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The Graduation On-Time Analysis and Lessons (GOAL) Project: Using Undergraduate Transcript Data to Identify Causes of Graduation Delays in Industrial and Systems Engineering

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The Graduation On-Time Analysis and Lessons (GOAL) Project: Using Undergraduate Transcript Data to Identify Causes of Graduation Delays in ISE

abstract

Four-year graduation remains a significant challenge in U.S. undergraduate engineering programs, with programs and universities alike facing pressure to reduce time to graduation. According to the most recently available data from 2015, reported by the American Society for Engineering Education, only about one-third of engineering students nationwide completed their degrees within four years. Delayed graduation results in higher financial and opportunity costs for students and institutions. Each additional year in college can cost $40,000-$60,000 in tuition, fees, and living expenses, based on institutional cost-of-attendance benchmarks. It can also add about $75,000 in lost wages, according to reported average starting salaries for new Industrial and Systems Engineering (ISE) graduates. The Graduation On-Time Analysis and Lessons (GOAL) project was developed to investigate the causes of delayed graduation in an undergraduate Industrial and Systems Engineering program at Virginia Tech. Using transcript and grade history data of students who entered between 2015 and 2019, the study applied context-specific analytics to identify key factors contributing to delayed graduation. The most common graduation delay causes were failing to pass prerequisite mathematics courses on time and taking co-op or gap semesters, without remedying the delays through summer coursework. Based on these findings, the department adopted a policy to identify students behind in graduation progress and support them through academic advising, encouraging them to take summer coursework to graduate on time. More broadly, the GOAL project provides a transferable framework that leverages transcript data and the structure of course prerequisites and availability to identify bottlenecks and support on-time graduation across engineering programs.

keywords: four-year graduation, graduation delay, transcript data, transcript analytics, higher education, engineering education.

introduction

Four-year graduation remains a significant challenge in U.S. engineering education, with engineering programs and universities alike facing pressure to reduce time to graduation [1]. According to the American Society for Engineering Education (ASEE), only about one-third of engineering students nationwide completed their degrees within four years as of 2015 [2]. As of 2025, delayed graduation can incur substantial financial penalties, an additional $40,000–$60,000 in extra tuition, fees, and living expenses, plus approximately $75,000 in forgone full-time earnings due to delayed entry into the workforce [3], [4]. These figures are estimated based on the Virginia Tech's cost of attendance benchmarks and average starting salaries in engineering [5].

Delayed graduation affects not only student outcomes, such as increased financial and opportunity costs, but also institutional efficiency and public investment, placing added pressure on college resources and taxpayer support [5]. Engineering curricula present particular challenges to on-time graduation due to their tightly chained prerequisites [6], demanding

coursework, and sometimes semester-restricted course availability. Within VT's Industrial and Systems Engineering (ISE) program, academic advisors, faculty, and administrators have observed recurring patterns among students who were graduating one or more years later than expected.

Therefore, the Graduation On-Time Analysis and Lessons (GOAL) project was initiated to systematically investigate the causes of delayed graduation in the ISE undergraduate program. Using transcript and grade history data for students entering between 2015 and 2019, the project applied context-specific logic and analytics to identify key contributing factors to graduation delay. This analysis informed actionable departmental interventions, including identification of students behind in graduation progress and provide advising for students to catch up via summer coursework.

Recent research highlights how institutional structures and student demographics shape graduation timelines in engineering. A 2024 study on first-year engineering persistence across Hispanic-Serving and Historically Black Institutions found that academic preparation, especially SAT scores, significantly influenced persistence, while financial need and first-generation status had less impact after controlling for other variables [7]. These findings suggest that demographic influences on graduation timing may vary across contexts, though structural academic readiness remains key. Additionally, rigid prerequisite sequences in math and core engineering continue to delay progress for many students, with a single instance of not passing leading to delays in subsequent courses [8]. These bottlenecks can be particularly harmful in programs with limited semester availability for required courses, where falling behind one term often means losing an entire academic year.

Participation in co-ops and internships can further extend time-to-degree despite their career benefits. While these experiences are increasingly recognized as essential for developing career-ready skills, they typically involve alternating academic and work terms, adding semesters to a student's path to graduation. This trade-off became even more apparent during the COVID-19 pandemic, which introduced logistical and instructional challenges that disrupted course delivery and further complicated academic planning in engineering programs [9]. Faculty, academic advisors, and university administrators have also noted that students often juggle internships alongside multiple summer courses, further complicating degree planning and progression.
The use of academic data to predict student risk has expanded significantly, yet much of the work still focuses on demographic data over detailed transcript data. Classification algorithms including logistic regression and decision trees have been utilized to predict student graduation outcomes [10]. Their results support the use of transcript-linked analytics to proactively identify students at risk of delayed graduation. More recent models such as the student graph representation utilize semester-by-semester academic records to flag students likely to fail core engineering courses, enabling timely intervention [11]. Despite this progress, few studies have directly incorporated detailed course enrollment data or prerequisite sequences, leaving a gap in predictive accuracy for structurally complex majors like engineering.

Several institutions are now integrating predictive analytics into academic advising to inform proactive support for engineering students. One study demonstrated the benefits of using analytics-informed advising for undeclared first-year engineering students, showing improved

retention when data were used to guide early advising conversations [12]. Another study emphasized that effective implementation of these tools requires structured training and institutional support to avoid misuse or oversimplification of predictive outputs [13]. Additionally, targeted interventions such as summer and intersession coursework have been identified as viable strategies to keep students on track to graduation, especially when traditional scheduling pathways are disrupted.

This paper outlines the design and implementation of the GOAL initiative, which uses context-based logic and analytics to identify causes of graduation delays among undergraduate ISE students at Virginia Tech. The analysis integrated data from student demographics, admissions records, grade distributions, and transcripts. Combined with the analysis of the ISE checksheets (also called plans of study) for the corresponding student cohorts, a rule-based framework was developed to systematically identify and classify delay causes for each student who graduated late. The results showed that the most common graduation delay cause was failure to pass core MATH courses, followed by gap or co-op semesters, failure to pass on-time critical ISE core courses, and participation in the Reserve Officers' Training Corps (ROTC).

methodology and analysis

The methodology for this study integrates data preparation, context-based analytical procedures, and interpretation in a continuous process. Rather than separating these elements, the analysis is embedded directly within each methodological step to provide a clear connection between data sources, processing logic, and the resulting insights. This structure ensures that each stage of the workflow, from defining cohorts to attributing causes of graduation delay, can be understood in both its procedural and analytical context.

The overall approach combines fusing institutional data, analyzing and applying curriculum requirements, and processing transcript data to identify possible causes leading to on-time graduation delay. Core steps include defining and grouping student cohorts, summarizing grade distribution, analyzing timely completion deadlines for core courses, extracting and cleaning transcript data, and, and applying structured logic to identify and attribute graduation delay causes. This sequential but iterative methodology is designed to remain consistent across multiple cohorts necessitated by curriculum changes. The list of courses relevant to this study is listed in Table 1.

Table 1. List of courses

Course	Name		Course	Name
ISE 2004	Introduction to ISE		ISE 4005	Project Management and Systems Design I
ISE 2014	Engineering Economy		ISE 4006	Project Management and Systems Design II
ISE 2024	Probability Foundations for ISEs		ISE 4204	Production Planning and Inventory Control
ISE 2034	Data Management for ISEs		ISE 4214	Lean Manufacturing
ISE 2204	Manufacturing Processes		ISE 4404	Statistical Quality Control

Course	Name		Course	Name
ISE 2214	Manufacturing Processes Lab		MATH 1225	Calculus of a Single Variable I
ISE 2404	Deterministic Operations Research I		MATH 1226	Calculus of a Single Variable II
ISE 3034	Technical Communication for Engineers		MATH 2114	Introduction to Linear Algebra
ISE 3214	Facilities Planning and Logistics		MATH 2204	Introduction to Multivariable Calculus
ISE 3414	Probabilistic Operations Research		MATH 2214	Introduction to Differential Equations
ISE 3424	Discrete-Event Computer Simulation		ESM 2104	Statics
ISE 3434	Deterministic Operations Research II		STAT 4105	Theoretical Statistics
ISE 3614	Human Factors Engineering and Ergonomics		STAT 4706	Probability and Statistics for Engineers
ISE 3624	Industrial Ergonomics		CHEM 1035	General Chemistry

student cohort and graduation grouping

The dataset for the Fall 2015 through Fall 2019 ISE undergraduate cohorts was constructed by joining major declaration records, demographic information, and graduation status data. A total of 909 students across the five cohorts were included. Students whose first semester at Virginia Tech was a Spring semester were excluded due to small sample size; in practice, most Spring-entry students align to a Fall-based schedule by shifting one semester forward, often through the use of summer courses, or backward.

Student grouping was based on administrative considerations and organized by both cohort year and graduation outcome: on-time (within four years) or late (more than four years). Grouping by cohort accounts for curriculum changes over time, as each entering class may follow a different checksheet (plan of study). Non-transfer students typically begin in General Engineering, then declare ranked choices of engineering majors. The following categories were defined for analysis:

- *I0 (on-time)*: admitted into ISE as the first major and graduated in four years.
- *I1 (late)*: admitted into ISE as the first major and graduated in more than four years.
- *I2 (left)*: admitted into ISE as the first major but subsequently left the ISE major, the College of Engineering (COE), or Virginia Tech entirely.
- *S (switch)*: admitted into another engineering major before switching into ISE, excluded from the analysis.
- *T (transfer)*: admitted into ISE from outside the COE or from another institution, excluded from the analysis.
- *A (study abroad)*: a few students who study abroad at the Virginia Tech ISE program for one or two semesters, excluded from the analysis.

Students who were admitted into ISE from another engineering major (S-Switch) showed a high degree of variation in the timing of the major changes and the courses they had completed, and were therefore excluded from the analysis. Similarly, students who transferred from another college outside the College of Engineering, or from institutions outside Virginia Tech (T-Transfer), were excluded for similar reasons. Students who attended Virginia Tech for only one or two semesters as part of study abroad programs were also excluded, due to lack of data of their subsequent semesters.

The administrative *four-year graduation metric* is calculated as *I0 / (I0 + I1 + I2)*. The Department of ISE offers a single undergraduate major, in contrast to some other engineering departments that house multiple majors. A notable minority of ISE students, approximately 5-10%, also participate in the Reserve Officers' Training Corps (ROTC) program. Although ROTC students commonly graduate in five years due to training commitments, they are administratively included in the four-year graduation metric.

semester coding, checksheet analysis, timely completion deadline, and on-time critical courses

Because the study cohorts span Fall 2015 through Fall 2019, a *semester coding* scheme was developed to align timelines across cohorts. For example, a student entering in Fall 2015 would have their first semester (1st Fall, Fall 2015) coded as 0.5, their second semester (1st Spring, Spring 2016) coded as 1.0, and so on, up to their eighth semester (4th Spring, Spring 2019) coded as 4.0, which is the expected graduation term. Following this semester coding scheme, the 1st Summer term is coded 0.25 and the 1st Winter term is coded 0.75.

The five ISE checksheets spanning 2015-2019 to 2019-2023 were analyzed and compared, focusing on prerequisite structures and semester-specific course offerings. Most ISE core courses at Virginia Tech are scheduled exclusively in either the Fall or the Spring semester, with relatively few offered in both terms. This limited availability restricts students' flexibility and increases the impact of course failures or scheduling disruptions.

For each required core (non-elective) course, its *timely completion deadline* (TCD) value was determined based on the recommended semester of enrollment. If a student did not successfully complete the course by its TCD and did not *remedy* the delay through winter or summer coursework, or by transferring credit from outside Virginia Tech (after taking the credits outside), graduation within four years would no longer be possible. Courses typically taken at their TCDs are designated as *on-time critical courses* (OTCCs), since their timely completion is essential for maintaining graduation progress. Several structural changes to the checksheets across the five-year span were identified through this analysis and are summarized in Table 2.

Table 2. Checksheet Comparison

Checksheet	**Comparison**	
	# credits required	***Major changes compared to previous checksheet***
2015-2019	133	None, baseline.
2016-2020	127	Removed ISE 2204 (3 creds), ISE 3434 (3 creds), these two classes became electives.

Checksheet	Comparison	
	# credits required	***Major changes compared to previous checksheet***
2017-2021	124	Removed ISE 4214 (3 creds), this class became elective. ISE 3214 is moved from 3rd Spring to 3rd Fall. ISE 3624 and ISE 4204 are moved from 4th Fall to 3rd Spring. ISE 4404 is moved from 3rd Spring to 4th Fall.
2018-2022	124	STAT 4105 is changed to ISE 2024, ISE 3034 is introduced to replace a Pathway (General Education) requirement.
2019-2023	124	No major change. Credit count for ISE 2004 and ISE 4005 reduced by 1 each.

The analysis of Virginia Tech ISE undergraduate checksheet revealed that the prerequisite structure is highly restrictive. The 2019-2023 BSISE (Bachelor of Science in Industrial and Systems Engineering) checksheet requires 124 credits for graduation and includes 32 core courses. Among these, 17 courses consist of 5 MATH courses, 1 STAT course, and 11 ISE courses are designated as OTCCs. Failing to complete a MATH course on time would lead to certain graduation delay, but students may remedy this through coursework taken outside Virginia Tech or through winter or summer coursework.

Most ISE OTCCs are offered only in either the Fall or Spring semester, not both. As a result, failing to pass an ISE OTCC on time typically results in a graduation delay unless the student completes the course during a winter or summer term. Furthermore, the 2019-2023 ISE checksheet required most OTCCs to be passed with a grade of C- or higher. As of 2025, this requirement has been revised to apply only to MATH and STAT courses. To help mitigate graduation delays, the ISE department offers most ISE core courses during the summer semester to allow students to catch up and remain on track for on-time graduation.

Table 3 presents an example subset of ISE core courses, including each course's classification as an on-time critical course (OTCC), its timely completion deadline (TCD, expressed in semester codes), the mode (DFW or FW), and the observed minimum, average, and maximum DFW% or FW% rates. Courses with a TCD value of "2.5/3" indicate that the deadline differs depending on the applicable checksheet. The OTCC and TCD values were computed from the previous stage of the analysis.

Table 3. Summary of select courses

Core Course	OTCC	TCD	DFW or FW	DFW%/FW% from 2010-2011 to 2023-2024		
				Min	Avg	Max
MATH 1225	Y	0.5	DFW	15.1%	21.7%	33.4%
MATH 1226	Y	1	FW	10.6%	20.3%	28.3%
MATH 2114	Y	1.5	DFW	8.2%	12.0%	17.9%
MATH 2204	Y	1.5	DFW	7.8%	15.7%	20.3%
MATH 2214	Y	2	DFW	7.5%	12.7%	15.7%

Core Course	OTCC	TCD	DFW or FW	DFW%/FW% from 2010-2011 to 2023-2024		
				Min	Avg	Max
STAT 4105	Y	2	DFW	2.0%	10.7%	28.6%
STAT 4706	Y	2.5	DFW	0.0%	1.6%	3.6%
ISE 2014		2	DFW	1.0%	6.5%	17.6%
ISE 2024	Y	2	DFW	1.1%	3.9%	5.4%
ISE 2404	Y	2	DFW	0.5%	3.7%	8.1%
ISE 3214	Y	2.5/3	DFW	0.0%	1.0%	5.9%
ISE 3414	Y	2.5	DFW	0.0%	4.8%	13.0%
ISE 4005	Y	3.5	DFW	0.0%	0.1%	0.5%
ISE 4006	Y	4	DFW	0.0%	0.1%	0.8%
ESM 2104		2.5/3	FW	6.1%	19.1%	33.4%
OTCC = on-time critical courses; TCD = timely completion deadline. TCD = 2.5/3 means 2.5 or 3 depending on checksheet.						

The required core courses from each ISE checksheet were identified, and historical grade distribution data from the 2010-2011 through 2023-2024 academic years were analyzed. For each course, the proportion of grades D+, D, D-, F, and W (referred to as the DFW% rate and FW% rate) was calculated as a percentage of total enrollments. These results were aggregated by academic year and course, and summary statistics (minimum, average, and maximum DFW% or FW% rates) were computed for the analysis period.

The checksheet and aggregate analysis reveals a clear pattern: MATH courses classified as on-time critical consistently exhibit disproportionately higher DFW% or FW% rates compared to ISE on-time critical courses and other non-ISE courses that are not time-sensitive. For example, MATH 1225 (Calculus of a Single Variable I) had an average DFW% rate of 21.7%, with peaks above 30% in certain years. High DFW% and FW% rates in these courses increase the likelihood of students falling off their graduation path, because these courses are OTCCs and serve as prerequisites for multiple subsequent courses. On the other hand, most other ISE OTCCs such as ISE 2024, ISE 2404, and ISE 3414 maintained average DFW% rates below 5%.

These findings provided the foundation for the analysis of graduation delay causes, in which transcript data were examined to determine the earliest semester in which students encounter graduation delay causes.

<u>transcript data processing and semester code alignment</u>

Student transcript data were processed to align each course record with the timely completion deadlines (TCD) established from the checksheet analysis. For each core course appearing in a student's transcript, if the student earned a passing grade (with respect to the C- requirement or not), the semester code (as defined in the semester coding scheme above) was recorded relative to the student's assigned cohort. If the course had not yet been taken or had not been passed, it was marked as NF (not found). For example, a Fall 2015 student completing a course in Fall 2015 would have a semester code of 0.5, in Spring 2016 a code of 1.0, and in Spring 2019 a code

of 4.0, the expected graduation term. This coding enabled direct comparison between when a requirement was fulfilled and the course's TCD value across different cohorts.

A small number of missing course records (e.g., MATH 1XXX or MATH 2XXX placeholders) were detected and resolved using information from subsequent enrollments. For example, successful completion of MATH 1226 implied that MATH 1225 had already been completed, even if the specific record was missing. Course substitutions were also incorporated using a predefined lookup table; for instance, MATH 2114H (honors) counts for MATH 2114, and the previously offered MATH 1114 also counts for MATH 2114.

The processed data were then summarized in a pivot-style table, with each row representing a single student. The table contained demographic and administrative information, and *First Semester Passing* columns indicating the semester codes in which each required core course was successfully completed relative to the student's cohort. A not-passed cored course receives a value of NF (not found). A snippet of this summary, displaying a limited set of columns, is presented in Table 4.

Table 4. Snippet of transcript summary

Student	**Cohort**	**Group**	**First Semester Passing**			
			MATH 2114	**ISE 2024**	**ISE 3414**	**ISE 4006**
S_0005	201509	I0	1.5	2.0	2.5	4.0
S_0008	201509	I1-Late	1.5	2.25	3.5	5.0
S_0150	201509	S	0.5	2.0	2.5	4.0
S_0161	201509	T	0.5	1.25	1.5	3.0
S_0204	201609	I0	1.5	2.25	2.5	4.0
S_0205	201609	I0	1.0	2.0	2.5	4.0
S_0227	201609	Late	1.5	3.0	4.25	5.0
S_0434	201709	I2-Out	1.5	2.0	NF	NF
S_0598	201809	I0	1.5	2.0	2.5	4.0
S_0600	201809	I2-Out	1.0	NF	NF	NF
S_0782	201909	I0	1.5	2.0	2.5	4.0
I0 (on-time, ISE as first major), I1 (late, ISE as first major), I2 (out, ISE as first major) S (switch to ISE from another major), T (transfer from outside engineering or Virginia Tech) 0.25 corresponds to 1st Summer, 0.5 to 1st Fall, 0.75 to 1st Winter, 1.0 to 1st Spring						

Only a limited number of columns are shown here for clarity. The full processed dataset contains all required core courses and additional administrative columns, and is maintained in a master Excel file for further analysis. This complete dataset serves as the foundation for the subsequent analysis of graduation delay causes. For example, in the case of student S_0227 shown above, ISE 2024 (with TCD = 2.0) was taken in semester 3.0 > 2.0, thus the course is passed late.

analysis of graduation delay causes

To further understand the causes of graduation delay, all students who graduated late were analyzed case-by-case. There were a total of 179 students (I1-Late) from the 2015-2019 cohorts who graduated late. The transcript data and class-taking schedule of the students were drilled-down and analyzed, and the different graduation delay causes were inferred from the transcript. In this analysis, for each student who graduated late (I1-Late), their graduation delay cause was defined as the first instance where:

- A core course was not passed on or before the timely completion deadline (TCD).
- And no sufficient *remedy* was done by the student. There are two common mechanisms for students to catch up: (1) taking the course outside Virginia Tech and transferring the credits in later, and (2) taking the course in the winter/summer terms.

The detection was facilitated by the results of the transcript data processing and semester code alignment. Each student's transcript is then drilled-down and further analyzed, and the different graduation delay causes are inferred from the class-taking schedule. There are cases where a student has two or more courses not taken on-time, but the first case was resolved through summer/winter classes. In this case, only the second graduation delay instance was counted. In the case where multiple causes (such as multiple courses were not passed) in the same semester, each delay cause is assigned an equally split delay score (e.g. two missed courses => each counted as 0.5). The structured logic was then verified and validated to ensure robustness, then reapplied consistently to all students who graduated late.

The drill-down analysis identified the following graduation delay cause category:

MATH – Not passing MATH courses: all of the MATH courses in the ISE checksheet are on-time critical courses (OTCCs). Not passing and then not remedying just a single MATH course will lead to certain graduation delay.

ISE – Not passing ISE on-time critical courses: many ISE core courses are on-time critical, and not passing and then not remedying one such course will also lead to certain graduation delay.

GAP – Gap/co-op semesters: from the transcript data, a student may have a Fall or Spring semester with no or very low number of credits taken (between 0 and 6). This is assumed to be either a gap semester or co-op semester. It is noted that students do not consistently register for co-op credits on their academic records, thus it is difficult to conclude whether it is gap or co-op.

CADET – Participation in the ROTC program: ISE students in the ROTC program typically follow a five-year graduation checksheet due to the additional ROTC training requirements. Administratively, students do have the Cadet tag in the database, but it was noted to be unreliable by the COE enrollment management team. Therefore, ROTC membership-required courses on the transcript data were used as signals for Cadet students.

OTHER – Other cases: other less common cases included double majoring, finishing a minor, starting outside COE, and spending a semester or two studying abroad.

To systematically attribute graduation delays, the following procedure was applied to all students classified as I1-Late. First, students whose transcripts indicated enrollment in one or more ROTC membership-required courses were classified under the CADET category, with the category count incremented by one. This designation reflects the typical five-year graduation pathway required by ROTC training commitments.

For the remaining late graduates, the earliest semester in which any core course's First Semester Passing (FSP, from Transcript Summary) exceeded its Timely Completion Deadline (TCD, from Summary of Core Courses) was identified. This condition indicates that the course was completed later than allowed, creating a graduation delay. Once this earliest delayed semester was identified, the preceding Fall or Spring semester was examined for evidence of a gap or co-op semester.

If a preceding gap or co-op semester was found, its potential impact was evaluated by checking for remedy such as successful transfer of equivalent course credits from another institution or coursework during winter or summer terms. In cases where the remedy fully addressed the delay, no delay cause was recorded for that semester. If the remedy was insufficient or not available, the delay was classified under GAP and the delay category GAP is incremented by one.

If a gap or co-op semester was not the case, the delayed semester was attributed to the specific core course or courses that were not completed on time. In cases where multiple on-time critical courses were delayed within the same semester, the delay score was divided equally among the affected courses. For example, two delayed courses in the same term would each receive a score of 0.5. This scoring ensured proportional attribution of graduation delay causes and preventing overcounting.

If the delay identified was fully remedied, the analysis proceeded to the next semester in which at least one core course's FSP exceeded its TCD. By definition, if a student graduated late, there was at least one occurrence where FSP exceeded TCD and a full remedy did not occur. This step was repeated until the first semester with an unremedied delay was found, and the graduation delay cause was attributed according to the procedure described above.

The process can be expressed in logical form; however, certain exceptions required professional judgment and, in some cases, consultation with the ISE academic advising team. Limited and rare cases were classified under OTHER, with a note specifying the most likely reasons of graduation delay. After an initial pass through the data, the procedure was refined and standardized, then reapplied to each cohort individually. This cohort-by-cohort approach was necessary to ensure consistency because each cohort has a slightly different ISE checksheet.

The results of the graduation delay attribution process were compiled for all late graduates (I1-Late) in the 2015–2019 cohorts. Each record identifies the student, cohort, attributed delay cause(s), the semester code of the earliest unremedied delay, and a brief description of the delay context. A snippet of the analysis output is shown in Table 5, with the full dataset stored in the project's master Excel file.

Table 5. Snippet of graduation delay cause analysis

Student	Cohort	Cause(s)	1st Delay Semester	Details
S_0008	201509	GAP	2.0	Gap semester 2.0 not sufficiently remedied
S_0019	201509	MATH 2204	1.5	Not passed by TCD, += 1
S_0021	201509	CADET	CADET	ROTC membership-required courses
S_0067	201509	MATH 1226	1.0	Not passed by TCD, += 1
S_0074	201509	ISE 2024 ISE 2404 MATH 2214	2.0	Not passed by TCD, += 0.3333 each
S_0092	201509	MATH 2114 MATH 2204	1.5	Not passed by TCD, += 0.5 each
S_0163	201509	OTHER	4.0	Double major ISE + ME: needs 2 more semesters
S_0264	201609	OTHER	4.0	BUSR minor: needs 1 more semester
TCD: Timely Completion Deadline 0.25 corresponds to 1st Summer, 0.5 to 1st Fall, 0.75 to 1st Winter, 1.0 to 1st Spring				

The snippet illustrates the diversity of graduation delay scenarios, including single-course, multi-course, gap semesters, ROTC-related timelines, and other categories such as double majors or minors. It is also noted that downstream ISE courses have substantially lower DFW% and FW% rates compared to upstream MATH courses, therefore, MATH courses are unlikely to be over-attributed to graduation delay in this analysis.

<u>limited analysis of non-retention cases</u>

A limited analysis was conducted on 60 cases of ISE students (of the same five cohorts) who left the ISE major, the College of Engineering (COE), or Virginia Tech entirely (coded as I2-Out). Determining the causes of non-retention is challenging, particularly for students who left the university, as no subsequent transcript data are available. Attribution was also difficult for students who transferred to other engineering or non-engineering programs within Virginia Tech, where individual motivations may be varied and undocumented.

Informal and inconclusive interviews with students and academic advisors suggested several possible reasons for leaving the ISE major:

- Transferring to a more preferred engineering discipline, such as Computer Science, which generally offers higher salary prospects. These cases are often associated with minimal (zero or one) ISE course enrollment.
- Switching to a non-engineering major due to academic difficulties, either in terms of graduation progress or GPA performance.
- Transferring to a different institution for financial, family, or personal reasons.

The sample size for this analysis was small, ranging from 6 to 16 students per cohort. For these cases, available data were used to record and summarize destination programs within the university or, where applicable, departure from Virginia Tech altogether. The findings are inconclusive, and further research is needed to better understand the underlying factors driving non-retention.

results and discussion

cohort composition and grade distribution trends

For this analysis, students were categorized into six groups discussed in subsection 0.0., based on admission pathway and graduation outcome. The I0 group includes students who entered ISE as their first major and graduated within four years, while the I1 group represents those who graduated in more than four years. The I2 group includes students who left the ISE major, the College of Engineering, or Virginia Tech altogether. The remaining groups represent cases excluded from detailed analysis: S for students who switched into ISE from another engineering major, T for transfers from outside the College of Engineering or another institution, and A for students in short-term study abroad programs with ISE. The composition of ISE undergraduate student cohorts from Fall 2015 (201509) through Fall 2019 (201909), with six groupings, is shown in Figure 1.

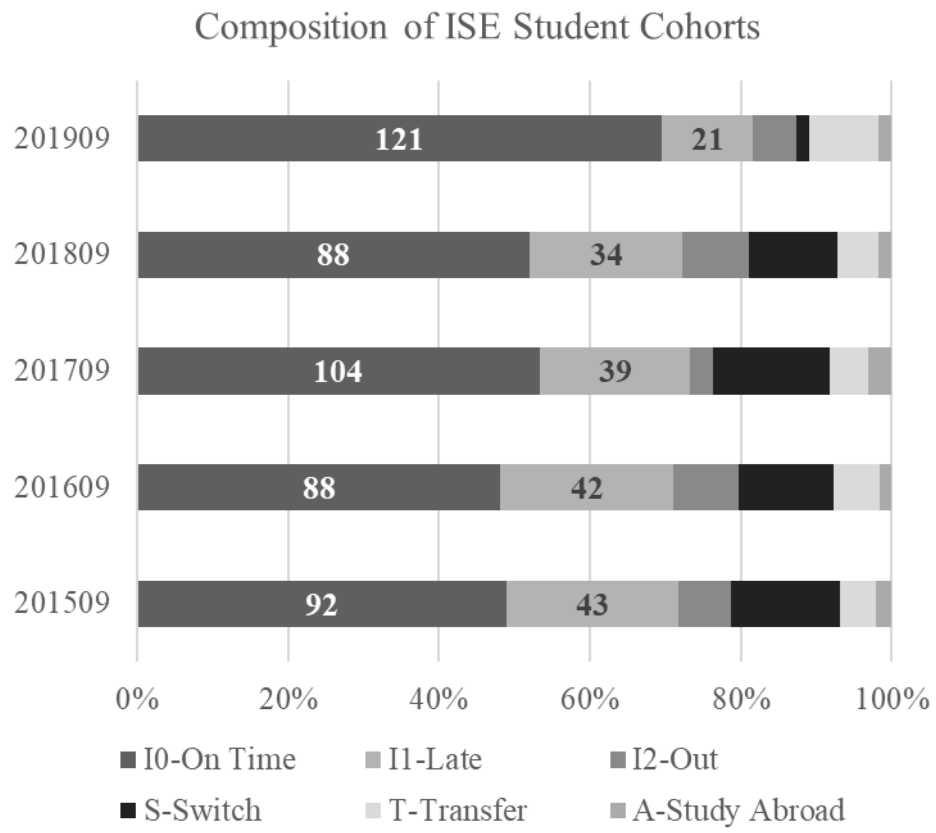

Figure 1. Composition of five ISE Student Cohorts from 2015-2019

Departmental undergraduate four-year graduation metric is calculated from the formula I0 / (I1 + I2 + I3), and ranged from 60.27% to 79.61%. It is noted that the 201909 cohort has a substantially higher four-year graduation rate of 79.61%, higher than the previous 60.27%-69.8% rates of the previous cohorts.

Figure 2 presents the annual DFW%/FW% rates for the these five core MATH courses from the 2014-2015 academic year through 2023-2024 academic year.

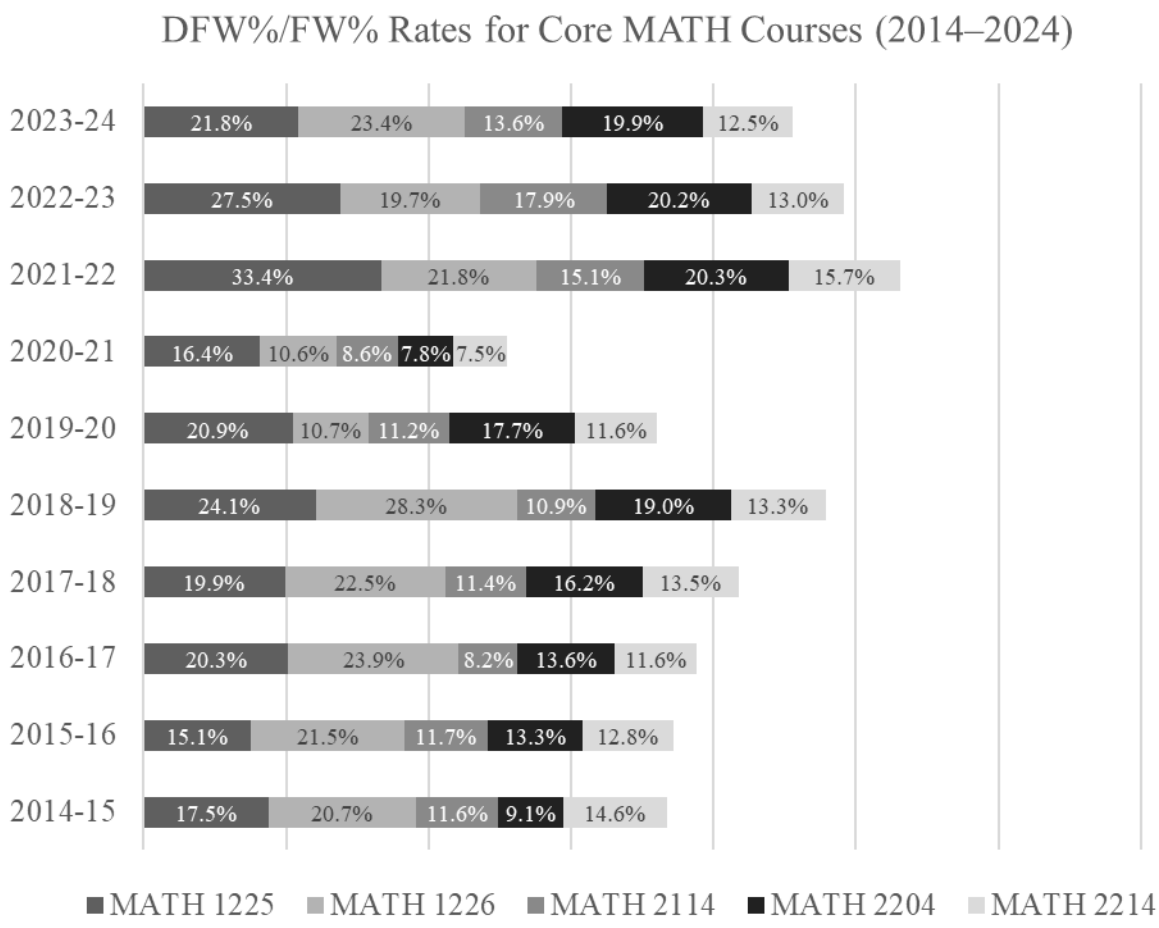

Figure 2. Annual DFW% Rates for Core MATH Courses in the ISE Curriculum (2014-2015 to 2023-2024, note that MATH 1226 uses FW% rate, while other courses uses DFW% rates)

The DFW% and FW% rates for the five core MATH courses on the ISE checksheets were examined over a ten-year period from 2014-2015 to 2023-2024. Earlier years were excluded because the MATH courses except MATH 2214 were not offered before year 2014. These five courses, MATH 1225 (Calculus of a Single Variable I), MATH 1226 (Calculus of a Single Variable II), MATH 2114 (Introduction to Linear Algebra), MATH 2204 (Introduction to Multivariable Calculus), and MATH 2214 (Introduction to Differential Equations), are on-time critical courses (OTCCs) for the ISE checksheet. Not passing any one of these courses on schedule, without sufficient remedy, results in a certain graduation delay.

The 2019-2020 and 2020-2021 academic years show substantially lower DFW% and FW% rates for these MATH courses compared to both preceding and subsequent years. The 201909 cohort primarily completed MATH 1225 and MATH 1226in 2019-2020, followed by MATH 2114, MATH 2204, and MATH 2214 in 2020-2021. This pronounced drop in failure and withdrawal rates largely explains the substantially higher four-year graduation rate of 79.61% for this cohort. A likely contributing factor was the reduction in co-op opportunities during COVID-19.

In addition to the MATH core courses, CHEM 1035 (General Chemistry) and ESM 2104 (Statics) also have comparatively high DFW% and FW% rates. From 2010 to 2024, CHEM 1035 recorded an average FW% rate of 15.6%, with annual values ranging from 9.8% to 22.2%. ESM 2104 had an even higher average FW% rate of 19.1% over the same period, with a range of 6.1% to 33.4%. However, because neither CHEM 1035 nor ESM 2104 is an OTCC, failing one of them does not necessarily delay graduation.

In contrast, core ISE courses generally have substantially lower DFW% rates, particularly after 2015. The highest historical DFW% rate among ISE core courses is found in ISE 3414 (Stochastic Operations Research), a course with significant Markov Chain content. The next highest is ISE 2014 (Engineering Economy), which, despite its higher DFW% rate, is not an OTCC. The trends in average DFW% rates for all ISE core courses over three time periods (2010-2015, 2015-2020, and 2020-2024) are summarized. Table 6 presents the average DFW% rates for all ISE core courses, grouped into three periods (2010-2015, 2015-2020, and 2020-2024), allowing comparison of trends.

Table 6. Trends of average DFW% rates of ISE core courses

ISE	2010-2015	2016-2020	2021-2024	ISE	2010-2015	2016-2020	2021-2024
2004	0.6%	0.4%	1.3%	**3424**	0.8%	0.3%	0.3%
2014	13.5%	14.2%	4.1%	**3434**	10.3%	0.8%	6.8%
2024	N/A	N/A	5.0%	**3614**	1.9%	0.3%	2.1%
2034	3.5%	2.2%	2.5%	**3624**	2.3%	1.6%	5.8%
2204	6.6%	3.0%	2.9%	**4005**	0.2%	0.2%	0.2%
2214	0.9%	0.4%	1.1%	**4006**	1.7%	0.0%	0.0%
2404	8.2%	5.6%	5.1%	**4204**	6.0%	0.5%	2.2%
3034	N/A	N/A	1.0%	**4214**	4.6%	0.7%	7.1%
3214	2.7%	1.4%	3.3%	**4404**	13.4%	0.1%	4.9%
3414	17.8%	6.8%	3.2%	**All**	5.6%	2.3%	3.1%
ISE 2024 and ISE 3034 were not offered before 2020.							

summary of the graduation delay cause analysis

This summary aggregates the average number of students in each cohort (2015–2019) whose graduation delay causes were classified into specific categories: CADET, GAP, MATH, ISE, and OTHER. Figure 3 presents a heatmap visualization of these graduation delay causes by category, highlighting both the magnitude and distribution across cohorts.

	201509	201609	201709	201809	201909	
CADET	3	2	3	5	5	10.06%
GAP	14	10	13	2	9.5	27.09%
MATH	15.33	14.33	20	22.5	5	43.11%
ISE	7.67	6.17	0	2	1	9.40%
OTHER	3	9.5	3	2.5	0.5	10.34%
TOTAL	43	42	39	34	21	

Figure 3. Heatmap of Graduation Delay Causes by Category (2015–2019 Cohorts)

The heatmap reveals that MATH courses stand out as the primary contributor to graduation delays, with the highest average impact (43.11% of students) across the five cohorts. Gap semesters are the second most prevalent cause, affecting approximately 26.85% of students on average. In contrast, factors such participation in the CADET program, not passing ISE courses, or other causes appear less frequently, each averaging about 10% of cases. These findings emphasize the outsized role of foundational math course performance in determining timely graduation outcomes.

	201509	201609	201709	201809	201909	
CADET	3	2	3	5	5	
GAP	14	10	13	2	9.5	
MATH 1225	2	3	3	6.5	1	20.09%
MATH 1226	3	1	5	4		16.85%
MATH 2114	2	0.5	3	3.5	2	14.25%
MATH 2204	8	8.5	7	8.5	2	44.06%
MATH 2214	0.33	1.33	2			4.75%
MATH Subtotal	15.33	14.33	20	22.5	5	
STAT 4105	0.33	1.33				
ISE 2404	4.33	1.33				
ISE 3414	1.5			1		
ISE 3424		3				
ISE 3614	1.5					
ISE 4005		0.5				
ISE 4404				1	1	
ISE Subtotal	7.67	6.17	0	2	1	
OTHER	3	9.5	3	2.5	0.5	
TOTAL	43	42	39	34	21	

Figure 4. Heatmap of Graduation Delay Causes by Specific Course or Category (2015–2019 Cohorts)

Figure 4 displays a detailed heatmap of average affected student counts for each course within the 2015–2019 cohorts, capturing both the course-level and category-level contributions to graduation delays.

To better understand which specific courses contribute most to graduation delays, the analysis further disaggregated the MATH and ISE categories into individual courses. The course-level heatmap indicates that MATH 1225 (Calculus of a Single Variable) and MATH 2204 (Introduction to Multivariable Calculus) were particularly high-impact bottlenecks. Among ISE courses, ISE 2404 (Deterministic Operations Research) and ISE 3414 (Stochastic Operations Research) appear most often as delay factors, though their impact is much smaller than the MATH courses. The relatively low counts for most ISE courses highlight that ISE courses are less frequent causes of graduation delay compared to foundational STEM prerequisites.

interpretation and implications

MATH courses remained the most significant bottleneck to on-time graduation. Addressing this challenge calls for a combination of strategies, including advising and counseling, tutoring, along with mentoring support for study skills, workload management, time management, and stress management. Encouraging the use of existing academic resources such as office hours, tutoring, review sessions, and supplemental instruction can also improve outcomes. Additionally, small-scale efforts like timely check-ins from faculty or advisors can reinforce accountability and provide students with a sense of support as they navigate these demanding courses.

Students who delay graduation due to gap semesters often have limited awareness of how such decisions affect their academic progress, as well as the associated financial and opportunity costs. For example, taking a gap or co-op semester could be remedied by completing up to four online summer courses may cost between $7,000 and $17,000, depending on residency status. While this represents a considerable expense, it is significantly lower than the estimated $40,000 to $60,000 cost of an additional year of attendance, not to mention approximately $75,000 in lost wages due to delayed workforce entry. Informal interviews with students suggested a general lack of awareness of these financial trade-offs, or in some cases, a reluctance to consider them given the substantial costs involved. Strengthening advising and outreach for students considering co-ops, internships, or studying abroad, can help mitigate these delays. Advisors can play a proactive role in recommending summer enrollment, online course options, and strategic scheduling to ensure that critical requirements are not unnecessarily postponed.

For categories such as CADET participation, the department's ability to influence graduation timing is limited, as these delays stem from commitments outside standard academic progression. For other lower-impact categories, targeted case-by-case advising can address individual circumstances without requiring large-scale policy changes.

applicability and limitations

The findings from this study are specific to Virginia Tech ISE undergraduate program and may not be directly applicable to other programs and institutions, even those with similar curricula.

Even small differences in prerequisite structures, such as variations in corequisites or prerequisite sequencing for otherwise similar core courses, can significantly affect graduation timelines. Course scheduling patterns, such as whether key courses are offered exclusively in fall or spring semesters, as well as the number and variety of summer offerings, also influence applicability elsewhere. Additionally, the academic advisor-to-student ratio, along with the fact that advisors often have other teaching, administrative, or program duties, can impact the timeliness and availability of guidance students receive. These administrative differences mean that the patterns observed at Virginia Tech ISE program may manifest differently in other academic programs.

Furthermore, temporal and external conditions during the study period may limit the generalizability of the results. Data collected during the COVID-19 era reflects unique, non-repeating circumstances, including widespread online instruction and a sharp decline in co-op and internship opportunities during COVID. The post-COVID period has introduced new challenges, with incoming students often demonstrating weaker math preparation compared to earlier cohorts. In addition, the rapid adoption of AI tools such as ChatGPT may alter student study behaviors, resource usage, and even course performance in ways that differ from historical trends. These evolving factors suggest that certain findings from the pre- and mid-pandemic years may not hold in future academic contexts without adjustment for these emerging conditions. These evolving conditions underscore the need for ongoing monitoring and reevaluation of both student performance trends and the effectiveness of academic interventions.

ongoing and related departmental initiatives

Building on the insights from this study, the ISE Department has implemented several initiatives to directly support on-time graduation. An Excel-based ISE Graduation Planning Tool that generates automated, personalized semester-by-semester schedules for students was developed and disseminated to students. The tool incorporates automated planning considering prerequisite relationships, semester-specific course offerings, and credit load limits. The tool enables students to plan their coursework more effectively and avoid graduation delays. The tool is Excel-based for accessibility and includes a brief tutorial along with a discussion of financial implications to further encourage student use. The graduation planning tool is introduced each semester to all incoming ISE students in the ISE 2004 (Introduction to ISE) course.

Based on the tools and transcript analytics developed in this study, transcript data are used to identify students who were behind on key coursework every fall and spring semester. Transcript data are downloaded and processed using an adjusted transcript data processing and semester code alignment workflow, as described in the previous sections. Based on this analysis, students who are behind in graduation progress are identified, and a list of missing coursework is generated for each student. These results are shared with ISE academic advisors to support more targeted and proactive advising. By providing advisors with clear information on each student's outstanding coursework and risk factors for delayed graduation, the analysis enables more informed discussions, timely interventions, and personalized academic planning aimed at keeping students on track for on-time graduation. Together, these projects translate research findings into actionable tools and practices that address the most common causes of graduation delays.

conclusion and future work

The GOAL project shows how combining student transcript data with the structure of a program's curriculum can help identify and address the key reasons why some engineering students graduate late. Within the ISE program at Virginia Tech, foundational mathematics courses are the most persistent bottlenecks, followed by gap or co-op semesters. These findings support earlier research showing that STEM programs with long chains of prerequisites can make it harder for students to recover from early course failures. They also show that non-academic decisions, such as taking a semester off for a co-op, can lead to graduation delays if students do not plan ahead or make up missed coursework.

By translating these insights into targeted departmental interventions such as early identification of at-risk students, proactive advising, and promotion of summer enrollment to remedy graduation delays, the GOAL initiative demonstrates how data-informed advising can directly support on-time graduation. This framework is not limited to the ISE program at Virginia Tech. Any engineering department can adapt the approach by incorporating its own curriculum structure, course scheduling patterns, and historical grade data into a similar analytics process. This allows institutions to identify key bottlenecks and causes of graduation delays within their specific programs.

Building on the current findings, the next phase of the GOAL project will explore predictive analytical methods to identify students at-risk of not passing core MATH courses. Machine learning and statistical methods will be applied to transcript data and admission data (high school GPA, high school location, standardized test scores, etc.) to identify students who may be at risk of failing these courses. These models are intended to help advisors intervene earlier and more effectively, improving student support before graduation delays occur.

Further work will focus on analyzing how curriculum structure influences graduation outcomes. Simulations will be developed using a bootstrap approach grounded in historical transcript data, allowing the project to model how changes in prerequisites, course scheduling, or pass rates could affect graduation rates. In addition, the project will expand beyond graduation timelines to study career outcomes such as internships, co-op participation, and direct employment. This broader analysis will combine transcript data with survey responses to better understand how transcript data and academic performances connect to career readiness and long-term student success.

Taken together, these efforts show how transcript data can be used not only to explain graduation delays but also to support concrete actions that help students stay on track to graduate on time. By focusing on context-specific logic and transcript data, the GOAL project provides a practical and adaptable approach for improving on-time graduation in engineering programs.

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