \quad \lambda_1 \leq \frac{y_1 - 60}{80 - 60}, \\
& \quad \sum_{m=1}^{38} \sum_{n=1}^{3} S_{mn} \times X_{mn} - d_1^* + d_1 = y_1, \\
& \quad \lambda_1 + f_1 = 1, \\
& \quad 60 \leq y_1 \leq 80, \\
& \quad d_1^*, d_1, f_1, \lambda_1 \geq 0,
\end{align*}
\]

(16) to (21)

In the above model, equations (16) to (21) are the standard MCGP-U model filled with data regarding the goal. In equations (22) and (23), \(X_{mn}\) is binary decision variable used to decide whether to select \(m\)th curriculum at \(n\)th scope level. If yes, it is 1; otherwise, it is 0. For equation (24), the identified seven curricula must be selected according to the National Standards. Equations (25) to (27) indicate the range of total credits for each model. Equation (28) indicates the range of total credits for compulsory curriculum. In terms of (29), the total number of curricula should be between 22 and 25.

By running LINGO 17.0 software, results are depicted in Figure 4. As illustrated, 25 curricula with 72 credits in total are selected as compulsory curriculum. They are composed of 6 preparatory curricula (15 credits), 8 core curricula (28 credits), and 11 practice/research-based curricula (29 credits). The rest 13 curricula that are not selected can be considered as elective curriculum and further selected in the second stage.

(2) Stage 2: determine elective curriculum and corresponding credits.

In this stage, there are three goals defined by the DMs:

(i) (G1) Make the competency contribution value of 30 with a linear and right triangular utility function, in which the level of utility achieved is the higher the better and the upper bound of the competency contribution value goal is 75.

(ii) (G2) Define the number of available elective curricula of less than 30 and at least 15 to provide more choice for the students with a linear and right triangular utility function, in which the level of utility achieved is also the higher the better.

(iii) (G3) The credit target value is 50 following a left triangular utility function and the upper bound is 75. The range can sufficiently satisfy the
graduation requirement. Students are required to complete at least 24 credits in major-related module and at least 9 credits in business interdisciplinary module for graduation. If less credits are provided, faculty can have more time to undertake research work.

$$\text{Min } d_1^+ + d_1^- + f_1^+ + d_2^+ + f_2^+ + d_3^+ + d_3^-,$$

\begin{align*}
\text{s.t. } & \lambda_1 \leq \frac{y_1 - 30}{75 - 30}, \\
& \lambda_2 \leq \frac{y_2 - 15}{30 - 15}, \\
& \lambda_3 \leq \frac{75 - y_3}{75 - 50}, \\
& \sum_{m=1}^{55} \sum_{n=1}^{3} p_m \times X_{mn} \times X_{mn} - d_1^- + d_1^+ = y_1, \\
& \sum_{m=1}^{55} \sum_{n=1}^{3} p_m \times X_{mn} - d_2^+ + d_2^- = y_2, \\
& \sum_{m=1}^{55} \sum_{n=1}^{3} p_m \times H_{mn} \times X_{mn} - d_3^+ + d_3^- = y_3, \\
& \lambda_1 + f_1^- = 1, \lambda_2 + f_2^- = 1, \lambda_3 + f_3^- = 1, \\
& 30 \leq y_1 \leq 75, \\
& 15 \leq y_2 \leq 30, \\
& 50 \leq y_3 \leq 75, \\
& d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^- , f_1^-, f_2^-, f_3^-, \lambda_1, \lambda_2, \lambda_3 \geq 0, \\
& \sum_{m=1}^{55} \sum_{n=1}^{3} p_m^1 \times H_{mn} \times X_{mn} \leq 50, \\
& 15 \leq \sum_{m=1}^{55} \sum_{n=1}^{3} p_m^2 \times H_{mn} \times X_{mn} \times X_{mn} \leq 25, \\
& \sum_{m=1}^{3} p_m \times X_{mn} \leq p_m^3, \\
& \sum_{m=1}^{3} X_{mn} \leq 1 \ m = 1, 2, \ldots, 55, \\
& X_{mn} = 0 \text{ or } 1; m = 1, 2, \ldots, 55; n = 1, 2, 3,
\end{align*}

In the above model, equations (30) to (41) are associated with the three goals defined in the second stage. Equations (42) to (43) define the range of total credits for major-related electives and interdisciplinary electives, respectively. Symbols $p_m^1$, $p_m^2$, and $p_m^3$ are constants that, respectively, determine whether $m$th curriculum is available for selection in the second phase, for the major-related module, and for the interdisciplinary module. 1 is used if the curriculum can be considered for selection, and 0 is used if not. The rest have been defined in the model of the first stage.

By running LINGO 17.0 software, the results are depicted in Figure 5. As illustrated, 23 curricula with 51.5 credits in total are selected as elective curriculum. They are composed of 15 major-related electives (36 credits) and 8 interdisciplinary electives (15.5 credits).

### 5. Results and Discussion

A combined AHP-FCE method helps to evaluate the candidate curriculum according to DMs’ preference over the competency. In the illustrated case, problem-solving ($c41$), communication ($c51$), and time management ($c52$) are viewed as the most important skills for the students to develop at university, while influence and negotiation ($c72$), finance and economics ($c61$), and people management ($c31$) are less important. Based on the determined competency weights using AHP, the importance score of each potential curriculum can be calculated through the FCE method. As a result, the top three curricula are identified as Capstone Projects in Supply Chain Management (A32), graduation internship (A36), and graduation thesis (A38). It makes sense that these curricula and activities are comprehensive and relevant to critical skills. These curricula are normally scheduled in the final year and require fundamental knowledge and skills in SCM. When the weights of SCM competency are changed, the specific ranking of curriculum can differ to a certain extent.

A solid curriculum plan is not merely based on the ranking of curriculum. DMs should consider possible credits that can be assigned to the curriculum instead of defining only one possibility of credits according to previous experience. Therefore, a competency contribution value of each curriculum by possible credits is estimated.
utilizing a proposed formula, which takes learning difficulty and importance score of curricula into account. While it takes time to go through and analyze the list of curricula, performing a more detailed analysis on the curriculum can lead to an informed decision. The contribution values by credits should follow the law of diminishing marginal utility as well.

Then, this study presents a two-stage MCGP-U-based approach for solving curriculum selection and credit allocation problems simultaneously, which involves several restrictions and requirements. Planning for compulsory curriculum and elective curriculum is performed in the first and second phases, respectively. As a result, of 55 candidate curricula, 25 compulsory curricula amounting to 72 credits are selected and 23 elective curricula with 51.5 credits are selected. In terms of compulsory curriculum, the total contribution value of 70.62 is realized, which is 17.7% higher than the lower bound of the objective. Among the compulsory curriculum, 13 curricula, 3 curricula, and 8 curricula will be, respectively, delivered at the introductory level, intermediate level, and advanced level. Regarding the elective curriculum, the results are also satisfactory. The total contribution value of 48.51 is realized, which is 61.7% higher than the lower bound of the objective; the number of credits is 53.3% higher than the lower bound of the objective; and the total number of credits is 31.3% below the upper bound of the objective. All the elective curricula will be taught at the introductory level, which is in line with the expectation of DMs.

Although this study presents a particular case of undergraduate SCM program, it can be easily generalized to solve curriculum planning problem for any other academic programs. The proposed structured framework is flexible to be adjusted in case of the change in National Standards. Such computer-based decision support tools serve as an aid to decision-makers and have substantial practical application.

6. Conclusion and Future Work

Curriculum planning is a necessary step for initiating any new academic programs. Meanwhile, the curriculum plan should be maintained to ensure that it remains current and relevant. In other words, curriculum planning also provides an opportunity to make desired changes to the existing degree programs [60]. SCM is not only a critical aspect of business in today’s challenging economic environment but also a hot major at Business School [11]. Professional and skilled SCM talents are in high demand nowadays, and the world is experiencing a widespread shortage of SCM talents. However, there is a lack of scientific methods in the curriculum planning process [37]. It is a priority to design a feasible curriculum plan to cultivate SCM talents, enabling the professional competencies of graduates to meet industrial requirements.

To the best of our knowledge, a systematic decision support model has not been developed to plan curriculum for undergraduate SCM program. A stand-alone method is not able to address such complex problem. Therefore, new integrated methods are necessary to achieve the planning goals and address the uncertainty in the process. To this end, this study introduces a novel decision support framework for curriculum planning of undergraduate SCM program, integrating AHP, FCE, and MCGP-U methods. AHP is applied to estimate the weights of SCM competency, and FCE is used to evaluate the importance of the curriculum based on the relevance of each curriculum with competency, and then, the two-stage MCGP-U model is adopted to assist DMs in determining the optimal portfolio of compulsory and elective curriculum according to the predefined multiple objectives. The rationale of the proposed integrated approach is that curriculum contribution to students’ competency development is changed by the assigned credits. Therefore, curriculum planning is a resource allocation problem rather than a simple ranking of curriculum based on the overall importance score only. Moreover, the contribution level of curriculum, the number of curriculum, and credits provided are desired to be higher/lower the better in a utility function, which cannot be solved by the traditional GP method and requires consideration of multiple aspirations. This study also presents a case of SCM curriculum planning in the context of a Chinese university for the first time by considering China’s National Standards. The results of the case study show that the proposed approach is flexible for solving similar problems. More importantly, this study explores a new research area, the determination of curriculum credits, by developing a novel indicator called competency contribution value of curriculum. In the last, this study promotes interdisciplinary study in education and sheds light on the curriculum planning process based on the actual needs, offering a scientific technique for education reforms, and enabling policymakers to utilize school resources wisely.

In future work, the following research directions can be considered: (1) comparisons can be conducted between the proposed methods in this study and other qualitative and quantitative methods for the purpose of curriculum evaluation and selection. For example, instead of the AHP method, researchers can apply other MCDM methods, such as ANP and best worst method (BWM), to obtain the weights of SCM competency and find out the best solution by making a result comparison among the different
approaches; (2) based on the determined curriculum and credits, the next step is to schedule the terms according to the prerequisite and goals, which has not been addressed in this study. To determine the semester of each selected curriculum, MCGP-U methods can be used to solve the scheduling problem as well by maximizing the curriculum assignment preferences. Similarly, the university curriculum timetabling problem is another crucial activity in higher education institutions. MCGP-U model can be applied to address the faculty-curriculum-timeslot-classroom assignment problem based on the institution’s preference and goals; (3) due to a lack of research linking the level of curriculum with competency development, the most difficult part of this exercise is to estimate appropriate competency contribution values for each curriculum. A further investigation into the relationship between contribution value of competency development and curriculum credits would be a major contribution in this area. For example, an empirical study can be conducted to measure the change in student competency level in one class at two points in time (e.g., after completion of 2 credits and after completion of 3 credits); and (4) further studies can also be conducted to apply the proposed framework to other academic contexts, including academic advising (e.g., course selection for students’ academic plan), optimization of an individual curriculum, academic program performance evaluation, and curriculum planning of different majors at the graduate level.

Data Availability
The datasets generated during and/or analysed during this study are available from the corresponding author on reasonable request.

Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this study.

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