

## Research Article

# An Optimization Model for the Student-to-Project Supervisor Assignment Problem-The Case of an Engineering Department

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*Purpose.* Empirical studies on the topic of assigning university project students to supervisors are currently underexplored. Such studies are critical to success of both the students and the university. Whilst extant research on this topic has contributed to an understanding of student assignments, what appears to be missing is application of a comprehensive framework to inform formulation and validation of a robust solution approach that takes account of both student and supervisor preferences, to optimize a real-life student-to-project supervisor assignment problem. *Methodology.* Questionnaire and interview surveys with project coordinators, project supervisors, head of department and students were conducted to identify factors surrounding the student-to-project supervisor assignment, through a case study approach in a university department offering engineering degree programs. This study not only develops a framework to understand an effective student-to-project supervisor assignment decision but also applies it in practice, through a case study in a University department offering engineering degree programs. An integer linear programming model was developed and implemented in an optimization software to optimize the student-to-project supervisor assignment, using data from the case study. *Findings.* Using OpenSolver, validated model results show improvements in matching both students and project supervisors' preferences, whilst complying with supervisors' workloads. These results also reveal an improvement in minimizing the project coordinator's time in doing the assignment by introducing a standardized approach that concurrently considers all variables in a consistent manner. *Originality.* The contribution lies in: (1) development of a robust framework for student-to-supervisor assignments, (2) explicit consideration of contextual factors that recognize different assignment scenarios, (3) identification of feedback loops to recognize not only the need for continuous improvement in student-to-supervisor assignments but also links to performance in final year projects, (4) unique insights to guide project coordinators in relation to an efficient, effective, comprehensive, and standardized approach to the student-to-project supervisor assignment, and (5) a deeper understanding of a comprehensive range of factors that play a role in student-to-project supervisor assignments in higher education institutions.

## 1. Introduction

The assignment of students to project supervisors represents a category of assignment problems. This assignment problem ought to be conducted in a transparent, standardized, comprehensive, and balanced manner free from decision makers' personal biases. Examples of applications of assignment problems include assignment of students to courses ([1]) and assignment to students to supervisors and projects [2–9].

Existing empirical studies from operations research literature have contributed to an understanding of the assignment of final year project students to supervisors, referred to in this study as the student-to-project supervisor assignment problem. This assignment problem, viewed as a process, has become an important area of interest for most universities, given the evolving nature of academic activities in relation to the need for effectiveness in processes. The literature reveals that this assignment process is treated informally in practice [10], in the context of reliance on intuitive approaches by

project coordinators. These intuitive approaches fall into two categories namely: (1) random assignment and (2) permitting students to choose supervisors (and hence projects) by themselves. Whilst these two approaches may be necessary for both creativity and accommodating students' preferences for certain supervisors, there is a need to complement these approaches with a standardized and balanced approach that accommodates a number of important decision criteria. This need is crucial, given the complexity of the assignment process. This formalized approach adds to our understanding of what constitutes an effective student-to-project supervisor assignment process. Although existing studies have contributed to an understanding of assignment problems in general, the gap lies in using a comprehensive framework to inform mathematical model formulation and practical validation of the resulting model, taking into account both students and supervisor preferences concurrently.

*1.1. Study Motivations and Research Gaps.* Existing studies have contributed significantly by formulating mathematical models to aid student-to-supervisor assignments. However, these models do not accommodate opportunities to develop junior academic staff supervisors in the context of fixed assignments. A second gap in existing studies is the absence of a framework that identifies not only a comprehensive list of criteria for student-to-supervisor assignments, but also explicit consideration of contextual factors, along with feedback loops to highlight opportunities for continuous improvement. A third research gap in existing studies on student-to-supervisor assignments lies in the absence of explicit identification of the type of mathematical models proposed, for example, static, dynamic, stochastic, and deterministic [11, 12]. This need is important to increase our understanding of the current state of knowledge concerning principles of mathematical modelling.

Motivated by the above gaps, this study aims to not only develop a mathematical model (static and deterministic) for effective student-to-project supervisor assignment (informed by a robust framework) but also apply it in practice, using data from a university department offering engineering degree programs.

This study was confined to the following:

- (i) Different aspects of the factors that play a role in the student-to-project supervisor assignment process.
- (ii) Undergraduate engineering degree students in one university department offering undergraduate engineering degree programs.
- (iii) Resources within the immediate scope of the student-to-project supervisor assignment process.
- (iv) Four informant groups, namely, project coordinators, head of department, project supervisors, and students.

*1.2. Study Contributions.* Given the identified research gaps, the contribution from this study is therefore five-folds: (1) development of a robust framework for student-to-supervisor

assignments that explicitly identifies a comprehensive list of criteria, (2) need to explicitly identify the type of mathematical model proposed, (3) need to accommodate academic junior staff supervisors in terms of development, (4) explicit consideration of contextual factors that recognize different assignment scenarios on the basis of context, and (5) identification of feedback loops to recognize not only the need for continuous improvement in student-to-supervisor assignments but also links to performance in engineering final year projects. Empirical model results that reveal agreement among key stakeholders (project supervisors and students) in relation to improved levels of match between stakeholder preferences, represents another contribution. Another contribution lies in verification and validation of the efficiency, effectiveness, accuracy, and consistency of model results, on the basis of real-life data from one university department.

The rest of the article is divided into four sections. Section 2 provides a theoretical foundation for the research. Section 3 describes the research approach used to achieve the aim of this study. Section 4 discusses implementation of the mathematical model in OpenSolver [13], including validation of model results. Section 5 concludes the study by providing implications for both theory and practice, including limitations and avenues for future research.

## 2. Literature Review

*2.1. Random Assignments.* The use of random assignments is predominant in some academic institutions, owing to the necessity to permit the use of intuition by project coordinators. Whilst this approach is necessary for creativity, it needs to be complemented with formalized management tools in the context of optimization techniques.

*2.2. Algorithms for Assignment Problems.* The algorithms used in assignment problems include mixed integer programming [14, 15], integer programming [16, 17], linear time algorithm [18, 19], and stable marriage pairing algorithm [20]. The problem of assigning students to project supervisors was solved using two linear-time algorithms to make a stable match between project students and project supervisors [18]. The first algorithm (model 1) was student-oriented as it finds the best match, where each project student is given the best project that the student can possibly be assigned to. Included in the formulation are students' preferences for available and unassigned projects that students desire. The second algorithm (model 2) was supervisor-oriented, as it finds the best outcome, where the supervisors' preferences are considered. Both algorithms are subject to some constraints.

Other algorithms were developed as a solution to assignment of projects. In particular, three linear programming (LP) models were developed. The first LP model involved minimizing projects supervised by lecturers. The second LP model involved assigning projects according to ranking from students. The third LP model involved assigning projects and creating student groups by virtue of assigned projects.

The criteria for assigning projects to students have similarities to the stable marriage pairing algorithm, which was developed by Gale and Shapley and studied in 1962. The aim was to solve the problem of matching between equal number of men and women [20]. The stable marriage problem deals with finding a stable pairing between two equally sized sets of groups, from preference order for each element in the group. A pseudocode is used in stable marriage pairing. Assigning a fixed number of students to a fixed number of projects has much in common to the coupling of number of men and women in the stable marriage pairing algorithm.

**2.3. Solution Methods.** Solution methods involving the use of mathematical models associated with optimization of scheduling problems, which encompass assignment problems (also known as allocation problems) have been proposed [17, 21–23]. These include exact methods as the first category. Examples of exact methods include, integer linear programming (ILP), mixed integer linear programming (MILP), and mixed integer nonlinear programming (MINLP). The second and third categories are Heuristics methods (e.g., dispatching rules) and meta-heuristics (e.g., genetic algorithm, tabu search, and simulated annealing). The fourth category is constraint programming. The fifth category is Hungarian method. The sixth category is hybrid-methods, which involve a combination of either exact methods and constraint programming or exact methods and heuristics or meta-heuristics and heuristics. The last category is artificial intelligence, examples of which include agent-based methods, rule-based methods, and expert systems.

**2.4. Framework for the Student-to-Supervisor Assignment.** Following reviews of literatures [24–33] identified gap relating to absence of a framework that identifies not only a comprehensive list of criteria but also explicit consideration of contextual factors, along with feedback loops to highlight opportunities for continuous improvement, a framework for effective student-to-supervisor assignment was developed in this study (see Figure 1). Unlike existing studies, this framework incorporates not only identification of explicit criteria but also links to both the department (and faculty) goals, in relation to strategic prioritization of final year projects, leading to both student performance on final year projects and departmental performance. A total of 16 criteria and 13 subcriteria were identified. These criteria were (1) total number of lecturers/supervisors, (2) total number of students (i.e., (2.1) minimum number of students permissible on any project and (2.2) maximum number of students permissible on any project), (3) total number of projects, (4) profile of student in terms of preferences or similarities in student preferences or choices over projects, (5) student discipline [34], (6) suitability of student discipline to project, (7) total number of disciplines, (8) final year project prerequisites, (9) lecturers/supervisors preferences, e.g., (9.1) research interests/areas, (9.2) lecturers' expertise/field of specialization [35, 36], (9.3) professional support [27, 37], (10) lecturer and student relationship [37], (11) popularity of project, e.g., (11.1)

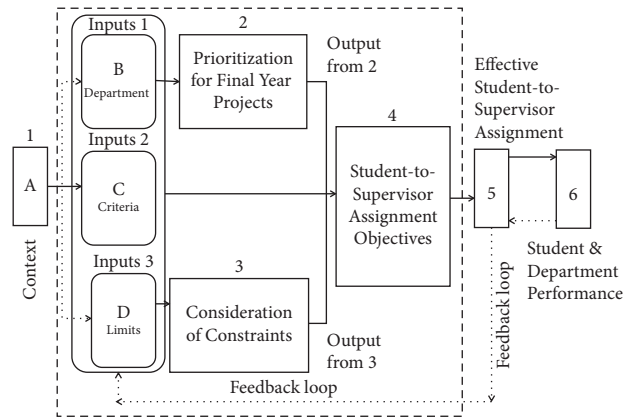


FIGURE 1: Framework for the student-to-supervisor assignment.

least popular/preferred and (11.2) most popular/preferred, (12) popularity of lecturer, (13) workload, e.g., (13.1) project and lecturers total capacity, (13.2) availability, (13.3) total project lower quota, (13.4) total lecturer lower quota, (13.5) individual student projects, (13.6) group student projects [34, 38], (14) students' performance on projects [31], (15) students' gender [27], and (16) Other (e.g., university requirements). The 16 criteria were encapsulated into the developed framework for this study, using process mapping principles to increase our understanding of the theory of student-to-supervisor assignments [39–41]. Three key aspects or steps were identified namely: prioritization for final year projects at department level, consideration of constraints in the student-to-supervisor assignment, and assignment objectives.

The graphical flow of information in the student-to-supervisor assignment is indicated by the numbers 1 to 6. Primary relationships for the three key aspects are represented by solid arrows. Assignment objectives include matching of students to supervisors in terms of preferences for both students and supervisors, and balancing workload distribution among supervisors. Each of the three key aspects is informed by respective inputs, each of which is in turn influenced by contextual factors (block A). Explicit recognition of contextual factors in the student-to-supervisor assignment process addresses a gap in existing studies and hence increases our understanding of this assignment process. The outputs from 2 and 3, including the general theme of inputs (blocks B, C, and D), become inputs that feed into and hence influence assignment objectives in 4. The 16 criteria are encapsulated by blocks B, C, and D and the numbers 2, 3, and 4, in terms of boundaries for the developed framework in this study. Using set theory, blocks B, C, and D are subsets of A [40, 41]. The solid arrows from blocks 4 and 5 indicate links to performance concepts, in relation to what constitutes an effective student-to-supervisor assignment (in 5) and both student performance on the final year project and departmental performance. The addition of feedback loops also increases our understanding of existing literature on the student-to-supervisor assignment process in the context of highlighting opportunities for continuous improvement from one academic year to the next.

### 3. Materials and Methods

An overview of the methodology employed in this study is depicted in Figure 2.

Based on both reviews of relevant literature and interviews with all four stakeholders, a framework for effective student-to-project supervisor assignment was developed. The structure and content of this framework (see Figure 1) was reviewed by industry experts and contained a list of 16 criteria and 13 subcriteria that influence the student-to-project supervisor assignment decision, which included workload of supervisors, supervision quotas, supervisors' research interests, supervisors' knowledge and experience in final year project supervision, supervisors' highest qualification, supervisors' academic rank, supervisors' preferences, supervisors' success rate in final year project supervision, project topic initiator, students' preferences, and project coordinator's years of experience in making student-to-project supervisor assignments.

**3.1. Current Assignment Process—Real Case in the Engineering Department.** An empirical study of the existing student-to-project supervisor assignment process in the department reveals informal behind the scenes discussions between students and potential supervisors, coupled with random assignments. Informal discussions may explain the imbalance in supervision workload, where certain supervisors supervise relatively larger numbers of students than other supervisors. Random assignments may explain evidence of reassignments (including late assignments), arising from mismatches in student and supervisor preferences. There was empirical evidence of the absence of consideration of clear assignment criteria in the case of industrial engineering program. However, in the case of mechanical engineering program, there was some evidence to suggest that the existing assignment process is characterized by a first in first out approach that takes account of the following criteria to some extent: student preferences, supervisor workload, and documentation (final year project manual).

**3.2. Mathematical Model.** Given a discussion of the current assignment process and a developed framework for the student-to-supervisor assignment, the list of criteria were

then used to inform development of a deterministic mathematical model for the student-to-project supervisor assignment. The mathematical model notation and formulation are presented next.

**3.2.1. Model Notation.** The notation used in the mathematical model formulation is presented next, in terms of decision variable definitions and parameters.

**3.2.2. Decision Variables**

- (i)  $S_{ij} = 1$  if student  $i$  is assigned to project supervisor  $j$ ; 0 otherwise
- (ii)  $B =$  the number of project topics (with students) assigned to a project supervisor
- (iii)  $D_{ij} =$  for every student  $i$ , project topic  $j$  is selected from the subset of student preferences list

This index accommodates a scenario where students indicate their preferences from a list of project topics submitted by supervisors, in the students' initial meeting with the project coordinator.

**3.2.3. Model Parameters**

- (i)  $S_t =$  total number of students to be assigned to a project supervisor
- (ii)  $J_t =$  total number of project supervisors to be assigned to students
- (iii)  $R =$  Supervisor's score in project supervision
- (iv)  $H =$  Hours available to do project work
- (v)  $C_{ij} =$  percentage match between preferences of student  $i$  and preferences of project supervisor  $j$
- (vi)  $S_{ij}^k =$  special knowledge ( $k$ ) possessed by supervisor  $i$ , which is required by project  $j$
- (vii)  $M_j =$  total number of projects  $j$ , where  $j$  takes values from 1 to the maximum allowable per supervisor

**3.2.4. Model Formulation and Assumptions**

$$\text{Maximize: } \sum_{i=1}^l \sum_{j=1}^n (C_{ij} E_{ij} D_{ij} S_{ij}) \dots \text{Total workload.} \quad (1)$$

ST:

$$\sum_{j=1}^o B S_{ij} \leq M_j \forall j [\text{where } M \text{ is max number of projects}], \quad (2)$$

$$E_{ij} = 1 \forall i, j \in [\text{project student to be re-assigned}], \quad (3)$$

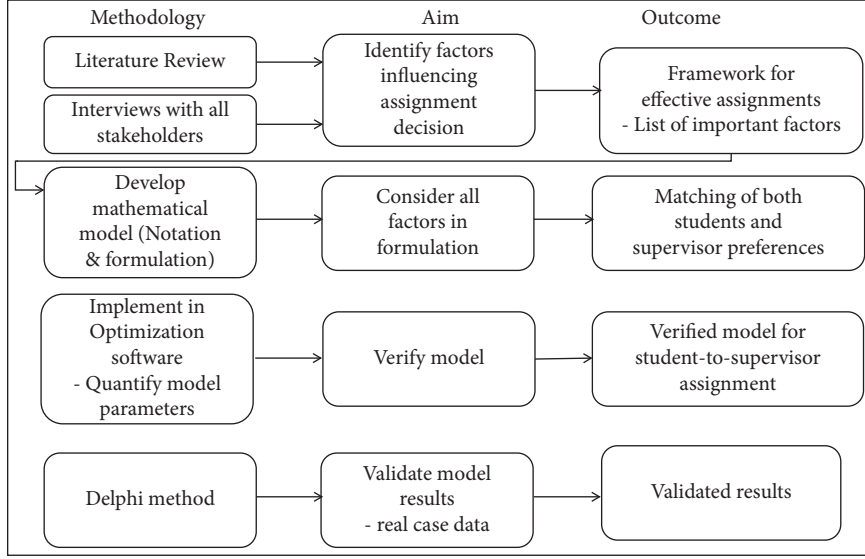


FIGURE 2: Overview of methodology.

$$S_{ij}^k = \begin{cases} 1, & \text{if supervisor } i \text{ has special knowledge } (k) \text{ required by project } j, \\ 0, & \text{otherwise,} \end{cases} \quad (4)$$

$$P_j = \begin{cases} 1, & \text{if project } j \text{ is a project type,} \\ 0, & \text{otherwise,} \end{cases} \quad (5)$$

$$\sum_{j=1}^q S_{ij} \geq 1 \forall j [\text{No supervisor with any students}], \quad (6)$$

$$\text{Fixed assignments: } S_{ij} = 1 \forall i, \text{ where } j \in [\text{fixed assignments}], \quad (7)$$

$$\text{Binary variables: } S_{ij}, S_j^k, P_j = 0, 1. \quad (8)$$

Equation (1) is the objective function to maximize total workload of supervisors, in the context of an even workload distribution. This equation seeks to assure uniformity or fairness in relation to even distribution of workload among all project supervisors within the department. This means that all project supervisors must have project students to supervise every semester, such that no supervisor has relatively large numbers of students and projects whilst another supervisor has very little or no students. Equation (1) also seeks to ensure a high level of match between preferences of students and supervisors, leading to satisfaction of both stakeholders. In the objective function (equation (1)),  $l$  is an upper limit for the 1<sup>st</sup> student while  $n$  is an upper limit for the  $n^{\text{th}}$  supervisor.

Equations (2) to (8) are constraints of the mathematical model, in relation to imposing lower or upper bounds on certain model parameters. In particular, equation (2) imposes a limit concerning the maximum number of projects under the supervision of a specific supervisor.  $O$  is an upper limit for the  $o^{\text{th}}$  project under the supervision of a specific supervisor. Equation (3) imposes a limit on the number of students to be

reassigned to a specific supervisor, arising from several reasons such as supervisor ill-health, transfer or resignation, including student's lack of progress on the final year project in the context of student-to-supervisor working relationship. The notation  $E_{ij}$  considers the effectiveness of supervisor  $j$  in managing the discontinuity of student  $i$  in the case of a reassignment. Equation (4) defines a specific supervisor  $i$  who possesses special knowledge ( $k$ ) required by specific project  $j$ . This equation accommodates the reality of final year projects, as regards the occasional need for special expertise in certain disciplines such as dynamics, engineering materials, and engineering design. Equation (5) denotes a type of project in relation to the two programs namely industrial engineering (course code IMB) and mechanical engineering (course code MMB). This equation sets a constraint on the student-to-supervisor assignment process, based on type of project, to accommodate and model the nature of final year projects in the engineering department. Equation (6) is a constraint set that imposes a lower bound in relation to the minimum number of students under the supervision of a specific supervisor, such that there is no idling supervisor.  $Q$  is the lower limit on the  $q^{\text{th}}$

student under supervisor  $j$ . Equation (7) accommodates soft issues in the student-to-project supervisor assignment, to model situations where consideration must be made to permit faculty staff working on critical research projects that are related to student projects or student projects that are interrelated, such that those students may be assigned to the same supervisor. This equation also accommodates the development of junior academic staff and addresses the identified gap in existing studies, as per the discussions in Section 1.1. Equation (8) imposes restrictions on the type of values in the model, such that they assume only two values, zeros and ones (i.e., binary variables). This equation simplifies the mathematical modelling and addresses issues concerning computer memory, algorithm run time and hence feasible solution.

The following assumptions were made in the formulation.

- (i) All students are full time (no part-time students) in terms of enrolment status.
- (ii) All project supervisors are full time.
- (iii) Static system where evaluations of all decision criteria relating to both entities (students and supervisors) are performed at the beginning of each semester [32].
- (iv) There are 32 weeks in an academic year. This information is important in evaluating project supervisors' time availabilities (hours) from the perspective of time demands of student supervision and given duration of academic year.

The use of algebraic equations in Section 3.2 suits both the nature of the proposed model (deterministic) and the assumption of a static system [32, 42]. In the context of bringing the application of mathematical modelling to a closer representation of reality concerning student-to-supervisor assignment, both hard and soft constraints were included [43]. An example of a hard constraint is the maximum number of students per supervisor, while a soft constraint includes consideration of preferences of both students and supervisors.

**3.3. Proposed Algorithm and Solution Methods.** Whilst several algorithms have been proposed in existing literature (see Section 2), this study proposes a deterministic integer linear programming model to solve the student-to-project assignment problem. Justification lies in that (1) all functions in the formulation are linear, where the variables assume integer values and (2) all variables can be quantified with some level of certainty, unlike stochastic models characterized by uncertainties due to unpredictability [42].

## 4. Results and Discussion

The scenario in the case organization involved assigning 10 new final year project students to 5 supervisors within one department, as summarized in Tables 1–6. The department offers two programs, namely, mechanical engineering and industrial engineering. The grouping in Table 1 was informed by collected data concerning the research interests of

supervisors within the existing faculty complement. The research interests in Table 1 dictate the project topics submitted by respective supervisors. The students in turn indicate their preferences (Table 2) for submitted project topics. The research interests of supervisors are to some extent, influenced by respective programs (industrial engineering and mechanical engineering) within the department.

A total of 8 projects (P1 to P8) were considered. These projects (with their topics) are classified into two categories namely project I and Project II. The categories indicate the two main stages of an engineering final year project within the department, on the basis of registration. For example, all engineering students who have met all applicable prerequisite requirements for stage 1 of a final year project (i.e., Project I) under both programs (IMB 511 for industrial engineering program and MMB 511 for mechanical engineering program) are eligible to register for project I. Similarly, all engineering students who have successfully completed project I are eligible to register for project II under a respective program (IMB 521 for industrial engineering program and MMB 521 for mechanical engineering program).

The 10 newly enrolled students for the final year project and hence awaiting assignment to respective supervisors indicated their preferences to project topics (linked to respective supervisors). These students' preferences are depicted in Table 2.

Table 3 depicts proposed projects by supervisors. A value of 1 indicates that a specific supervisor ( $PS_i$ ) is eligible to supervise a specific project (project  $j$ ) and 0 otherwise, given issues such as suitability and existing workload. Project 1 in Table 3 was proposed by a student while all remaining projects were proposed by supervisors. Table 4 depicts details of each project, covering the two major stages of final year projects.

From Table 5, the supervisor overall scores were computed by using the product of  $C_{ij}$  and  $R$ .  $C_{ij}$  indicates the level of match (percentage) between preferences of student  $i$  and preferences of supervisor  $j$ . Given that  $R$  is a supervisor's score arising from his/her supervision experience (i.e., number of years of supervision experience), a supervisors' overall score in terms of his/her effectiveness to supervise a particular project topic (chosen by a particular student) is computed by a product of level of match in student and supervisor preferences and supervisor score. The proportion of supervisors' nonrelated and related project work in terms of student supervision is depicted in Table 6.

**4.1. Implementation in Optimization Software.** Following formulation described in Section 3.2, the next step was to quantify model parameters and use them as input data in implementing the model formulation in OpenSolver. For example, all parameters (such as  $S_{ij}^k$ ) were included in a spreadsheet as part of data that was implemented in OpenSolver, such that the optimization engine runs the algorithm by concurrently taking account of all model parameters, variables, and constraints, to yield an output shown in Figure 3. This step is part of verification, in the



TABLE 1: Grouping of supervisors' research interests.

Interest group	Interests
Optimization (I1)	Systems optimization Productivity improvement Optimizing decision making Process improvement Lean manufacturing
Manufacturing (I2)	Lean six sigma Advanced manufacturing Bio fuels
Quality and systems control (I3)	Quality control Systems control
Logistics management (I4)	Logistics and supply chain management
Simulation (I5)	Simulation modelling
Project management (I6)	Project and program management
Hybrid systems (I7)	Hybrid systems

TABLE 2: Student preferences for project topics.

Students ( $S_i$ )	Student preferences on project topics			$D_{ij}$
	1 <sup>st</sup> preference	2 <sup>nd</sup> preference	3 <sup>rd</sup> preference	
S1	P1	—	—	—
S2	P2	P6	P4	1
S3	P4	P6	P5	1
S4	P6	P5	P2	1
S5	P4	P2	P3	1
S6	P2	P6	P4	1
S7	P4	P5	P2	1
S8	P3	P5	P4	1
S9	P3	P7	P8	1
S10	P7	P8	P5	1

TABLE 3: Proposed projects-supervisors and students.

Supervisors ( $PS_i$ )	Project ( $P_j$ )							
	P1	P2	P3	P4	P5	P6	P7	P8
PS1	0	1	0	0	0	0	1	0
PS2	0	0	1	0	0	0	0	0
PS3	0	0	0	1	0	0	0	0
PS4	0	0	0	0	1	0	0	0
PS5	0	0	0	0	0	1	0	1
PS (max = 2)	1	1	1	1	1	1	1	1

context of using real case data pertaining to one department. In essence, details of the formulation (i.e., model base) were implemented in OpenSolver and the algorithm activated to process the model base residing on an excel spreadsheet [13]. Table 7 shows the percentage match between students' preferences and the requirements of each project topic. Project 1 was proposed by a student (student 1) while projects 2 to 8 were proposed by supervisors.

Table 8 depicts computations for students' scores relative to requirements of each project. The computations were based on the product of percentage match ( $C_{ij}$ ) and hours of project work in an academic year ( $H$ ).

Similarly, the matching scores between supervisors and projects are shown in Table 9. These matching scores were based on the percentage match between research interests of supervisors ( $C_{ij}$ ) and project requirements.

4.2. *Model Output and Discussion.* The model output is depicted in Figure 3.

From Figure 3, the optimal assignments relating to the first entity (students) is as follows: assign students 1 and 2 to projects 1 and 6 respectively; assign students 3 and 7 to project 4; assign student 4 to project 5; assign students 5 and 8 to project 3; assign student 6 to project 2; assign students 9 and 10 to project 7.

As regards the second entity (supervisors), the optimal solution is to assign: supervisor 1 to projects 2 and 7; supervisor 2 to projects 1 and 3; supervisor 3 to projects 1 and 4; supervisor 4 to project 5; and supervisor 5 to projects 6 and 8. The resulting student-to-project supervisor assignment is as follows: students 6, 9, and 10 to supervisor 1; students 5 and 8 to supervisor 2; students 1 and 7 to supervisor 3; student 4 to supervisor 4; student 2 to supervisor 5. These assignments resulted in a maximum objective function value of 1,362,432. All constraints were satisfied. For example, both student preferences and supervisor preferences were considered in relation to each project topic requirements.

It is worth noting that the objective function value is very large. The reason for a very large objective function value (an outcome of running the algorithm) is associated with an algorithm consisting of parameters with some very large values (e.g., Tables 8 and 9). The relatively large objective function value is not considered a challenge, particularly in view of the problem size (number of students, number of projects, and number of supervisors) in this study.

4.3. *Validation.* Decision science literature reveals several validation methods for validating optimization models, in the context of decision support systems [44]. These methods include: focus groups, panel-based validation, Delphi [45–47], direct assessment, performance validation, and case studies. Focus groups and Delphi were rejected given the challenge to assemble the right participants into one physical venue. Panel-based validation was considered unsuitable since the proposed model is tailored to a specific department. Direct assessment was

TABLE 4: Project details.

Identifier	P1	P2	P3	P4	P5	P6	P7	P8
Project duration (weeks)	32	32	32	32	32	32	32	32
Project type	I3	I5	I6	Yes	I1	I4	I7	I2
Project phase	Project I	Project I	Project I	Project I	Project I	Project I	Project I	Project II
Existing or new project?	New	New	New	New	New	New	New	Existing
Current PS	None	None	None	None	None	None	None	PS2

NB: PS = project supervisor, project I = IMB/MMB 511, project II = IMB/MMB 521, I1 to I7 = Table 2 grouping.

TABLE 5: Supervisor overall scores.

PSi	Years of supervision experience	Supervisor’s academic rank	Supervising experience score (R)	Supervisor overall score ( $C_{ij} \times R$ )
PS1	At most 5 years	Senior lecturer	0.25	22.5
PS2	At most 15 years	Associate professor	0.75	60
PS3	At least 20 years	Professor	1	60
PS4	At most 5 years	Lecturer	0.25	5
PS5	At most 5 years	Lecturer	0.25	2.5

TABLE 6: Supervisors’ nonrelated and related project work.

Data set (supervisors and students)	Proportion of nonproject work (%)	Proportion of project work (%)	Project work proportion (in decimals)	Academic year (hours)	Project work (hours)
PS1	80	20	0.2	1280	256
PS2	70	30	0.3	1280	384
PS3	50	50	0.5	1280	640
PS4	60	40	0.4	1280	512
PS5	80	20	0.2	1280	256

	P1	P2	P3	P4	P5	P6	P7	P8	B (Total)	P (Total)
PS1	0	1	1	0	0	0	1	0	2	
PS2	1	0	0	0	0	0	0	0	2	
PS3	1	0	0	1	0	0	0	0	2	
PS4	0	0	0	0	1	0	0	0	1	
PS5	0	0	0	0	0	1	0	1	2	
s1	1	0	0	0	0	0	0	0		1
s2	0	0	0	0	0	1	0	0		1
s3	0	0	0	1	0	0	0	0		1
s4	0	0	0	0	1	0	0	0		1
s5	0	0	1	0	0	0	0	0		1
s6	0	1	0	0	0	0	0	0		1
s7	0	0	0	1	0	0	0	0		1
s8	0	0	1	0	0	0	0	0		1
s9	0	0	0	0	0	0	1	0		1
s10	0	0	0	0	0	0	1	0		1
L (Total number)	2	1	1	1	1	1	1	1		
S (Total number)	1	1	2	2	1	1	2	0		
Student allocation score	392704									
Supervisor allocation score	61440									
Total allocation score	454144									
Optimal allocation score	1362432									

FIGURE 3: Model output.

rejected given the challenge to engage intended users throughout entire optimization model development cycle, in the context of user availability. Performance validation was considered unsuitable for two reasons, namely, (1) absence of actual implementation and (2) absence of sensitivity analysis of the proposed model, which require field test results conducted over time. Case studies and

specifically prospective validation using a single case study approach [48], was chosen on the basis of suitability to validate the proposed model’s perceived usefulness to intended users, particularly in the context of an engineering department.

A presentation was conducted in a lecture format to two groups of participants: academic staff from industrial



TABLE 7: Percentage match between student preferences and project topic requirements.

SP <sub>ij</sub>	P1	P2	P3	P4	P5	P6	P7	P8
s1	91	0	0	0	0	0	0	0
s2	0	50	0	60	0	80	0	0
s3	0	0	0	70	40	60	0	0
s4	0	60	0	0	56	54	0	0
s5	0	70	70	90	0	0	0	0
s6	0	100	0	60	0	70	0	0
s7	0	60	0	90	70	0	0	0
s8	0	0	100	50	60	0	0	0
s9	0	0	60	0	0	0	80	60
s10	0	0	0	0	40	0	80	40

TABLE 8: Student scores relative to projects.

$C_{ij} \times H$	P1	P2	P3	P4	P5	P6	P7	P8
s1	0	0	0	0	0	0	0	0
s2	0	25600	0	30720	0	40960	0	0
s3	0	0	0	44800	25600	38400	0	0
s4	0	0	0	0	21504	20736	0	0
s5	0	17920	17920	23040	0	0	0	0
s6	0	76800	0	0	0	53760	0	0
s7	0	38400	0	57600	44800	0	0	0
s8	0	0	51200	25600	30720	0	0	0
s9	0	0	23040	0	0	0	30720	23040
s10	0	0	0	0	25600	0	51200	25600

TABLE 9: Matching scores between supervisors and projects.

PS <sub>i</sub>	P1 (% match)	P2 (% match)	P3 (% match)	P4 (% match)	P5 (% match)	P6 (% match)	P7 (% match)	P8 (% match)
PS1	30	92	55	65	70	68	91	78
PS2	90	75	92	72	82	80	78	80
PS3	90	80	81	88	75	68	65	72
PS4	74	70	30	28	93	58	45	65
PS5	60	65	81	61	71	90	83	92

engineering program and academic staff from mechanical engineering program. Among these academic staff were final year project coordinators (one from each engineering program) and head of department. The purpose of the presentation was two folds: to describe and verify the existing student-to-supervisor assignment and demonstrate the proposed model's functionality in terms of its superiority over the existing assignment process within the department. Following the presentation, including a question and answer session, a questionnaire survey with the relevant informants was then conducted. Whilst a side-by-side comparison of the current and proposed model was included in this prospective validation, the aspect of assessing the proposed model's suitability and usefulness to users in the engineering department were included [49].

## 5. Conclusions

This study not only developed an integer linear programming model to optimize student-to-project supervisor assignment but also applied it in practice using real data from a mechanical engineering university department offering engineering degree programs. The model base was

implemented in OpenSolver. Following verification and validation of the proposed model output, the results suggest that the model is applicable to optimizing student-to-project assignments in the case organization, owing to its robustness in concurrently processing the decision criteria and yielding a timely output. The contribution lies in introducing a standardized and consistent measurement tool that proved to be useful in terms of minimizing mismatches between both students and supervisors' preferences.

This contribution has implications for project coordinators, in the context of the need to minimize subjectivity and hence improve stakeholder motivation. Project coordinators in other universities and educational institutions may benefit from the proposed model validated in this study, in terms of an improvement in working practices associated with assigning students to project supervisors. However, contextual factors applicable in the different universities must be considered. Future work includes building a graphical user interface (with a configurable menu to accommodate contextual factors) to address the issue of user-friendliness to practitioners, who may not be conversant with complex details of mathematical modelling. Future work also includes conducting a sensitivity analysis of the proposed and validated

model, to determine the effect of changes in model parameters. For a more robust analysis, the sensitivity analysis may first include conducting a performance validation over a specified period. This period will give intended users the opportunity to use the proposed model over a specified time, with a view to evaluate the model results more rigorously. Another avenue for future work includes modifying the developed mathematical model to accommodate reassignments that may be necessitated by real-world events such as supervisor ill-health and inability to work together in terms of possible personality clashes between supervisor and student. For example, an addition can be made in the objective function to accommodate reassignments of existing students to other supervisors, with a view to bring the mathematical model to a closer representation of the reality of student-to-supervisor assignments. In this scenario, a function can be added within the objective function to assess the effectiveness of the in-coming supervisor, in terms of his/her ability to manage the discontinuity of an existing project that was under the supervision of a previous supervisor.

Lastly, an avenue for future research is to extend the scope of the study to incorporate flexibility in the developed mathematical model, in the context of diverse resource assignment concepts and applications. These may include: assigning final year project reports to internal examiners for grading, assigning human resources to research and development projects, assigning courses/modules to venue, assigning project managers to projects. On this basis, a graphical user interface may be developed, with a view to address user friendliness to practitioners, who may be put off by complex details of the mathematical model. In this future research, the graphical user interface may also be equipped with proficiency for a configurable menu, where users in different application contexts can have the opportunity to select their applicable criteria from a comprehensive configurable menu, for application to their specific resource assignment context. This future research avenue may lead to potential commercialisation of the proposed mathematical model in sequential phases involving version control or enhancements, similar to system introductions.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest concerning the publication of this paper.

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