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AN INTEGRATED DEA–FUZZY LOGIC FRAMEWORK FOR CURRICULUM PERFORMANCE EVALUATION

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ABSTRACT

This study proposes an integrated DEA–Fuzzy Logic framework for the systematic and quantitative evaluation of curriculum performance within a multi-criteria decision-making context. The framework addresses two key challenges in curriculum assessment: the subjectivity of expert judgments and the need to determine the relative importance and efficiency of courses across multiple competency criteria. For the evaluation, a performance analysis was conducted by considering the weekly course hours and credits of the courses, along with the levels of contribution they provide to the defined competency areas associated with the programs in which they are offered. The contribution of each course to these competencies is evaluated using a seven-level linguistic scale via the experts. To manage uncertainty and ambiguity in qualitative assessments, triangular fuzzy numbers are employed, converting linguistic judgments into measurable performance scores. This process generates a structured and comparable multi-criteria dataset for the Data Envelopment Analysis (DEA) model. Courses are treated as decision-making units, where weekly course hours and course credits are considered as input variables, while the quantified competency-areas scores constitute the output variables. Using an output-oriented Variable Returns to Scale (VRS) DEA model, the relative efficiency of courses is assessed without requiring predefined weights. This non-parametric optimization approach enables courses to be ranked according to the extent to which they contribute to curriculum competencies relative to the instructional resources allocated to them. The proposed framework is applied to an associate degree vocational education curriculum as a case study to demonstrate its operational validity. The findings indicate that the integrated DEA–Fuzzy Logic approach provides a robust, flexible, and decision-supportive tool for evidence-based curriculum evaluation.

Keywords: *Curriculum, Performance Evaluation, Data Envelopment Analysis (DEA), Fuzzy Logic, Multi-Criteria Decision Making (MCDM)*

Introduction

Curricula are regarded as the heart of educational processes (Supriani et al., 2022). In the educational process, their role in preparing students for the living and working conditions in their respective fields is undeniable (Tong et al., 2020). Therefore, changes and developments in professional requirements, educational tools, and educational systems necessitate that curricula be systematically addressed as a dynamic phenomenon. Unfortunately, curricula are sometimes shaped by random and unplanned approaches rather than being based on a specific philosophy (Tribe, 2014).

Curricula have the power to reflect the sum of all experiences provided in educational institutions (Bharvad, 2009), and curriculum improvements are considered one of the most important keys to success for educational institutions (Puplampu and Mugo, 2020). A systematic evaluation process is needed to update this dynamic system in a way that suits the needs. Curriculum evaluation is considered the process of examining the value, effectiveness, and quality of an educational program (Nouraey et al., 2020). The literature on curriculum assessment is quite rich and diverse, both in terms of assessment focuses and theoretical models used. On one hand, there are studies on the impact of curriculum design strategies on student learning (Cunningham et al., 2020), assessment of learning outcomes (Hernández-Campos et al., 2025), and industry-participatory designs (Arun Kumar, 2022), while on the other hand, different models have been developed that systematically address the assessment process. These include the CIPP model proposed by Stufflebeam (2000), which considers the assessment process within a complete life cycle consisting of context, input, process, and output dimensions; Kirkpatrick's Four-Level Model (Kirkpatrick and Kirkpatrick, 2006), which evaluates participants' gains at the response, learning, behavior, and outcome levels; and Phillips' ROI Model (Phillips, 2012), which adds a fifth level, Return on Investment (ROI), to the assessment, thus including the economic dimension. Stake's Evaluation Model (Stake, 1967), which examines the congruence between the intended, implemented, and observed aspects of the curriculum by including the time dimension before and after the process in the evaluation, and Tyler's Goal-Based Evaluation Model (Tyler, 2013), which focuses on the extent to which educational goals have been achieved and is quite simple and understandable, are quite noteworthy.

As stated by Stufflebeam (2000), curriculum evaluations are expected to provide data for planning, implementation, and development decisions. Unlike existing curriculum evaluation approaches, this study, for the first time in the literature, evaluates the performance of the courses in the curriculum, considering their contribution to the core competencies of the program along with the educational resources used (course hours and credits). This approach provides a data source for curriculum updates by enabling the determination of the relative performance of the courses.

An analysis of the current state of curricula should be regarded as the first step toward planning curriculum development efforts. While the most fundamental stakeholders of curricula are the educational institutions and teachers who deliver them, along with

the students receiving the education, the curriculum is undoubtedly a social element. In this study, an approach is presented to systematically examine such an effective tool for shaping the future of societies. The focus of the evaluation approach lies on the courses within the curriculum and the diverse professional perspectives the curriculum offers to students (Yaşlı and Yüncü, 2023). The contributions of courses to the programme are multifaceted. Some courses may contribute to multiple competencies at a low-to-medium level, while others may contribute intensively to a small number of competencies. If weighting for multiple competencies is involved and the contributions of courses under the relevant competencies can be scored, courses can be given a single score across multiple domains through weighted summation. However, in an educational environment where resources such as credits and course hours are limited, interpreting courses based solely on their contributions will not be sufficient. In this context, evaluating courses using DEA (Data Envelopment Analysis) reveals their relative performance based on their contributions and resources. DEA enables courses to be evaluated under multiple competencies without any weights being assigned to competencies through mathematical optimisation, while fuzzy logic allows linguistic expressions to be used for expert evaluations.

Therefore, the proposed assessment methodology employs an integrated DEA–Fuzzy Logic approach. The defined competency areas form the curriculum evaluation criteria, and fuzzy logic allows for the quantification of evaluators' ambiguous and subjective opinions to be quantified and facilitates the evaluation of courses' contribution to multiple competency domains. This study presents a systematic and data-driven evaluation approach for analyzing the relative performance of courses within the curriculum. The methodology was applied to the curriculum courses of a program offering associate-level vocational education in the field of rail system operations, and the results are presented.

Methodology

Fuzzy Logic

Fuzzy logic is used to reflect mathematical expressions by quantifying the ambiguity in human thoughts and judgments. Fuzzy set theory, introduced by Zadeh (1965), offers the advantage of mathematically capturing the distinctions between linguistic expressions such as "very high," "high," "low," and "very low." Over the years, numerous different types of fuzzy numbers have been proposed in the literature on fuzzy logic to address uncertainties using fuzzy sets. Zadeh (1975) proposed that ambiguity could be quantified by developing a membership concept ranging from 0 to 1 for mathematical expressions. Fuzzy numbers, which vary in the literature as triangular, trapezoidal, intuitionistic, type-2, interval type-2, pythagorean, spherical, q-rung orthopair, and fermatean, offer a more realistic representation of the uncertainty in human judgments and provide computational flexibility (Torra, 2010; Kutlu Gündoğdu and Kahraman, 2019; Yager, 2013; Senapati and Yager, 2020; Atanassov, 2016). In this study, triangular fuzzy

numbers, which represent the most fundamental application of fuzzy logic, were used. Triangular fuzzy numbers are represented as *(l, m, u),* where *'l'* represents the smallest possible value, *'m'* the most likely value, and *'u'* the largest possible value. All fuzzy numbers (x) within a fuzzy set ($\tilde{F}$) (Eq. 1), along with their membership degree ($\mu_{\tilde{F}}$) (Eq. 2), are defined as follows.

$$\tilde{F} = \left\{ x, \mu_{\tilde{F}}(x) \mid x \in \tilde{F}, \mu_{\tilde{F}}(x) \in [0.1] \right\} \quad \text{Eq. 1}$$

$$\mu_{\tilde{F}}(x) = \begin{cases} \dfrac{r-l}{m-l} & for\ l \le x \le m, \\ \dfrac{u-r}{u-m} & for\ m \le x \le u, \\ 0 & otherwise. \end{cases} \quad \text{Eq. 2}$$

Table 1 shows the linguistic expressions used in the study to determine the level of contribution of the courses under the defined competency areas, along with the corresponding fuzzy triangular numbers.

Since the study uses k expert opinions, the multiple evaluations of the courses are aggregated using the fuzzy arithmetic operations presented in Eq. 3 and Eq. 4 (Zadeh, 1965). After aggregating and combining the expert judgments, which correspond to fuzzy numbers, the defuzzification process given in Eq. 5 is applied to obtain the crisp values of the courses under the specified competency area. For the defuzzification process, the expected value method, proposed by Heilpern (1992), which increases the related representation of the value by giving 2 times the weight to the 'm' value representing the most likely value, is used.

Table 1. Evaluation scale

Linguistic Expressions		**Corresponding TFN (l, m, u)**
1 – Insignificant	The course is insignificant within that competency area.	(0, 0, 0.1)
2 – Very low level	The course contributes at a very low level to that competency area.	(0, 0.1, 0.3)
3 – Low level	The course contributes at a low level to that competency area.	(0.1, 0.3, 0.5)
4 – Medium level	The course contributes at a medium level to that competency area.	(0.3, 0.5, 0.7)
5 – High level	The course contributes at a high level to that competency area.	(0.5, 0.7, 0.9)
6 – Very high level	The course contributes at a very high level to that competency area.	(0.7, 0.9, 1)
7 – Absolutely important	The course contributes with absolute importance to that competency area.	(0.9, 1, 1)

$$\tilde{F}_1 \oplus F_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad \text{Eq. 3}$$

$$\frac{\tilde{F}_1}{\tilde{F}_2} k = \frac{(l_1, m_1, u_1)}{k} = (l_1 / k, m_1 / k, u_1 / k) \quad \text{Eq. 4}$$

$$F^* = (i + 2m + u)/4 \quad \text{Eq. 5}$$

Data Envelopment Analysis

DEA enables the relative comparison of evaluation units – treated as decision-making units (DMU) – through mathematical optimization, using their values under multiple criteria. Proposed by Farrell (1957) and popularized by Charnes et al. (1978), DEA involves determining efficiency frontiers based on the input and output values of the units. In relative performance evaluations conducted using DEA, the proper identification of input and output variables is critical. Efficient frontiers are identified through the highest values determined based on the units' output-to-input ratios. If high outputs are achieved with low inputs, these units are considered efficient under the DEA approach (Nishiuchi et al., 2015).

The performance of DMUs is evaluated based on their distance from the efficient frontier determined through mathematical optimization. DEA employs two different approaches regarding returns to scale: constant and variable. If outputs are expected to vary in a constant manner relative to input levels, the constant return to scale approach is recommended; otherwise, the variable return to scale approach is suggested (Tsai et al., 2015). Additionally, DEA models can be considered input-oriented or output-oriented. At this point, it is important to determine whether interventions can be made on the inputs or outputs of the evaluated units. The focus is determined based on which is more feasible to intervene in. In our study, inputs were defined as the weekly class hours and credits of courses, and it was assumed that interventions could only be made on the outputs of all units. Furthermore, since using the constant returns assumption would not be theoretically appropriate for determining performance based on the contributions of courses, a variable returns model was employed. Thus, the convexity constraint that ensures the variable returns assumption has allowed the scale effect at the input levels of courses to be disregarded and has prevented courses from being in a superior or disadvantaged position based on scale advantages depending on their weekly class hours and credit levels. In this study, an output-oriented variable returns model was used, and the model employed in this study is presented in Eq. 6.

$$\begin{aligned} &\max \theta \\ &\sum_{j=1}^{n} \lambda_j = 1 \\ &\sum_{j=1}^{n} \lambda_j x_{ij} \le x_{io}, \quad \forall i \\ &\sum_{j=1}^{n} \lambda_j y_{rj} \ge \theta y_{ro}, \quad \forall r \\ &\lambda_j \ge 0 \end{aligned} \quad \text{Eq. 6.}$$

The programme courses to be evaluated are defined as the DMUs of the DEA model. It should be noted that this study only considers programme courses whose content, credits and class hours can be planned and updated by the administration as required. Therefore, courses whose content and credit structure are determined by the Higher Education Council and cannot be changed at programme level should be excluded from the evaluation. Consequently, the evaluation framework focuses on courses where the programme can make direct decisions and implement improvements. The courses' class hours and credit information serving as input variables; the contribution values obtained using the fuzzy logic approach based on predetermined criteria were treated as outputs. In the model, where θ represents the activity coefficient, the value $1/\theta$ indicates the course's final performance on a scale of 0 to 1. Within the scope of this study, units with an efficiency coefficient of 1 – which can also be considered an output expansion coefficient – are the courses with the highest contribution to the program based on their inputs; as this value decreases, the course's performance also decreases. While y_{rj} represents the rth output value of the j^{th} DMU, the value indicates the rth output of the oth DMU being evaluated. Similarly, while represents the i^{th} input value of the j^{th} DMU, the value y_{ro} indicates the i^{th} input of the o^{th} DMU being evaluated. The value λ_j indicates the level of contribution each DMU makes to the formation of the efficiency frontier. The constraint that the sum of all lambda values equals 1 is included in the model as the convexity constraint that ensures the assumption of variable returns.

Application

Definition of the Program's Competency Areas

It is generally accepted that every curriculum aims to provide students with learning outcomes from multiple perspectives; within the scope of this study, the competency areas offered to students by the curriculum within the relevant program are defined. As part of this study, an evaluation was conducted of the courses in the Rail Systems Management program at the Vocational School of Transportation at Eskişehir Technical University. The competency areas offered by the educational program through its curriculum have been defined by department heads as technical, managerial, and organizational culture, and are presented in Table 2.

Table 2. Defined education perspectives

	Education Perspectives in Rail Systems Management Program
Technical Knowledge	Having knowledge of technical aspects related to rail system components such as trains, tracks, machinery, etc.
Managerial Knowledge	Having knowledge of system planning, management, and operation of rail systems.
Working Culture	Gaining the social requirements of working in rail system units and acquiring railway culture.

Evaluation of the Courses

In the curriculum of the relevant program, all 23 required courses and 25 professional elective courses – excluding the Turkish Language and History courses mandated by the Higher Education Council – were included in the evaluation. The courses are defined as DMUs as shown in Table 3.

Table 3. Course names and corresponding DMU codes

Course Name	DMU	Course Name	DMU
Labor Legislation	DMU1	Organizational Behavior	DMU25
Historical Development of Railways	DMU2	Marketing	DMU26
Maintenance and Certification of Rail Vehicles	DMU3	Marketing Management	DMU27
Rail Transportation I	DMU4	Human Resources Management	DMU28
Rail Transportation II	DMU5	Rail Vehicle Mechatronics I	DMU29
Scientific Principles of Rail Technology	DMU6	Rail Vehicle Mechatronics II	DMU30
Emerging Approaches in Railway Traffic Management	DMU7	Introduction to Rail System	DMU31
General Electric-Electronics Fundamentals	DMU8	Rail System Operations Management	DMU32
Introduction to Business	DMU9	Cost Analysis in Rail System	DMU33
General Mechanical Fundamentals	DMU10	Rail Traffic Operations	DMU34
Principles of Accounting	DMU11	Emerging Technologies in Rail Systems	DMU35
Railway Track Fundamentals	DMU12	Cultural Values in Rail Transportation	DMU36
Public Relations	DMU13	Internship	DMU37
Service Marketing	DMU14	Transportation Management	DMU38
English I	DMU15	Transportation of Dangerous Goods	DMU39
English II	DMU16	Technical English	DMU40
Occupational Health and Safety	DMU17	Technical Drawing	DMU41
Statistics	DMU18	Scientific Principles of Technology I	DMU42
Economics of Road Transportation	DMU19	Scientific Principles of Technology II	DMU43
Urban Rail Transit Systems I	DMU20	Fundamentals of Computer Applications	DMU44
Urban Rail Transit Systems II	DMU21	Commercial Law	DMU45
Logistics Management	DMU22	Topography	DMU46
Mathematics I	DMU23	Train Mechanics	DMU47
Mathematics II	DMU24	Train and Wagon Planning	DMU48

After defining the weekly class hours and credits of the courses as input values for the DMUs in the model, the opinions of 10 faculty members teaching in the program were utilized to evaluate the courses under the established educational perspectives. Table 4 presents the minimum, maximum, mean, and standard deviation values for the evaluations given by ten experts within the three educational perspectives for each course.

Table 4. Descriptive statistics of expert evaluations for the courses (DMUs)

DMUs	Technical Knowledge				Management Knowledge				Working Culture			
	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd
DMU1	1	5	3.2	1.32	3	7	5.2	1.23	4	7	5.1	1.20
DMU2	1	5	2.7	1.25	1	6	3.5	1.35	3	7	5.7	1.34
DMU3	2	7	6	1.49	4	7	5.1	1.10	1	6	2.9	1.37
DMU4	2	7	5	1.63	2	7	6	1.56	2	5	3.4	1.07
DMU5	2	7	5	1.63	2	7	6	1.56	2	5	3.4	1.07
DMU6	3	7	5	1.56	1	6	3.4	1.26	1	5	2.2	1.55
DMU7	2	6	4.5	1.18	2	7	5.1	1.60	1	5	3.2	1.32
DMU8	1	7	4.9	1.73	1	5	3	1.49	1	4	2.3	1.06
DMU9	1	6	2.5	1.51	4	7	5.4	1.17	2	7	3.9	1.45
DMU10	4	7	6.1	0.99	2	6	3.9	1.45	1	5	2.6	1.43
DMU11	1	5	2.2	1.48	3	7	5.2	1.32	1	4	2.3	0.95
DMU12	1	7	4.9	1.97	2	6	4.1	1.29	1	5	2.9	1.45
DMU13	1	5	2.1	1.37	1	7	4.9	2.02	2	7	4.4	1.58
DMU14	1	4	2.1	1.37	4	7	5.5	0.97	2	6	3.8	1.40
DMU15	1	6	3.8	1.81	1	7	4	2.21	1	6	3.6	1.84
DMU16	1	6	3.8	1.81	1	7	4	2.21	1	6	3.8	1.75
DMU17	1	7	4.6	1.78	4	7	5.6	1.17	2	7	4.9	2.08
DMU18	5	6	5.2	0.42	4	7	5.4	0.84	1	5	2.7	1.70
DMU19	1	5	2.9	1.66	3	7	5.5	1.18	1	7	3.7	2.16
DMU20	2	7	5.6	1.58	3	7	5.7	1.49	1	7	3.8	1.69
DMU21	2	7	5.6	1.58	3	7	5.7	1.49	1	7	3.8	1.69
DMU22	2	6	3.6	1.51	4	7	5.9	1.10	1	7	3.2	1.93
DMU23	1	7	4.4	2.07	1	7	3.6	2.01	1	5	2	1.63
DMU24	1	7	4.4	2.07	1	7	3.6	2.01	1	5	2	1.63
DMU25	1	5	2	1.63	2	7	4.4	1.58	2	7	4.9	1.45
DMU26	1	4	2	1.25	2	7	5.1	1.52	2	5	3.4	1.17
DMU27	1	4	2	1.25	2	7	5.2	1.48	2	5	3.5	1.27
DMU28	1	5	3	1.63	2	7	5.2	1.62	2	7	4.7	1.49
DMU29	4	7	5.9	1.20	1	6	3.5	1.72	1	5	2.5	1.65
DMU30	4	7	5.9	1.20	1	6	3.5	1.72	1	5	2.5	1.65

DMUs	Technical Knowledge				Management Knowledge				Working Culture			
	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd
DMU31	4	7	5.6	1.26	3	7	5.5	1.78	1	6	4.1	1.60
DMU32	2	6	4.2	1.62	5	7	6.4	0.97	2	7	4.4	1.71
DMU33	2	6	3.7	1.64	5	7	6.5	0.85	1	6	3.4	1.96
DMU34	1	7	5.1	1.66	4	7	5.9	1.45	2	6	4.1	1.45
DMU35	2	7	5	1.33	2	6	4.4	1.17	1	5	3.3	1.34
DMU36	1	4	3	1.15	2	5	3.8	1.40	5	7	6.2	0.92
DMU37	3	7	5.6	1.65	4	7	6	1.15	5	7	6.1	0.88
DMU38	2	7	4.1	1.52	5	7	6.2	0.92	2	7	4.3	1.34
DMU39	2	7	4.8	1.75	3	7	5.5	1.27	2	7	3.7	1.70
DMU40	2	7	5	1.41	2	7	5.1	1.97	2	5	3.6	1.35
DMU41	4	7	5.6	0.97	1	6	3.1	1.97	1	5	2.6	1.51
DMU42	3	7	5.6	1.17	1	6	3	1.83	1	6	2.3	1.83
DMU43	3	7	5.6	1.17	1	6	2.9	1.85	1	6	2.44	1.88
DMU44	1	7	4.1	2.38	1	7	4.9	2.08	1	6	3.1	1.97
DMU45	1	5	2.5	1.58	3	7	5.5	1.43	2	5	3.2	1.40
DMU46	1	7	4.6	2.01	1	5	2.9	1.52	1	5	2.4	1.65
DMU47	4	7	6.3	1.06	1	6	4.2	1.62	1	6	2.7	2.06
DMU48	4	7	5.7	1.25	4	7	6.2	1.14	1	7	3.5	2.22

Descriptive statistics summarise the distribution of expert evaluations by course. As can be seen in the table, expert evaluations vary to varying degrees across courses and educational perspectives. This variability is consistent with the subjective nature of educational evaluations, revealing that experts can evaluate the contributions of courses from different perspectives. In this study, no weighting or pre-selection was applied to the expert opinions; all evaluations were considered equally. Expert evaluations were then converted into relevant fuzzy numbers using the fuzzy logic approach, and these were used to create the output variables in the DEA model.The input and output values determined for the courses are presented in Table 5.

Table 5. Courses of the Curriculum and the Related Data for the DEA

Course Name	Hours	Credit	Tech.	Man.	Culture
Labor Legislation	4	4	0.3625	0.7020	0.6913
Historical Development of Railways	4	4	0.2744	0.4090	0.7959
Maintenance and Certification of Rail Vehicles	4	4	0.8471	0.6939	0.2794
Rail Transportation I	3	3	0.6765	0.8413	0.3817
Rail Transportation II	3	3	0.6765	0.8413	0.3817
Scientific Principles of Rail Technology	4	4	0.6576	0.4073	0.2081

Course Name	Hours	Credit	Tech.	Man.	Culture
Emerging Approaches in Railway Traffic Management	4	4	0.6020	0.7020	0.3625
General Electric-Electronics Fundamentals	4	4	0.6570	0.3308	0.2026
Introduction to Business	3	3.5	0.2576	0.7526	0.4616
General Mechanical Fundamentals	4	4	0.8538	0.4988	0.2654
Principles of Accounting	3	4.5	0.2244	0.7288	0.1863
Railway Track Fundamentals	4	4	0.6584	0.5206	0.3070
Public Relations	3	3	0.2035	0.6660	0.5596
Service Marketing	3	4.5	0.2006	0.7799	0.4520
English I	3	3	0.4985	0.5323	0.4238
English II	3	3	0.4985	0.5323	0.4674
Occupational Health and Safety	2	3.5	0.6267	0.7802	0.6253
Statistics	3	3	0.7366	0.7640	0.2802
Economics of Road Transportation	2	2	0.3160	0.7721	0.4334
Urban Rail Transit Systems I	3	4	0.7724	0.7881	0.4529
Urban Rail Transit Systems II	3	4	0.7724	0.7881	0.4529
Logistics Management	4	4	0.4282	0.8311	0.3378
Mathematics I	3	4	0.6023	0.4610	0.1860
Mathematics II	3	4	0.6023	0.4610	0.1860
Organizational Behavior	3	4	0.2029	0.5916	0.6622
Marketing	2	3	0.1773	0.7032	0.3756
Marketing Management	3	4.5	0.1773	0.7241	0.3965
Human Resources Management	4	4	0.3471	0.7119	0.6131
Rail Vehicle Mechatronics I	4	4	0.8154	0.4224	0.2503
Rail Vehicle Mechatronics II	4	4	0.8154	0.4224	0.2503
Introduction to Rail System	3	5	0.7733	0.7474	0.5302
Rail System Operations Management	4	3	0.5529	0.8919	0.5503
Cost Analysis in Rail System	2	2	0.4512	0.9113	0.3927
Rail Traffic Operations	3	4	0.7174	0.8160	0.5270
Emerging Technologies in Rail Systems	4	4	0.6919	0.5881	0.3672
Cultural Values in Rail Transportation	4	4	0.3279	0.4791	0.8721
Internship	2	5	0.7491	0.8369	0.8605
Transportation Management	4	4	0.5238	0.8744	0.5369
Transportation of Dangerous Goods	4	4	0.6314	0.7765	0.4189
Technical English	3	3	0.6892	0.6892	0.4148
Technical Drawing	4	4.5	0.7962	0.3773	0.2672
Scientific Principles of Technology I	2	2	0.7878	0.3468	0.2279
Scientific Principles of Technology II	2	2	0.7878	0.3265	0.2259
Fundamentals of Computer Applications	4	5	0.5314	0.6674	0.3552

Course Name	Hours	Credit	Tech.	Man.	Culture
Commercial Law	2	3	0.2610	0.7637	0.3390
Topography	4	4.5	0.5942	0.3169	0.2352
Train Mechanics	4	3	0.8712	0.5558	0.2953
Train and Wagon Planning	5	4	0.7884	0.8735	0.3930

Table 6. Courses in the curriculum and performance scores

Course Name	S	Course Name	S
Labour Legislation	1	Organizational Behavior	1
Historical Development of Railways	1	Marketing	1
Maintenance and Certification of Rail Vehicles	0.7924	Marketing Management	1
Rail Transportation I	0.9259	Human Resources Management	0.9709
Rail Transportation II	0.9259	Rail Vehicle Mechatronics I	0.4724
Scientific Principles of Rail Technology	0.4511	Rail Vehicle Mechatronics II	0.4724
Emerging Approaches in Railway Traffic Management	0.7782	Introduction to Rail Systems	0.8518
General Electric-Electronics Fundamentals	0.3706	Rail Systems Operations Management	1
Introduction to Business	0.9737	Cost Analysis in Rail Systems	1
General Mechanical Fundamentals	0.5537	Rail Traffic Operations	0.9217
Principles of Accounting	1	Emerging Technologies in Rail Systems	0.6601
Railway Track Fundamentals	0.5817	Cultural Values in Rail Transportation	1
Public Relations	1	Internship	1
Services Marketing	1	Transportation Management	0.9901
English I	0.7008	Transportation of Dangerous Goods	0.8628
English II	0.7474	Technical English	0.7734
Occupational Health and Safety	0.9671	Technical Drawing	0.4292
Statistics	1	Scientific Principles of Technology I	0.8993
Economics of Road Transportation	1	Scientific Principles of Technology II	0.8993
Urban Rail Transit Systems I	0.8811	Fundamentals of Computer Applications	0.7413
Urban Rail Transit Systems II	0.8811	Commercial Law	1
Logistics Management	0.9443	Topography	0.3654
Mathematics I	0.5258	Train Mechanics	0.6169
Mathematics II	0.5258	Train and Wagon Planning	0.9606

Following the fuzzy logic approach and DEA application described in the Methodology section, the performance scores for the courses were obtained as shown in Table 6.

Based on the results, 15 of the 48 courses in the curriculum were found to be fully effective ($\theta = 1$). This result indicates that one-third of the courses fall above the effectiveness threshold. Considering the number of class hours and credits for these courses, it is evident that they are the core courses that contribute most significantly to the program's defined educational objectives.

The performance level of 60% of the courses is above 0.8. This result demonstrates that a significant portion of the courses in the curriculum exhibit high performance and effectively contribute to the achievement of program outcomes. The courses identified as having effective performance within the program are Labor Law, Historical Development of Railways, General Accounting, Public Relations, Service Marketing, Statistics, Road Transport Economics, Organizational Behavior, Marketing, Marketing Management, Railway System Operations, Railway System Cost Analysis, Cultural Values in Rail Transportation, Internship, and Commercial Law. These courses serve as benchmarks for other courses and are relatively the most successful under the current performance indicators. In contrast, it was determined that foundational courses such as Mathematics I-II, Topography, General Electrical and Electronic Knowledge, and Technical Drawing are far from the effective threshold. The fact that these courses receive lower performance scores does not imply that they are unimportant. On the contrary, since the DEA model uses course hours and credits as input variables, these results indicate that the contribution of these courses to program outcomes is lower relative to the number of hours and credits they carry. Efforts to improve these courses may include aligning learning outcomes more closely with program competencies, reviewing teaching methods, restructuring course hours and credit loads, and integrating content with similar courses. If necessary, the course's place and role within the program can also be re-evaluated. It is also important to determine expectations for the course through feedback from different stakeholders, such as students and industry representatives, and to update the course content accordingly. The resulting activity scores can then be used as a decision-making support tool to identify which courses should be prioritized in curriculum improvement efforts.

In terms of course status, it is evident that 15 of the 23 required courses and 14 of the 25 professional elective courses have a performance rating of 0.8 or higher. This indicates that both groups of courses make significant contributions to the program's educational objectives.

Overall, the results indicate that the required courses, which form the core of the program, play a decisive role in imparting program competencies, while professional elective courses serve a complementary function by supporting and diversifying these competencies. Furthermore, DEA findings reveal that the curriculum draws significantly not only from technical specialization areas but also from courses in management, law, communication, and social sciences. This indicates that the rail systems management program possesses an educational structure that balances sector-specific technical knowledge with managerial and social competencies.

Conclusions

This study examines the relative effectiveness of courses in terms of their contribution to the program's three core educational perspectives, as compared to their weekly class hours and credits. The analysis is treated as a multi-criteria decision-making problem aimed at examining curriculum performance through courses. An integrated DEA–Fuzzy Logic approach was used for the systematic and quantitative evaluation of courses. A qualitative assessment of courses was conducted using a seven-level linguistic scale based on expert judgments, and the uncertainty and ambiguity in these expert judgments were addressed through fuzzy logic. Furthermore, all expert opinions were included in the study with equal weighting, on the basis that different expert evaluations contain valuable information that can inform the decision-making process. It is suggested that future studies weight expert opinions by considering characteristics such as academic title, length of experience in the relevant program, and total experience in the field. Additionally, analysing inter-rater consistency and potential outlier evaluations using appropriate statistical methods may provide further insight into the evaluation process. Using inputs consisting of the courses' weekly class hours and credit values, a relative performance evaluation was conducted by utilizing output values based on defined competency criteria. For the relative performance ranking, the courses were treated as DMUs, and the DEA method was utilized without requiring any predefined weights for the evaluation criteria. DEA enables the comparison of units' values under multiple criteria through mathematical optimization and reveals the efficiency levels of the courses. Thus, the performance of the courses is examined in relation to the competency gains they provide for the program, compared to the institutional resources they utilize within the curriculum.

According to the analysis results, while the average effectiveness value for required courses was 0.875, the average effectiveness value for vocational elective courses was calculated as 0.776. This finding demonstrates that required courses, which aim to impart the program's core competencies, contribute more effectively to the program's educational objectives when class hours and credit loads are taken into account. While vocational elective courses serve the function of providing specialization and diversity, their average effectiveness levels remained lower than those of required courses. This result indicates that required courses, which form the core structure of the curriculum, play a more central role in achieving program outcomes. It is conceivable that reviewing the teaching methods, assessment processes, and course content of courses identified as having low performance through DEA analysis could lead to an improvement in the overall performance of the program curriculum.

It is recommended that, for future studies, feedback from external stakeholders regarding the program be sought, courses from other similar programs in the country and around the world be incorporated into the evaluation, and the analysis be repeated as needed under different definitions of educational learning outcomes.

AUTHOR NOTE

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