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LEAN THINKING TO IMPROVE CURRICULUM DELIVERY IN CIVIL ENGINEERING USING MONTE CARLO SIMULATION

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ABSTRACT

Lean education can refer to teaching Lean principles or applying Lean thinking to improve educational content delivery. Applying Lean in education can enhance supportive services such as admissions and program selections. In this paper, we developed a simulation study to examine course offerings in the third and fourth years of civil engineering at the University of Alberta, given an anticipated number of students registered in different subdisciplines. This study uses Monte Carlo simulation to model student enrolment in the curriculum aiming to reduce curriculum planning time and incorporate the end users' (i.e., the students) preferences into the course offerings by evaluating various what-if scenarios. The study investigates the effect of course selection flexibility on curriculum delivery and estimates the seating capacity to accommodate all enrolled students. In one scenario, all variables were simulated using random numbers and predefined statistical distributions. In a second scenario, we introduced restrictions where one subdiscipline offers limited courses, and graduate course offerings are restricted. In a third scenario, an additional restriction was added by raising the GPA eligibility threshold for graduate courses. The results show that simulation is an effective tool to test and incorporate Lean ideas into curriculum planning and management.

KEYWORDS

Continuous Improvement, Curriculum Development, Engineering Education, Learning, Simulation.

INTRODUCTION

The core of today's Lean thinking and methodology is based on the success of the Toyota Production System (TPS) (Ohno 1988), which founded the worldwide spread of Lean principles, not only in the manufacturing sector but also in other industries and service environments. Many researchers have investigated the Lean applications in the construction industry (Lauri Koskela 1992; Ballard and Howell 2003; Alarcón et al. 2008; Jørgensen and Emmitt 2009). Also, Lean tools and techniques were utilized in various

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service fields such as healthcare (Ker et al. 2014), hospitality (Abdelhadi 2016), and finance (Wang and Chen 2010).

The application of Lean principles in higher education institutions (HEIs) provides numerous benefits at operational, administrative, and strategic levels. The inclusion of Lean thinking and principles in education is two folds: 1) as curriculum contents and 2) as a method of improving educational delivery (Alves et al. 2017). Specifically, the quality of engineering education affects, to a large extent, the quality of future engineers; hence, HEIs are required to identify and search for the skills and competencies that a modern engineer must retain. Lean higher education (LHE) refers to the adoption of Lean philosophy and thinking in higher education, both at academic activity levels (e.g., course design, improving degree programs, managing assignments) and administrative activity levels (e.g., admission process, hiring, purchasing) (Vukadinovic et al. 2016).

The fundamental nature of Lean philosophy is to eliminate all types of waste, shortfalls, and non-value-adding activities. Lean practices and principles have the potential to significantly improve the curriculum planning process. To the best of our knowledge, there are rarely any studies that attempt to incorporate Lean thinking into the curriculum planning processes via the use of Monte Carlo simulation. This paper intends to use simulation modeling to examine the effect of applying different sets of rules that restrict undergraduate student enrollment in the civil engineering program courses at the University of Alberta. We propose that a curriculum simulation modeling can be used and lead to a lean planning process by reducing the time required to forecast seat requirements for each subdiscipline. Also, it allows curriculum planners to better prepare for unforeseen changes in course offerings and curriculum guidelines. This approach will also improve the student experience by allowing planners to match the course offerings with the students' preferences and forecasted enrollment. The implemented method in this study supports the Lean principles of 1) “Create a continuous process flow to bring problems to the surface,” and 2) “Make decisions slowly by consensus, thoroughly considering all options,” as described by Liker (Liker 2021). Without using the proposed model, curriculum and program planners have to spend a significant amount of time trying to satisfy many contradicting constraints regarding student enrolment and course offerings. In addition, using our proposed model, the decisions made by the planners are based on objective measures and forecasts and are less prone to subjectivity.

The paper starts with a brief literature review about Lean application in higher education. Then, the study methodology is presented, followed by results and a discussion section. Concluding remarks are then presented, including suggestions for future work.

LITERATURE REVIEW

The literature on Lean application in higher education institutions is still evolving compared to the wealth of information on lean in the manufacturing industry (Thomas et al. 2015). In this section, we provide a brief overview of the literature on Lean application in higher education as well as curriculum development.

LEAN FOR EDUCATION

Lean is gaining attention in the educational sector as valuable organizational philosophy and administrative toolkit. Lean initiatives have been developed and implemented to promote sustainable universities by identifying the best Lean practice at the institutional level (Comm and Mathaisel 2003). Also, Emiliani (2004) described the application of Lean principles and practices to improve the consistency of business courses taken by part-time students who are working professionals. In a subsequent paper, the author used the Kaizen process for ten courses in a part-time executive management degree and concluded that Kaizen could be an effective way to improve business courses and values for students (Emiliani 2005). In applying Lean principles and techniques at HEIs, Balzer et al. (2015) discussed the respective successes, challenges, and potentials for improving institutional readiness, enhancing leadership awareness and support, and facilitating an institution-wide transition to LHE.

Other authors tried to combine different techniques with Lean to achieve a more efficient curriculum delivery. For example, Thomas et al. (2017) proposed a framework that attempts to create a more balanced and integrated approach between Lean and Six Sigma that can accomplish enhanced efficacy of curriculum and program development in a higher education environment. On the other hand, Tsao et al. (2013) discussed distinct perspectives on teaching Lean Construction (LC) in a university setting. They illustrated how LC could be taught effectively by combining a broad range of tasks that integrate theory with action. These tasks may include readings, lectures, discussions, exercises, field trips, and guest speakers. Also, Pusca and Northwood (2016) demonstrated how Lean principles can be applied to improve the quality of an engineering design course in terms of course content, delivery, and assessment. They considered engineering design education a process, and the instructors can apply value stream mapping, root cause analysis, and Kaizen to improve the quality of teaching and learning.

More recently, and intending to eliminate waste in the business school curriculum, Kazancoglu and Ozkan-Ozen (2019) defined eight wastes of lean philosophy in higher education institutions. They investigated the causal relationship to create an importance-order using a multicriteria decision-making method. Lean thinking and practices can also be applied for other educational purposes. In one study, the authors proposed a “hands-on team simulation exercises” method to teach LC. The technique is used to accommodate different learning styles and engage students throughout the learning process by replicating various real-life processes, projects, and systems to enhance teaching, analyzing, and understanding (Hamzeh et al. 2017). In another study, the authors examined the use of "Lean Simulation" as an effective way to learn lean principles and understand the impact on process optimization. The authors developed a simulation model on a digital platform that supports user interactions to educate participants about lean principles, including the Last Planner ® system (Cisterna et al. 2021). Also, Hao and Florez-Perez (2021) conducted empirical research to identify the effect of the physical classroom environment on the motivational attributes of students in HEI. Based on the Lean thinking methodology, the authors provided design recommendations that support absenteeism reduction, enthusiasm boost, and improving the "person-environment relationship" to fulfill the students' needs.

CURRICULUM DEVELOPMENT

With the increasing competition for student recruitment and retention, credit transfer flexibility, and quality assurance strategies at HEI, continuous curriculum development has become a necessity in today's global higher education. A curriculum has been defined by Hubball and Gold (2007) as "a coherent program of study (such as a four-year B.Sc.) that is responsive to the needs and circumstances of the pedagogical context and is carefully designed to develop students' knowledge, abilities, and skills through multiple integrated and progressively challenging course learning experiences." Due to many social, economic, organizational, and individual factors, as well as the various phases of development and the number of people involved at several institutional levels, undergraduate curriculum development is a multifaceted and complex process (Wiles and Bondi 2015).

Wolf (2007) presented a model used to systematically assess the department's undergraduate curriculum at the University of Guelph. The model is based on a data-driven approach that engages faculty members and teaching supportive services using curriculum assessment to foster a continuous improvement process in curriculum development. The process consists of three phases: 1) curriculum visioning, 2) curriculum development, and 3) alignment, coordination, and development. Hines and Lethbridge (2008) argued that the academic environment is more challenging to change than many other conventional environments and have presented the steps necessary for developing an effective Lean enterprise in such an environment. The authors proposed the Lean iceberg model in which the technology, tools, and techniques that affect the processes are just a visible part of the iceberg. Litzinger et al. (2011) proposed that curriculum-level instructional processes should be used to design and implement changes to improve the alignment of developing expertise and engineering education. They asserted that the engineering education curriculum should embrace a set of learning skills that grant students deep conceptual knowledge, technical and professional fluency, and engagement in real-world engineering projects where the students adapt to address novel and complex problems.

One of the recent studies used Monte Carlo simulation to assess curriculum efficiency and propose improvements to increase graduation rates by identifying bottlenecks in a degree plan (e.g., course prerequisites). The study is designed to predict the time it takes each student to complete a degree by enrolling a large number of virtual students and simulating their progress in a degree plan (Torres et al. 2021).

It is observed that curriculum development is an essential process in the success of engineering programs, and it has been an active area of research in the past few years. More recently, Lean thinking and philosophy have seen increasing interest as it applies to higher education. However, using Monte Carlo simulation to examine the different processes that can improve the engineering program curriculum and produce a "leaner" degree plan is a promising approach that has not been investigated well in the literature. This study is conducted to fill this gap and to promote using simulation with Lean Thinking to support curriculum development in HEI.

RESEARCH METHOD

This study examines different cases of student progression through the civil engineering degree plan by enforcing various restrictions on what courses the student is allowed to take during the sixth, seventh and eighth semesters. Different scenarios are examined using a Monte Carlo simulation developed in MS Excel. Program administrators can utilize this tool to select the most feasible set of rules in terms of optimizing the overall seat utilization for all course sections while at the same time providing flexibility for students to select the courses and specializations that are of interest to them. The methodology that guided the activities in this study is outlined in Figure 1.

Every year, the number of students enrolling in and graduating from each term of civil engineering faculty can not be predicted with certainty. The authors acknowledge that enrolment unpredictability can be said about any faculty in a given university. However, this paper focuses only on the civil engineering faculty at the University of Alberta. The factors that contribute to the unpredictability of students' flow through curriculum include, but are not limited to, failure to score passing marks, cooperative students who alternate semesters between working and studying, students taking breaks or switching to part-time programs, and of course, the choices students make between different classes and specialties.

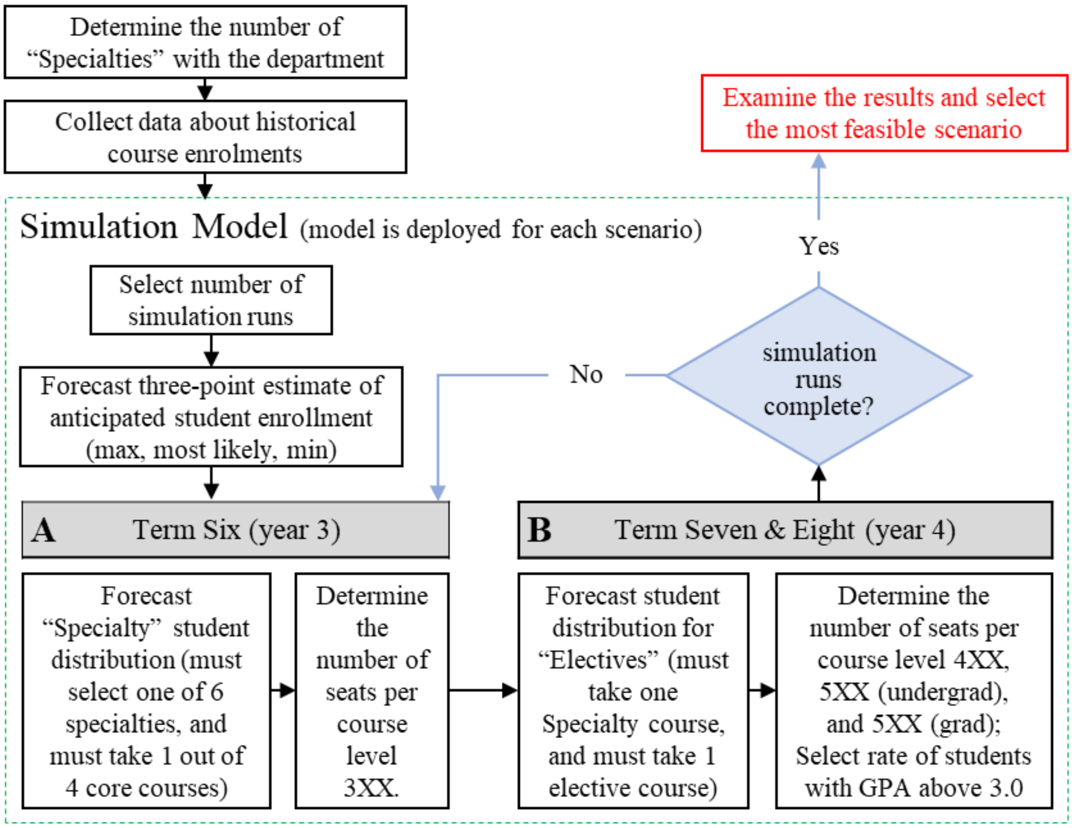

Figure 1: Research methodology

The traditional way of dealing with these uncertainties is to rely on historical data and base the estimate on the average attendance. However, this is a new curriculum, and historical data do not hold much weight in this case. There is no doubt that the conventional method works to some extent; nevertheless, after applying Lean Thinking to the problem, the authors quickly realized that a more sophisticated approach is required to deal with enrolment uncertainties. To quote a great statistician, "Plans based on average assumptions will be wrong on average" (Savage 2009).

MONTE CARLO SIMULATION MODEL

Monte Carlo simulation is a great tool that can be used to optimize deterministic problems based on "known unknowns." From the students' standpoint, their choices are determined based on circumstances, causes, and their will. On the other hand, all these deterministic factors are unknown from the curriculum planner's standpoint. Hence, students' choices can be considered stochastic (random) in nature. In the Monte Carlo method (Metropolis and Ulam 1949), random numbers are used to simulate "known unknowns." These numbers are generated in the range between zero and one and then transformed into variables based on predefined distributions or custom-made distributions supported by empirical data. In statistical layman terms, the random number represents cumulative density function (CDF) which is then inversely transformed into probability density function (PDF, area under the curve). Every iteration of random numbers constitutes a possible scenario in which all other dependable elements of the model are calculated (e.g., number of students per semester, number of courses per semester).

In our study, we used the Monte Carlo method to simulate the flow of students through the curriculum of the civil engineering department for terms six, seven, and eight. These terms were not chosen arbitrarily by the researchers but were aligned with the ongoing engineering department reorganization, which had an emphasis on the third and fours academic years. This is because the courses offered in the first two years are common for all students. The students have no flexibility to select elective courses until they reach the third year. Nevertheless, the developed Monte Carlo model can be customized to accommodate any number of semesters or for all semesters together, simulating the whole degree length.

RESULTS AND DISCUSSION

In the developed model, hypothetical students choose their specialty in the second semester of the third year (i.e., term six). They can select one of the following civil engineering subdisciplines: Structural, Environmental, Geotechnical, Water Resources, Construction, or Transportation. In addition, they need to choose three more courses in term six as electives from which one course can be from their specialty (two specialty courses maximum in one term; a maximum of four specialty courses in three terms combined). In the following terms (i.e., terms seven and eight), students are required to select two core courses each term (specialty or elective) with the constraint of having two identical electives maximum over the three terms.

Table 1: Model inputs, their respective values, and distributions

Inputs	Min	Most likely	Max	Probability density function
Anticipated number of students	125	150	160	Beta-Pert
GPA above 3.0/4.0	-	30%	-	Constant
Students’ distribution across specialties:				
Structural	24%	26%	28%	Normal
Geotechnical	17%	19%	21%	Normal
Water	17%	19%	21%	Normal
Environmental	17%	19%	21%	Normal
Construction	8%	10%	12%	Normal
Transportation	5%	7%	9%	Normal

In Figure 1, the process is illustrated by the two boxes A and B, which depict the sequence of inputs that need to be forecasted or extracted from historical databases to run the model. Refer to Figure 2 for a visualization of two examples of a student progressing through the civil engineering curriculum. All the inputs presented in this paper are aligned with the ongoing restructuring of the undergraduate curriculum and course offerings. The inputs are shown in Table 1. The probability density functions for each input are selected based on the granularity of available data. The anticipated number of students' input required more flexibility in minimum and maximum extremities adjustment (possibility of asymmetry). GPA input was modeled as constant since it is a hard threshold required by the department. The PDF for students' distribution inputs (for each specialty) is selected as normal due to the absence of precise historical data. Experienced curriculum planners predict these inputs as "most likely plus-minus percentage" (symmetrical).

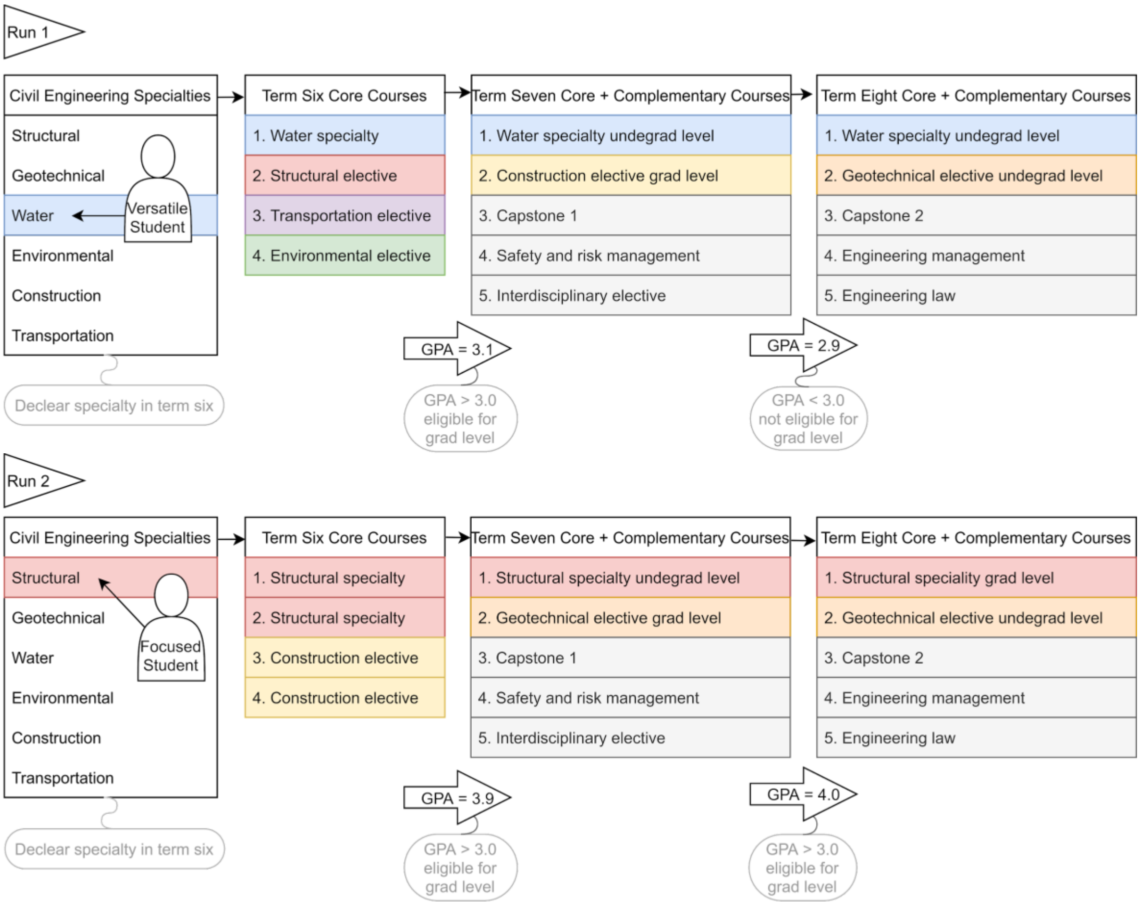

Figure 2: Example of students' flow through Monte Carlo simulation in two iterations

In Figure 2, we describe a flow of two hypothetical students through the simulated curriculum in two iterations (runs)—for example, student 34 in iteration one and student 151 in iteration two. Every student in the model undergoes a similar flow. As it can be observed, in the first run, a student chooses the "Water" specialty in term six and selects three more courses from structural, transportation, and environmental engineering specializations. After finishing term six, their GPA is generated as 3.1; hence they are eligible for graduate-level core courses (maximum of one graduate-level core course per semester). In term seven, the same student picks one specialty course from the undergraduate level and one elective graduate-level course from the construction specialization. The other three complementary courses (in grey) are the same for all the students in the civil engineering program. After finishing term seven, the student's GPA is generated as 2.9, which is lower than 3.0—a threshold for graduate-level courses. In this case, both their core courses must be undergraduate level in term eight. In the second run, we show another student whose flow through the curriculum is somewhat similar except for being less versatile in selecting courses from different specializations.

To demonstrate the capabilities of the Monte Carlo simulation model, we consider three different what-if scenarios. In the first scenario, the curriculum is simulated using the distributions shown in Table 1, with the output being the number of course seats needed for each program specialty. Further, we assume a seat cap for each specialty with the constraint of a maximum of 100 seats. The seat cap constraint of 100 seats is assumed based on the largest auditorium capacity and desirable student-teacher ratio. Lastly, we find several courses (or sections) needed for each specialty and a planned seat utilization ratio for the whole term. The simulation results constitute the 80^{th} percentile of 1000 Monte Carlo simulation runs, which can be found in Table 2. The 80^{th} percentile is chosen to accommodate most of the possible student choices.

In the second scenario, we assume, "what if the Environmental department is too busy and refuses to offer any courses for the civil engineering department?" In addition, we put a hard constraint on graduate course availability. In the second scenario, they are only offered in the winter (seventh) term.

In the third scenario, in addition to the constraints used in the two previous scenarios, we assume that the Transportation department decides to offer courses only in winter terms. Furthermore, the percentage of students eligible for graduate courses is increased to 40%. It is worth mentioning that graduate courses are out of the scope of this paper and are not showcased in Table 2. According to the newly developed curriculum, the students who qualify for the grad level are simply added to the existing graduate courses.

The three scenarios are chosen not hypothetically but as real-world circumstances of curriculum planning that took place during the Civil Engineering program reorganization at the University of Alberta.

In Table 2, "Seats” refers to the required number of course seats to accommodate all the student choices simulated by the model (model’s output). “Cap” refers to the established course seat limit, which is set based on maximizing seat utilization ratio and the maximum seat limit of 100. “Ut. r.” stands for utilization ratio and indicates the percentage of filled seats based on simulation results. “Courses” refers to the number of courses that each specialty must offer to accommodate all the student choices.

From observing the results in Table 2, we can see that in Scenario 1, the simulated number of seats is somewhat proportional to the initial student distribution in Table 1. This is the case due to students virtually having no restrictions on their choices. After introducing a what-if case and a hard constraint in Scenario 2, we observe that the seat allocation has considerably altered. Because graduate courses are not offered in term eight anymore, the seat requirement for undergraduate courses is increased. In addition, due to the absence of Environmental offerings, the number of seats for each specialty is also increased in each term. At last, in the third scenario, the seat requirements are further altered due to additional what-if cases and a modified GPA threshold.

Table 2: Simulated results (in bold), calculated number of courses, and seat utilization ratios for the three scenarios

Scenario 1: All specialties offer courses according to the distribution from Table 1									
	Term six (fall)			Term seven (winter)			Term eight (fall)		
	Seats	Cap	Courses	**Seats**	Cap	Courses	**Seats**	Cap	Courses
Structural	**147**	75	2	**76**	80	1	**76**	75	1
Geotechnical	**118**	60	2	**56**	60	1	**56**	60	1
Water	**118**	60	2	**55**	60	1	**56**	60	1
Environmental	**118**	60	2	**56**	60	1	**56**	60	1
Construction	**68**	70	1	**30**	35	1	**29**	30	1
Transportation	**49**	50	1	**21**	25	1	**21**	25	1
	Ut. r.	98%	Σ 10	Ut. r.	91%	Σ 6	Ut. r.	94%	Σ 6
Scenario 2: Scenario 1 + Environmental does not offer courses + Graduate courses are only offered in the winter term									
	Term six (fall)			Term seven (winter)			Term eight (fall)		
	Seats	Cap	Courses	**Seats**	Cap	Courses	**Seats**	Cap	Courses
Structural	**175**	90	2	**93**	100	1	**108**	60	2
Geotechnical	**146**	75	2	**68**	70	1	**80**	85	1
Water	**146**	75	2	**68**	70	1	**80**	85	1
Environmental	**-**	-	-	**-**	-	-	**-**	-	-
Construction	**87**	90	1	**36**	40	1	**43**	45	1
Transportation	**63**	65	1	**26**	30	1	**31**	35	1
	Ut. r.	97%	Σ 8	Ut. r.	93%	Σ 5	Ut. r.	92%	Σ 6
Scenario 3: Scenario 2 + Transportation offers courses only in winter terms as electives + Percentage of students with GPA above 3.0 increases to 40%									
	Term six (fall)			Term seven (winter)			Term eight (fall)		
	Seats	Cap	Courses	**Seats**	Cap	Courses	**Seats**	Cap	Courses
Structural	**191**	95	2	**92**	95	1	**118**	60	2
Geotechnical	**163**	85	2	**70**	75	1	**88**	95	1
Water	**163**	85	2	**68**	75	1	**88**	95	1
Environmental	**-**	-	-	**-**	-	-	**-**	-	-
Construction	**98**	100	1	**37**	40	1	**47**	50	1
Transportation	**-**	-	-	**13**	15	1	**-**	-	-
	Ut. r.	98%	Σ 7	Ut. r.	92%	Σ 5	Ut. r.	93%	Σ 5

The results described in this paper were presented to various stakeholders (i.e., those at the highest level of the faculty at the University of Alberta). The findings were highly appreciated, and a note was made that such simulations should be used across all engineering programs. The added value that our modeling approach brings to the table is to serve two customers, namely the curriculum planners and the students. The curriculum planner team emphasized that using this model will considerably reduce curriculum preparation time for future semesters and significantly improve the existing planning methodology. Moreover, students gain the freedom of choosing their specialty and elective courses with minimal limitations. Students are often promised by their departments a variety of course choices that quickly become invalid due to numerous course overlapping.

CONCLUSIONS

In this paper, we presented a Monte Carlo simulation model in an attempt to introduce Lean thinking to the higher educational institution. To our knowledge, there have not been any undertakings in merging the Monte Carlo simulation, curriculum planning, and Lean principles. We suppose that the current approach to the curriculum planning practices can be significantly improved using Lean philosophy by developing a tool to examine continuous improvement efforts in less time as well as incorporating the end users' (i.e., students) preferences into the planning process.

The authors want to emphasize that the main contribution to the body of Lean knowledge is not in the results of the model but in the approach to curriculum planning. The findings of this study suggest that a minimal amount of data or even knowledge of experienced curriculum planners in combination with the showcased Monte Carlo model can reduce the time in organizing course offerings and increase the quality and accuracy of a curriculum plan. The introduction of what-if scenarios further demonstrated the flexibility of the model and its capabilities to provide meaningful results outside of its original settings. Curriculum administration practitioners can use this modeling approach for a variety of department specializations.

From our perspective, educational institutions are yet at the entry point to Lean thinking and Lean practices. The current or similar Lean modeling approaches to curriculum planning can be used by any educational institution regardless of geographical location, department structure, or accreditation level.

It is important to note that while the Monte Carlo curriculum simulation model is very powerful, it may render itself useless without accurate inputs. In the current study, the authors used data created by experienced curriculum planners, and it is theoretical in nature. At this stage, the curriculum of the University of Alberta is being reorganized, and real-world data does not exist yet. In the future, more work is required to test real datasets and improve the model's assumptions, distributions, and constraints. For future work, the authors consider (1) adding Lean, collaborative courses with much smaller seat caps that will add another layer of complexity to the existing model; (2) limiting the number of project-intensive courses that prevent the curriculum from being lean by adding extra inter-course constraints.

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