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A Transdisciplinary Approach to the Academic Timetabling Problem

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Abstract. Higher education institutions must decide every term a) which courses to offer along with the number of sections for each, and b) which professors will teach which subjects and sections in which facilities (classrooms, laboratories etc.). This challenge, known as Academic Timetabling, forms the operational backbone of every higher education institution. It involves optimising the use of the institution's resources (academic programs, physical infrastructure, human and economic); safeguarding financial and academic performance; enhancing stakeholder satisfaction; and preserving the long-term reputation of the institution. While much of the existing academic literature offers quantitative models designed to optimise the use of infrastructure and human resources in benchmark problems, comprehensive industrial real-size applications are comparatively scant. The primary contribution of this article is not a new mathematical model or algorithm for solving timetabling problems. Instead, it introduces a transdisciplinary framework to address the literature gap on real-size instances. The framework serves as a decision support tool that considers all campus stakeholders (professors, students, university operations executives, department and program chairs, information technology, and corporate governance), all majors, and all facilities (classrooms, laboratories, etc.). The objective is to maximise the expected academic performance by assigning professors to courses, sections, and time slots that best align with their preferences and profile affinity; this is achieved through a quantitative model embedded in a broader, transdisciplinary approach. Moreover, the framework includes elements to guide its implementation. The paper provides an example of an industrial-size instance to illustrate the framework to benefit practitioners.

Keywords. Academic timetabling, decision support tools and methods, discrete optimisation, key value indicators, systemic performance measurements, transdisciplinary approach, university stakeholders

Introduction

Wren [1] defines Timetabling as "The allocation of given resources to specific objects being placed in space and time". Burke et al. [2] focused upon a definition of general timetabling, describing the four main critical elements of the problem: "T, a finite set of times; R, a finite set of resources; M, a finite set of meetings; and C, a finite set of constraints." In which the problem is to assign times and resources to the meetings to satisfy the constraints as much as possible. Timetabling covers a variety of applications in which a significant amount of research has been conducted. Those broad domains encompass planning and scheduling of educational, transport, employee, sports, and healthcare settings [3]. Academic timetabling is one of the most critical and time-

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consuming tasks, and it is the backbone of the operation of higher education institutions (HEI). This process occurs periodically in multiple parallel operational academic cycles in all HEIs. Timetabling quality significantly impacts a broad range of stakeholders, such as professors, students, university operations executives, department and program chairs, and corporate governance [4]. Variants of Academic timetabling include subject timetabling, exam timetabling, and course timetabling. Course and exam timetabling are relatively close problems [5], but significant differences exist [6].

Academic literature on this topic is rich with practices, tools, and timetabling algorithms [7]. As per Kingston [8], much of the research from each sub-discipline can generally be categorised into two types: case study papers and solver papers. Case study papers delineate a problem, showcase one or a few instances of it, and resolve those instances. They are instrumental in uncovering new sub-disciplines and emerging requirements within those. Conversely, a solver paper approaches a pre-defined problem and presents one or more solutions for it, comparing these with prior solvers using standard datasets [9]. In the past decade, fresh benchmark examination timetabling problems have been developed and meticulously tested, but these problem reformulations have only mirrored some constraints of real-world situations. Even when the International Timetabling Competition introduced more complex and realistic academic timetabling problems to researchers in 2007, they still encapsulated simplified versions of real-world problems.

Schaerf [10] notably highlighted the "gap between theory and practice" in the scheduling research context. The key differences between many studied problems and their real-life equivalents are the increased complexity imposed by course structures, a plethora of constraints, and the distributed responsibility for information necessary to solve these problems on a university-wide scale [10]. Hertz [11] probed a broad spectrum of research topics, acknowledging the high levels of complexity produced by real-world problems. McCollum [12] argued for more efforts to synergise techniques and integrate methodologies more efficiently and effectively. Qu et al. [13] contended that the primary hurdle in resolving current university course timetabling problems is the considerable rise in complexity beyond standard problem formulations. As this complexity increases, finding a practical solution becomes arduous. Qualizza and Serafini [14] pointed out that even when a solution is unearthed, it is unlikely to be universally applicable across HEIs or all problems within a single institution.

References [15], [16] and [17] are representative works that published endeavours to solve practical timetabling problems. They represent many publications, where some institutions preferred students, professors, or course sequencing or the three but in a reduced universe of only one department (Industrial Engineering Department, for example). The academic literature is scant on comprehensive industrial real-size applications of HEIs, given the inherent complexity of a problem of this magnitude, where the resource assignment needed to address does not lie in a single area, department or even discipline. And it is here where the concept of Transdisciplinarity becomes relevant and meaningful. Mokhtari et al. [17] emphasise that an ideal transdisciplinary process is not aimed at implementing a solution. Instead, the outcome of a transdisciplinary approach is an improved decision-making capacity built during the transdisciplinary process, where Transdisciplinarity raises the question of a problem solution and a problem choice [18], where practice goals need to be defined, encompassing different functional purposes, like technical as well as human resources and management goals. Thus, in this academic timetabling problem, one needs to see the operative efficiency outcome, the whole network of academic processes, and relevant stakeholders in this operational activity.

Departing from the traditionally dichotomous approach of case study papers and solver papers in academic timetabling research methods, this present work seeks a model that can be implemented in real scenarios with tangible complexities. The focus is not to propose a better mathematical solution but to introduce a transdisciplinary methodology to address the multifaceted challenges in real-life scenarios.

Explicitly focused on deterministic course timetabling, and in contrast to numerous existing studies that primarily focus on algorithmic solutions, the primary contribution of this article is to propose a transdisciplinary framework. This framework, designed as a decision support tool, addresses the literature gap on real-size instances, offering a fresh perspective in this extensively explored field. This framework considers all stakeholders, including professors, students, university operations executives (department and program chairs, information technology, etc.), and corporate governance. It encompasses the institution's programs (majors) and all campus facilities (classrooms, laboratories, etc.). This holistic inclusion aligns with the organisational capability theory, which posits that organisations can leverage unique knowledge and skills to compete effectively [21]. This approach fosters the development of unique, hard-to-imitate capabilities, including innovation, adaptability, operational efficiency, and talent development. By employing the transdisciplinary approach, as illustrated in Kleimn [19], we tackle the inherent complexity of academic timetabling problems while challenging knowledge fragmentation. This strategy goes beyond seeking operational efficiency; it ensures that the academic requirements of the institution and the needs of various stakeholders are not overlooked. In line with Scholz and Steiner [18], our goal is not just about implementing a solution; we aim to enhance the institution's decision-making capabilities, thus contributing to its unique organisational capabilities in the long run. Ultimately, this transdisciplinary approach promises to improve overall performance and develop enduring, unique organisational capabilities to address complex scheduling issues.

The rest of the paper is as follows. Section 1 includes the problem definition and assumptions, the mathematical model and the Transdisciplinarity framework proposed. Section 2 shows the implementation of the framework on an actual size timetabling problem, and finally, Section 3 states the conclusions and further research.

1. Methodology

This section is divided into two parts, problem definition (section 1.1), where the timetabling model is stated and second, where the transdisciplinary framework (section 1.2) to solve it is defined.

1.1. Problem definition

The timetabling problem to work on in this article is defined by a time planning horizon *TPH*, usually referred to as a week. The problem data follows in subsections 1.1.1 through 1.1.7.

1.1.1. The schedule sets

$IFT=\{1,...,i_{ft},...,n_{IFT}\}$ of full-time professors, $IPT=\{1,...,i_{pt},...,n_{IPT}\}$ of part-time professors, $I=\{IFP\ U\ IPT\}$, $J=\{1,...,j,...,n_J\}$ set of courses, $C=\{1,...,c,...,n_C\}$, classroom types, $P=\{1,...,p,...,n_P\}$ academic programs, $T_e = \{1,\ldots, t_e,\ldots,n_{Te}\}$ as the set of terms (usually quarters or semesters), $T= \{1,...,t,...,n_T\}$ course schedules. *TS* is a set of subsets of *T* related to courses, where each course *j* is associated with a $TS= \{S_1,...,Sn_{TCS}\}$ member (S_j), and $TW = \{1,...,tw,...n_{TW}\}$ set of time minimum common multiple of time intervals during *TPH* (usually half hour intervals). The coordination of *TW* and *T* is achieved as in [22].

1.1.2. The Problem parameters

$CA_{tw,c}$= Number of units of classroom type c available at time *tw*.
$D_{j,c}$ = Number of sections demanded from course j to be taught in a classroom type c.
$ETA_{i,j}$ = Expected academic performance if professor *i* is assigned to course *j*.
FA_i = Faculty academic load capacity during the term to teach courses (could represent hours/week or courses per week).
CH_j=Number of synchronous hours in which course *j* is taught during *TPH.*

1.1.3. Assumptions

1. Full-time professors must be assigned to meet *FA(i)* at equality.
2. Part-time professors must be assigned to meet *FA(i).*

1.1.4. The Transdisciplinarity approach

HEIs are multifaceted organisations encompassing many stakeholders, including professors, students, management staff, academic authorities, and certification institutions. Therefore, the objective function of our model must aim to benefit all these stakeholders. As an example, in our chosen institution, we define these elements as follows:

$PI_{i,j}$ = Professor *i* preference about teaching course *j* on a scale of 0 to 100.
$SA_{i,j}$ = Historic average of student appreciation of professor *i* teaching course *j* on a scale of 0 to 100.
$IA_{i,j}$= The institution's validation of professor i teaching course j. This takes into consideration institutional regulations and accreditations, and it is represented as a binary measure of either 0 or 1.

Let us allocate weights for professor and student preference and appreciation, respectively, denoted by WP and WS, which sum up to 1 (WP + WS = 1). By doing so, we factor in the needs and feedback from both parties, allowing the model to provide a balanced solution. The transdisciplinary proposal takes into account all stakeholders by computing the expected academic performance of professor *i* if it is assigned to course *j* as $EAP_{i,j} = (W_P\, PI_{i,j}+W_S\, SA_{i,j})\, IA_{i,j}$.

It's important to note, however, that the model outlined above is specific to some evaluation systems and may differ from other HEI; some changes may be necessary to accommodate different modes of evaluation and stakeholder preference determination. The key takeaway here is not the specific metrics or weighting system used but the transdisciplinary approach that calculates professor assignment based on the preferences of various stakeholders. This ensures a more comprehensive and inclusive decision-making process that can be customised according to the unique needs of any institution.

1.1.5. Objective Function

To maximise the weighted (by *CH*) average of *EAP* time tabling assignment during the *TPH*.

1.1.6. Constraints

The following section provides an in-depth discussion of the constraints that must be considered in formulating our timetabling optimisation model. These constraints are broken down into hard and soft to ensure the model's efficacy and practicality.

1.1.6.1. Hard constraints

Hard constraints are strict conditions that must be strictly adhered to. The use of a dummy professor is recommended to increase flexibility. These include:

1. Every full-time professor i_{ft} must teach his/her academic load $FC_{ift,j}$ at equality during *TPH*.
2. Every part-time professor's academic load i_{pt} is bounded above by his/her $FC_{ipt,j}$ during the *TPH.*
3. Every course *j* must be assigned to precisely as many sections as demanded by $D_{j,c}$
4. Each professor *i* could be assigned at most once to every period *tw*.

1.1.6.2. Soft constraints

On the other hand, soft constraints are more flexible and may be compromised under certain circumstances, although attempts should be made to uphold them as much as possible. These include:

5. Classroom types must not be assigned beyond their capacity CA_{twc} for each period *tw*.
6. Sections of the same subject must not overlap for every *t* in their S_j. where S_j in *TS*.
7. The number of course sections associated with the same program *p* and term t_e must not exceed one at every *tw*.

1.1.7. Decision *variables*

Let $x_{i,j,t,c}$ equal 1 of professor *i* is assigned to teach a section of course *j* at schedule *t* in classroom type *c*, and zero otherwise.

1.2. The transdisciplinary framework

Table 1 includes the transdisciplinary approach to solving the university timetabling problem. It consists of three phases strategic planning, structural data building and the steps to solve the periodic timetabling problem.

Table 1. Transdisciplinary academic timetabling framework

Phase I Strategic planification	Step 1: Identify the stakeholders (Professors, heads of departments, institution executives etc.). Step 2: Assemble a representative Transdisciplinarity Team (TT).
Phase II Structural data building	Step 3: Define the time planning horizon (*TPH*) and the scope of the endeavour as the number of programs and terms (P, T_e) to be included. Step 4: Define the time minimum common multiple of time intervals (*TW*) during *TPH*. Step 5: Identify the time schedules (*T*) where each set member must be assembled as the union of the number of members of the set *TW*. Step 6: Identify the sets of feasible time schedules (*TCS*) for courses, where each member is formed as the union of set members of *T*. Step 7: Identify the institution's facility capacity per classroom type c at any time tw ($CA_{tw,c}$). Step 8: Build a data set of course (*J*) and the classroom types (*C*) that could be taught at TPH for all Terms (T_e). Step 9: Identify the set of full and part-time professors (*IFT, IPT*) along with their academic load (FA_i). Step 10: Define wights W_P , W_S. Use historical data to compute $EAP_{i,j}$ for each professor *i* and course *j*.
Phase III Periodical solution	Step 11: Define the number of sections required for the present term ($D_{j,c}$), the related classroom types, their available capacities and the subset of program terms to avoid overlapping according to section 1.4.6. Step 12: Update the problem parameters using the latest available data. Step 13: Instance analytics: 13.1 Compute the classroom types and facility utilisation using available classroom type capacity during TPH ($CA_{tw,c}$) and course Demand $D_{j,c}$. 13.2 For every course *j* compare the number of professors that can teach it ($\sum_{\forall i \in I \; and \; EAP_{i,j}>0} 1$) with the number of sections demanded ($\sum_{\forall c \in C} Demand_{j,c}$). 13.3 If either 13.1 or 13.2 are inconsistent, TT must consider adding professors, schedules and/or facility capacity to promote problem feasibility. Step 14: Build and solve* the mathematical model described in sections 1.1.5, 1.1.6 and 1.1.7. Step 15: If the solution is infeasible: Identify any source of infeasibility regarding faculty, schedules and classroom availability, act in consequence and go to Step 12. Step 16. Implement the timetabling schedule.

*Timetabling literature is fertile in methodologies to solve timetabling models. Let us refer the reader to [2, 5, 6, 7, 8, 22, 23 and 24].

2. Numerical Illustration

To illustrate the framework introduced in Table 1, let us consider an institution interested in optimising its comprehensive expected academic performance in the terms defined in Section 1 by implementing the framework stated in Table 1.

Phase I: Step 1. The stakeholders are all faculty members, all students registered in this term, all heads of academic departments, and management executives of the institution.

Step 2. The TT is assembled by the head of the registrar's office, the head of physical facility administration, department heads, program heads, the certification compliance officer, and an analytics department officer. School deans support the initiative.

Phase II: Steps 3-10. The institution runs three academic programs (n_P =3), each comprising six terms (n_{Te}= 6). The institution owns nine types of classrooms (n_C=9), thirty-four (n_{FT}=34) full-time professors and sixty-nine (n_{PT}=69) part-time professors. The institution opens from 7:00 am to 10 pm Monday through Friday, but classrooms operates from 7:30 to 16:30 hours. Since course sessions are multiples of 30 minutes, the set *TW* considers members representing 30 minutes in advance from Monday through Friday, starting at 7:00 am and finishing at 21:30 (n_{TW}= 150). Nine classroom types are available (*C*) with capacity ($CA_{tw,C}$) {19,2,2,1,2,1,4,4,5} respectively from 7:30 am to 16:30 Monday through Friday. Sixty-two schedules are considered (n_T= 62) in T nine subsets (n_{CS}=9).

The sets *T* and TS={S_j} are shown in Table 2. Schedule codifications are described as **Starting time/Number of half hours per session and date code**. Date codes are L (referring to Mondays, Wednesdays and Fridays), M (Tuesdays and Thursdays), Lu (Mondays), Ma (Tuesdays), Mi (Wednesdays), Ju (Thursdays), Vi (Fridays), D (Daily from Monday through Friday).

Two examples of a date code are: a) 7/3M means a course that starts at 7:00 am, each session last 90 minutes, and is taught on Tuesdays (M is Spanish for *Martes*) and Thursdays; and b) 13+/3Lu 13+/3Mi defines a course session from 13:30 through 15:00 on Monday and Wednesday.

TT defined $W_P = W_S = 0.5$ to compute $EAP_{i,j}$ from $PI_{i,j}$ *and* $SE_{i,j}$.

Table 2. Set members of *TS(S)* and *T*.

TS={*T02S,T03,T03S,T04,T04S,T05,T05S,T7.5,T01S*}
where:
T02S ={7+/2M,12+/2M}
T03 ={7+/2L,8+/2L,9+/2L,10+/2L,11+/2L,12+/2L,13+/2L,14+/2L,15+/2L,7+/3M,9/3M,10+/3M,12/3M, 13+/3M,8/3M,9+/3M,11/3M,12+/3M,14/3M}
T03S ={13+/3Lu13+/3Mi}
T04 ={13+/4Lu13+/4Mi,13+/4Ma13+/4Ju,11+/4Ma11+/4Ju}
T04S ={8+/4Lu8+/2Mi8+/2Vi,8+/4Ma8+/2Ju8+/2Vi}
T05 ={7+/2D,8+/2D,9+/2D,10+/2D,11+/2D,12+/2D,13+/2D,14+/2D,15+/2D
T05S ={7+/4Lu7+/4Mi7+/2Vi,7+/4Ma7+/4Ju8+/2Vi,9+/4Lu9+/4Mi9+/2Vi,9+/4Ma9+/4Ju10+/2Vi, 13+/4Ma 13+/4Ju14+/2Vi,11+/4Lu11+/4Mi11+/2Vi,11+/4Ma11+/4Ju12+/2Vi}
T7.5 ={7+/3D,8/3D,8+/3D,9/3D,9+/3D,10/3D,10+/3D,11/3D,11+/3D,12/3D,12+/3D,13/3D,13+/3D,14/3D, 14+/3D,15/3D,15+/3D}
T01S ={13+/2Vi,14+/2Vi}

with *T* ={Union of set members in *TS*}.

Phase III: Steps 11 and 12. Academic analytics used information from the last term and defined the need for one hundred and eighteen (n_J= 118) courses representing 260 sections in the matrix $D_{j,c}$. Table 3 shows S_j and $D_{j,c}$ for the current term. Table 4 shows the professors and student preferences $PI_{i,j}$ and $SA_{i,j}$. Table 5 shows the set relating programs (*P*), terms (T_e) and courses (*J*). Table 6 shows the set of professors J, in relation with their type (Full or part time) and their FA_i.

Table 3. Set of schedules associated with each course (S_j) and Demand of sections for each course per classroom type ($D_{j,c}$).

		Classroom types (C)								
J	TCSj	1	2	3	4	5	6	7	8	9
1001	T7p5	0	0	0	0	0	0	2	0	0
1002	T7p5	0	0	0	0	0	0	2	0	0
1003	T7p6	0	0	0	0	0	0	2	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1116	T01S	1	0	0	0	0	0	0	0	0
1117	T03S	1	0	0	0	0	0	0	0	0
1118	T02	1	0	0	0	0	0	0	0	0

Table 4. Professors interest $PI_{i,j}$ and student appreciation $SA_{i,j}$, all with $IA_{i,j}$=1.

I	J	Professor	Students
1001	1091	70	90
1001	1107	90	81
1002	1110	90	99
1002	1035	90	80
⋮	⋮	⋮	⋮
1102	1046	100	85
1102	1048	100	100
1102	1050	80	98
1102	1052	100	88
1103	1017	90	96

Table 5. The set of Programs, Terms and Courses

P	Term	J
1	1	1001
1	1	1017
1	1	1018
⋮	⋮	⋮
3	6	1116
3	6	1117
3	6	1118

Table 6. Professors type, and FA(i).

I	Professor type	Academic load FA(i)
1001	Full Time	2
1002	Part time	2
1003	Full Time	3
⋮	⋮	⋮
1101	Full Time	1
1102	Part time	4
1103	Full Time	1

Due to the actual size of the data involved in this timetabling instance, Tables 3 through 6 show the first and last three rows of them. For replication purposes the complete data sets for Tables 3 through 6 are available upon request to the corresponding author of this article.

Step 13. Course 116 demands four sections, but only three professors can teach it. This does not necessarily mean the problem is infeasible since a professor can teach two or more sections of the same course depending on his/her FA_j. But it is something to keep in mind. Analysing classroom type utilisation, one can notice that classroom type 7 has the highest utilisation for this term, 90.28% of the available time TPH time. Institution utilisation is 55.61%. Notice that facility utilisation depends not on the assignments of $x_{i,j,t,c}$ but on availability and course section demand ($D_{i,j}$).

Step 14. The model was implemented in GAMS 37.1.0, running a Cplex solver under a Mac Air with an M1 processor with 16 Gig RAM. The resulting model was found to be infeasible. Even though the computer process (Generation of the model, solver execution, reading solution and output report generation) took around three minutes, Cplex time (solver) took less than three seconds.

Step 15. There are three types of resources to work on to achieve problem feasibility. They are schedules, facilities, and professors. Thus, a) additional working hours (schedules) were added to *TW,* from 7:00 to 7:30 and 16:00 to 21:30, both Monday to Friday, additionally Saturday from 8:00 am to 15:00; b) Classroom capacity for these new times was allowed with a penalty; c) A dummy professor (named **g**) was added, it can teach any course, but negligible preference (0.001%.) for any course and student preference was imposed.

Under this new scenario, an optimal solution was achieved in 2:51 minutes, with only **1.23 seconds of Cplex (solver) time**. The original problem size is **21,497 constraints, 6,847,776 binary variables and 11,529 continuous variables**. After pre-processing, the problem was reduced to 2,232 constraints, 3,386 binary variables and 1,073 continuous variables.

A feasible solution was found at EAP of 87.39% (84.72% of professor's interest and 90.07% of student appreciation). The **optimal EAP is 88.39%** (86.69% of professors' interest and 90.10% of students' appreciation). Since the difference from the first feasible solution to the optimal is small (1.0%), one may conjecture that the feasible region might be small.

Let us analyse the solution provided. The full report has 4,496 lines, so it cannot be fully included in this article. The comprehensive output file is available upon request to the corresponding author of this article. Now, let us highlight the solution.

Three-course sections were assigned to professor g respectively a) course 1057, schedule 11+/2L, classroom type 9, b) course 1114, schedule 13+/2Vi, classroom type 1; and c) course 1116, schedule 13+/2Vi, classroom type 1. Thus, to make this assignment feasible, the related head of departments must find faculty (full-time or part-time) to meet these assignments. The EAP will probably increase after assigning these three courses since professor g was assigned with a factor of 0.001% preference and student appreciation.

Classroom type 7 capacity must be increased from 16:30 to 17:00 from Monday through Friday from zero to three.

Courses 1051 and 1052 have two overlapping sections each, course 1051 at 11+/2D and 1052 at 8+/2D. Since they both demanded ten sections and the number of members in sub-schedule T05 is nine, there is no way to avoid these overlaps without expanding the subset members in T05.

The program, Term overlapping sections: Since in most of the courses there are several sections, the model could not find zero section overlaps at each tw, p, t_e. The output report shows all overlaps. So, let us focus on one example of them. Program 1, Term 4 contains 8 courses, making 53 sections. On schedule Monday from 12:30 to 13:00, seven sections are overlapping. Program and department heads must analyse these overlaps and check student registration feasibility to give the ok to the timetable.

3. Conclusions and further research

The timetabling problem is considered one of the most complex problems in optimisation. In this article, a framework was developed to emphasise the importance of a transdisciplinary approach while solving the timetabling problem. The endeavour effectively integrates stakeholder preferences and institution-specific factors comprehensively. This approach challenges the fragmentation of knowledge and considers the entirety of the institution's resources, operational requirements, and stakeholder needs. This research highlights the potential of transdisciplinary methods in addressing scheduling challenges, providing a foundation for future studies and practical tools for HEIs. It showcases how applying a transdisciplinary approach can evolve into an organisational capability, thus improving operational efficiency and stakeholder satisfaction.

The framework and strategy proposed in this work could be transferable to the rest of the academic timetabling problems with some adjustments. A real timetabling data set was included to illustrate the framework. The deterministic model involved was solved using optimal methods in negligible time, this may not be the case in general, but the framework does not propose a solution to solve the model. Still, it encourages practitioners to use the best method for their circumstances.

This transdisciplinary approach to academic timetabling could be broadened and refined along several avenues for future research. The deterministic model could be extended to include stochastic variables, thereby accommodating demand variability based on current and anticipated enrolments. Integrating budgetary constraints for full-time and part-time professors into the model would better reflect the financial realities of institutions while factoring in spatial logistics could account for the time required for movement between different campus locations. Finally, a detailed analysis of section overlaps across programs could result in more efficient resource utilisation and heightened course flexibility, further bolstering student satisfaction. These future directions would further enhance the robustness and versatility of the transdisciplinary model.

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