Teaching Statistics for Engineering and Master's in Engineering Management Programs

Mazen Hussein
Tennessee Tech University

Abstract

Several engineering disciplines, such as industrial engineering (including systems engineering), are well-known for using statistics as a prerequisite for many advanced required and elective courses. However, engineers from all disciplines with different backgrounds can find statistics a useful tool to satisfy some job requirements and for career advancement. Statistics becomes more useful for the engineers who decide to join engineering graduate programs. The statistics "for engineers" courses are structured differently than most other introductory statistics courses but the level of statistics coverage and topics vary between disciplines and universities. The number of masters in engineering management programs, mainly virtual ones, has increased in the last few years. Math, statistics, and data analysis requirements can be used to distinguish these programs from other management related programs. This paper presents a comparison between engineering programs from different levels and rankings based on statistics coverage in the curriculum. The work in this paper is intended to be the first step of evaluating and improving teaching statistics for engineering students.

Keywords

Engineering statistics, statistics topics, master's in engineering management, statistics curriculum comparison, engineering programs ranking.

Introduction and Background

Robust analytical tools along with the ability to draw conclusions from the available data sets are some of the basic requirements needed in several today's engineering-oriented jobs to handle the huge flux of information and the fierce competition in the market. Statistics can provide the engineers with the analytical and decision-making skills that different industries may need.

Statistics is the science of data that helps in making decisions and drawing conclusions in the presence of uncertainty and variability. Statistics has a tool set that includes data collection and sampling, data organization and summarization, analysis, and interpretation of the data and calculation outputs. Engineering statistics is the science of using statistics to solve engineering problems which includes collecting and summarizing engineering problem data then draw applicable formal conclusions for engineering applications. The importance of statistics has grown in the last few decades due to the substantial increase of the available data and the emergence of new fields which are the cornerstone of today's economy and human prosperity such as data science and artificial intelligence.

Teaching statistics for engineering majors can focus on one or two of the statistics approaches, classic; based on frequency or data proportion, and Bayesian; based on Bayes' theorem.

Mathematical-theoretical statistics deals with the derivation and proof of statistical laws and theorems. While the other aspect of statistics, applied statistics, doesn't stress much on the derivation of statistical theorems but focuses on the application of those statistical theorems and laws to solve real-world problems. Applied statistics uses extensively descriptive statistics, techniques and methods to summarize and present data, techniques and methods to reach conclusions and make decisions about a population based on a sample or samples from populations, inferential statistics, and regression modeling. Most undergraduate engineering programs consider teaching applied statistics. For better preparation of engineering students, teaching statistics has to be evaluated and enhanced periodically to reflect the new developments in industry and the increased importance of data science. The inputs and outputs of teaching statistics for engineering students need to be evaluated from different perspectives using surveys, questionnaires, and analytical tools before moving to the next phase - improvement. The focus of this paper is on understanding the inputs based on the topics covered at different levels in 4-year undergraduate engineering programs.

This paper main concentration is on three popular college level engineering disciplines, mechanical, civil, and industrial, where statistics can be a core required course in the curriculum. Mechanical engineers need statistics to be able to use or to grasp better understanding of data modeling, quality control, reliability, multivariate models, experimental design, material properties and behavior, and statistical finite elements. Civil (including environmental) engineers need a good understanding of probability and statistics to deal with the available data and the variability that affects transportation planning, estimating the traffic demand, urban planning and development, structure designs, soil pressures, rainfall fluctuation, river flows, water level in aquifers and so on. Statistics is a main core course in most if not all industrial engineering curricula. Statistics is needed for advanced courses in industrial engineering that includes topics such as systems simulation and discrete-event simulation, mathematical modeling, stochastic models, forecasting, inventory models, scheduling, quality control, reliability, project management, time and motion, and ergonomics. This paper doesn't provide a comprehensive solution to improve teaching statistics for engineering students, but provides some of the necessary inputs for the next steps/phases of a study to improve teaching statistics for engineering students. For this purpose, the paper also presents a comprehensive and in-depth survey of the available related sources in the literature.

Statistics is important for scientific research and experimental work at both the undergraduate and graduate levels. The master's in engineering management programs are becoming more popular since these programs give the engineers knowledge and experience in management and business administration based on their engineering background. Most of the new master's in engineering management programs are online programs, and many of which include data analysis and decision making in their curriculum, which can't be effectively covered without a sufficient previous knowledge in statistics (descriptive and inferential) for all students.

Literature Review

Usually the engineering and engineering technology students take a statistics course as a prerequisite for other engineering courses but they rarely use the statistics knowledge they learned until they face a real-world problem after graduation. Statistics is important for analysis, measuring errors in the systems, risk assessment, and many other fields. For instance, statistical methods have been used by Japanese manufacturing industry since the 50s of the 20th century to improve quality as emphasized by quality control pioneers such as Deming and Juran. This improvement was tremendous in the last two decades[1]. Some statisticians believe that the goals of an introductory statistics course should be redirected from mathematical technique to data analysis. Statistical reasoning should take precedence over statistical methods according to some statisticians[2,3]. Hogg mentioned that, "At the beginning level, statistics should not be presented as a branch of mathematics. Good statistics is not equated with mathematical purity or rigor but is more closely associated with careful thinking" according to Hogg.

One solution to help students have better understanding on statistics is to integrate active-learning strategies that grants students to apprehend what they have heard and read about statistics[2,4]. Funny et al., 2019, designed instructional activity based on design research to improve the mathematics education toward the reflective thinking skills. Combining the innovative design and the project-based learning gives an intervention for the students to learn statistics while reveal their reflective thinking skills according to Funny et al.[4] The need to educate students to be creative has drawn increasing attention in STEM education and creativity is widely recognized as being one of STEM education’s critical goals. The Engineering Accreditation Commission of ABET (2016 –2017) has called for creativity in applying knowledge and decries the limited pedagogical focus on knowledge acquisition. A mixed methods educational study was developed by Katz-Buonincontro et al.[5] The study tested different types of open-ended assignments requiring creative responses on 55 undergraduate students from a probability and statistics class in in a midsize STEM school. This study designed open-ended assignments in engineering classes, measured students’ creative responses on these assignments and how the responses corresponded to student perceptions of creative competence. The assumption was made that creativity can be developed in a domain or subject, and that creativity can be taught not only in design courses but also in engineering math courses. The results show that students’ perceived creativity had varied relationships with actual creativity[5].

Statistical knowledge is needed for industrial engineers to perform many processes in industry such as quality control and regression analysis. However, the experience show that industrial engineers have often insufficient knowledge in statistics and statistics techniques, which is partially due to the focus of the undergraduate statistics courses on the mathematical aspect of statistics more than the technical aspect. Different approaches have been suggested to address the gap between instruction and practice of statistics for industrial engineering students. A problem-solving approach embedded within an industrial environment statistics course has given the industrial engineering students better understanding of statistics than the traditional-way statistics course based on a study by Silva and Aguilar[6].

There are many benefits of exposing probability and statistics to engineering students in their freshman year instead of waiting until sophomore year. The benefits include that the students can recognize earlier that statistics and engineering are not two distinct unrelated areas and the importance of probability and statistics to address some engineering problems. Due to the course-space availability and limited classroom time, Marino et al.[7] integrated probability and statistics topics into an existing first year first term “Introduction to Freshman Design” course. Three weeks of the course focused on statistical concepts and topics such as: central tendency, descriptive statistics, probability and distributions. Several statistics teaching approaches were applied such as multi-faceted activities, cognitive visualization of graphed data, and tactile measurement of tangible objects to understand variability of data, and interpreting and defining outliers. Direct and indirect assessments were conducted to measure the success of this course. The students' ability to analyze engineering data using basic descriptive statistics and appropriate software after taking the course was increased by 9.5% as indicated by student surveys[7].

The six recommendations for teaching introductory college statistics courses by the Assessment and Instruction in Statistics Education (GAISE) project, funded by the American Statistical Association (ASA), are: (1) Emphasize statistical literacy and develop statistical thinking; (2) Use real data; (3) Stress conceptual understanding rather than mere knowledge of procedures; (4) Foster active learning in the classroom; (5) Use technology for developing conceptual understanding and analyzing data; and (6) Integrate assessments that are aligned with course goals to improve as well as evaluate student learning[8].

Nolan and Speed developed an undergraduate upper-level statistic course through the use of in-depth case studies (labs). An integration of statistical theory and practice was used in the labs. The material covered in the course developed by Nolan and Speed was divided into 5 broad categories: summary statistics, sampling, estimation and testing, regression and simple linear least squares, and analysis of variance and multiple linear least squares. Typically, they spent 1 week on the first category and 3 weeks on the other four categories[9]. Experiential learning implementation is a learning process that prioritizes experience during the learning process[10]. Fardillah et al. studied the effects of experiential learning on students' statistical reasoning abilities. The subjects of this study were the industrial engineering students who took statistics courses for industrial engineering. The results of this study show that the students' statistical reasoning abilities increase through experiential learning.

The Engineering Management Master's Program (EMMP) developed in Wayne State University in the 90's of last century is an educational partnership between Wayne State University and the Ford Motor Company that targets the working engineer on the path to technical leadership. Although much of the curriculum was built on the strength of existing MS and MBA programs at Wayne State University, the courses were redesigned to target critical issues that face technology-based product development and manufacturing firms. The program is limited to just 42 semester credit hours plus a probability/statistics prerequisite. Those students who do not have an adequate background in probability and statistics, must take a 10-week refresher course[11]. The EMMP program has four principal components: engineering management core: (12 credits), business core: (12 credits), engineering cognate: (12 credits), and engineering management leadership project: (6 credits). The engineering cognate is composed of six two-credit courses: stochastic system models and simulation, information systems for the manufacturing enterprise, agile systems for the manufacturing enterprise, deterministic system models and optimization, technical systems design, and best practices and future technology[11].

Survey and Comparison

Undergraduate Engineering Programs and Statistics Requirement

A survey of the statistics coverage in engineering curricula was conducted on 66 engineering colleges from R1 and R2 ranked universities. Two equal sized samples were selected randomly from each rank. The offering of statistics core courses in terms of credit hours and topics in three engineering disciplines; mechanical (ME), civil (CE), and industrial engineering (IE), was investigated in this survey. These three disciplines were selected due to their popularity and/or the importance of statistics in the fields related to them.

Basic statistics is covered in 1, 3, 4, 6, and 7 credit hour courses in most of the ME, CE, and IE programs which can be satisfied by taking one or more statistics courses to complete the graduation requirements. Probability theory is part of most of these courses. Two courses of statistics are offered if the program requires 6 or more credit hours for graduation. Table 1 shows examples of the topics covered in some statistics related courses based on credit hours. Application of statistics courses such as statistical quality control and statistical thermodynamics in addition to technical elective courses for tracks/emphases were not considered in the survey.

Different programs have included statistics (basics and beyond basics) in more data/data-analysis oriented courses. This is more noticeable in R1 engineering programs. This can be a good step toward developing more rigorous advanced data science courses as new engineering graduates need to know how to deal and handle data in today's industry. The credit hours of this kind of courses are between 3 to 7 divided on one or two courses. Examples of the topics covered in statistics-data oriented courses or courses with explicit data analysis title are shown in Table 2. The information in Tables 1 and 2 was collected from the catalogs of some R1 and R2 university in the fall of 2021.

Table 1: Examples of the topics covered in some statistics courses based on the required credit hours.

Req Cr. Hr.	Topics
1	The practical application of statistical principles as they apply to scientific and engineering topics, with focus on solving engineering problems in various disciplines such as civil, electrical, and mechanical engineering.
3	Probability and basic statistical concepts, random variables, discrete and continuous distributions, sampling distributions, inferences concerning means, simple regression, and correlation. Experiments demonstrating probabilistic and statistical concepts are conducted.
4	Fundamentals of probability theory for parameter estimation and decision making under uncertainty. Applications to information systems as well as other physical and biological systems. Topics include: discrete and continuous random variables, conditional expectations, Bayes' rules, laws of large numbers, central limit theorems, Markov chains, Bayesian statistical inferences, and parameter estimations.
6	Graphical Representation of Data; Axioms of Probability; Conditioning, Bayes Theorem; Discrete Distributions (Geometric, Binomial, Poisson); Continuous Distributions (Normal Exponential, Weibull); Covariance and Correlation; Point and Interval Estimation, Likelihood Functions, Test of Hypotheses for Means, Variances and Proportions for One and Two Populations. Introduction to data analysis methods and statistical tools, linear regression and correlation, multiple linear regression, stepwise selection, nonlinear regression, logistic regression, analysis of variance, introduction to design of experiments.

Table 2: Topics covered in statistics-data oriented courses.

Req Cr. Hr.	Topics
3 cr.	Nature of probabilistic models for observed data; discrete and continuous distribution function models; inferences on universe parameters based on sample values; control charts, acceptance sampling, and measurement theory.
4 cr.	Measurement fundamentals, design of experiments, elementary statistics and uncertainty analysis. Topics in statistics include probability, error propagation, confidence intervals, hypothesis testing, linear regression, one- and two-factor ANOVA and time series analysis. Carrying out experiments and analyzing the results.
7 cr. hrs. (3 +4)	Application of the concepts and methods of probability theory and statistical inference to civil engineering problems and data; graphical data analysis and sampling; elements of set theory; elements of probability theory; random variables and expectation; simulation; statistical inference. Use of computer programming languages for analysis of civil engineering-related data and problems. The course also introduces the student to various domains of uncertainty analysis, inferential thinking, computational thinking, and real-world relevance. Given data arising from some real-world phenomenon, how does one analyze that data so as to understand that phenomenon? The course teaches critical concepts and skills in computer programming and statistical inference, in conjunction with hands-on analysis of real-world datasets, including economic data, document collections, geographical data, and social networks. It delves into social and legal issues surrounding data analysis, including issues of privacy and data ownership.

Table 3 shows a comparison between R1 and R2 engineering programs based on the number of credit hours of statistics. 67% of the surveyed mechanical engineering programs from R1 colleges require statistics to fulfil the graduation requirements while this rate is 59% for the surveyed R2 programs. The average required credit hours (cr. hrs.) of statistics for the surveyed R1 mechanical engineering programs is 2.12 cr. hrs. with 0.33 coefficient of variation (CV) and 1.75 cr. hrs. with 0.87 CV for the R2 ones. The percentage of programs that require statistics in their curriculum is up to 100% for industrial engineering programs from both rankings with an average cr. hr. of 3.56 for R1 programs and 3.44 for R2 programs.

For the surveyed programs, the average required cr. hr. of statistics of the R1 programs is greater than the R2 programs. The average required cr. hrs. are greater in R1 than R2 by 17.5%, 6.5%, and 8.3% for the mechanical, civil, and industrial engineering programs respectively. Figure 1 shows different comparisons between programs within the same ranking and between rankings.

Table 3: Comparison between R1 & R2 programs based on statistics requirement for graduation.

Program	**ME**		**CE**		**IE**	
Rank	**R1**	**R2**	**R1**	**R2**	**R1**	**R2**
# of programs	33	32	24	26	16	9
Programs w/stat (%)	67%	59%	92%	88%	100%	100%
Average cr. hrs. of required stat.	2.12	1.75	2.92	2.73	3.75	3.44
Std Dev - cr. hrs.	1.58	1.52	1.25	1.25	1.18	1.01
CV	0.74	0.87	0.43	0.46	0.32	0.29

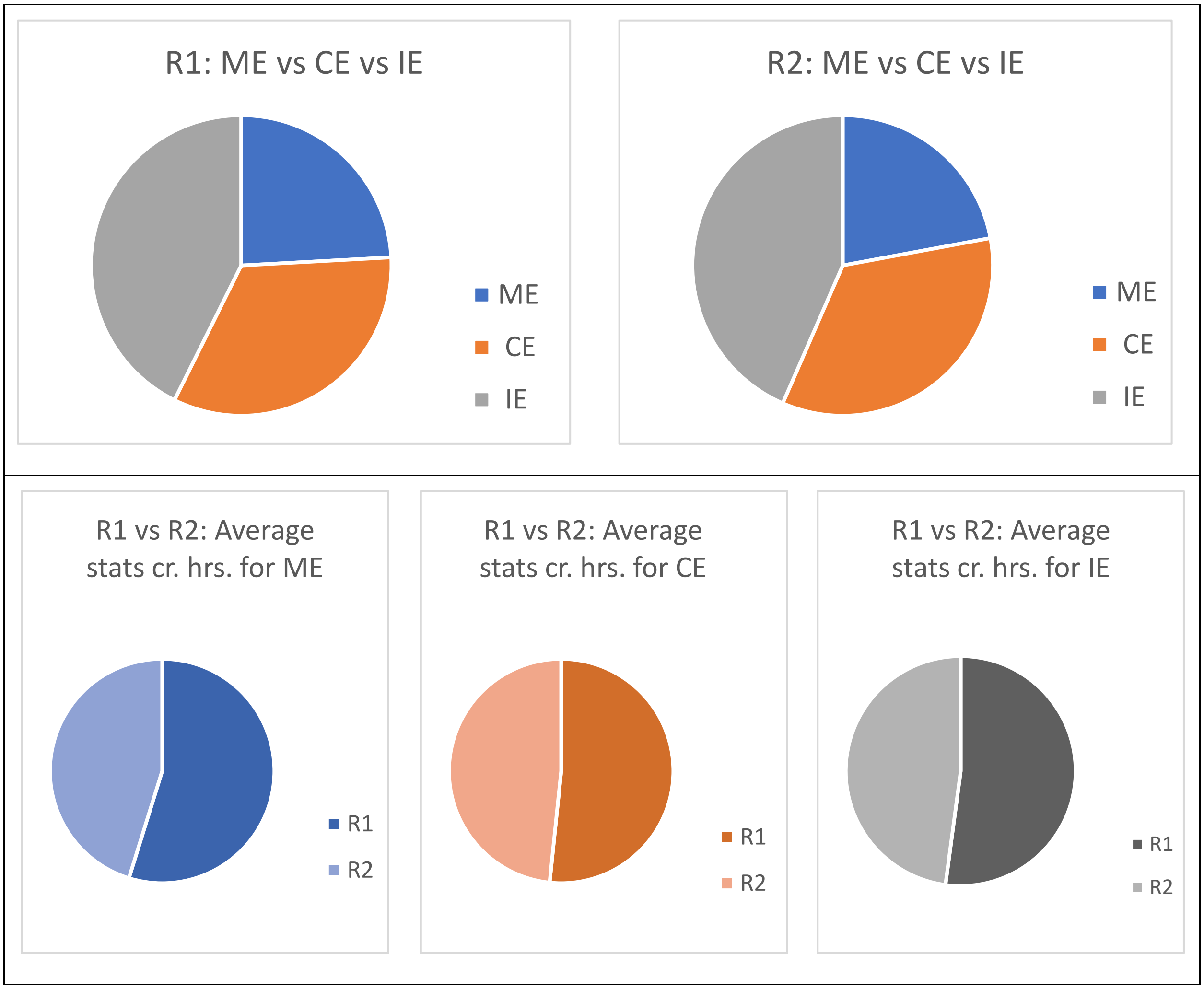

Figure 1: Comparisons between programs within the same ranking and between rankings regarding the average credit hours of statistics in the curriculum.

Master's in Engineering Management Programs and Statistics Requirement

More universities offer new master's in engineering management (MEM) programs. Many of these programs are delivered completely online in addition to the conventional in-person and hybrid programs. The hybrid programs either have the two track options, online and in-person, or some or all courses offered both online and in-person. Data analysis and decision making is a common topic in many of the MEM programs; it will be more rewarding if they are connected, as programs, with data science through statistics. This connection can prepare the graduates for the new challenges in the job market and emphasizes more on the engineering component of these programs.

A survey of 40 master's in engineering management programs (20 from R1 universities and 20 from R2) in the fall of 2021 shows that 60 % of the surveyed programs don't have statistics requirements as either an independent core course or a prerequisite knowledge for admission. Table 4 shows the distribution of the MEM programs based on the ranking and offering method. The majority of the R1 and R2 in-person MEM programs have statistics requirements. One thesis path and two nonthesis path MEM programs require statistics knowledge for admission and include a statistics-oriented core course in the curriculum; two of these programs are from R1 universities and one from R2. The MEM programs are directly or indirectly using the industrial engineering curriculum and body of knowledge as references so that the statistics topics covered in these programs are based on the industrial engineering requirements. A required statistics course for one of the MEM programs covers the following topics: Random variables, inference for one population, inference on two populations, simple and multiple linear regression, control charts, and design of experiments.

Table 4: Statistics requirements for 40 R1 and R2 MEM programs.

	Offering Method	Counts **(out of 20)**	Thesis **(Yes, %)**	Probs & Stats Prerequisite **(Yes, %)**	Probs & Stats Core Course **(Yes, %)**
***R1* Programs**	*In-Person*	3	2 (*66.7%*)	2 (*66.7%*)	2 (*66.7%*)
	Online	3	0 (*0%*)	1 (*33.3%*)	1 (*33.3%*)
	Hybrid	14	4 (*28.6%*)	3 (*21.4%*)	4 (*28.6%*)
***R2* Programs**	*In-Person*	5	2 (*40%*)	3 (*60%*)	1 (*20%*)
	Online	3	1 (*33.3%*)	1 (*33.3%*)	1 (*33.3%*)
	Hybrid	12	3 (*25%*)	1 (*8.33%*)	2 (*16.67%*)

The number of R1 MEM programs with statistics requirements (prerequisite knowledge of statistics for admission and/or statistics core course) is greater than R2 by 10% as in Figure 2 and 3. The thesis path is not a determinant factor to have statistics prerequisite requirement for admission or to include it as a core course in the curriculum as in Figure 4.

For figures 2-4, Thesis (Y): Thesis path MEM program. Thesis (N): Non-thesis path MEM program. PreReq (Y): Prerequisite knowledge of statistics is required for admission. PreReq (N): No prerequisite knowledge of statistics is required for admission. Core (Y): Core course of statistics in the curriculum. Core (N): No core course of statistics in the curriculum.

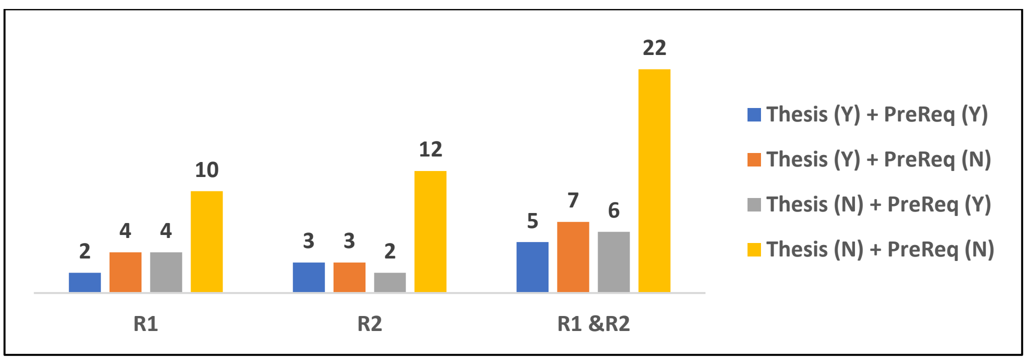

Figure 2: Statistics prerequisite admission requirement for thesis and nonthesis paths of the MEM programs from 40 R1 and R2 universities in 2021 fall.

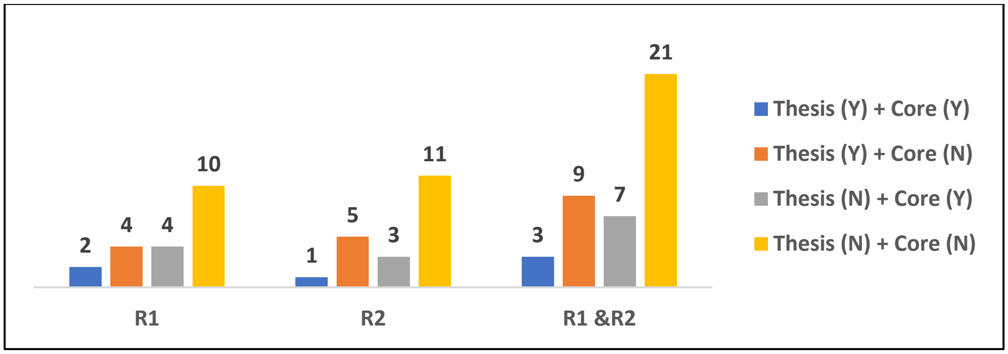

Figure 3: Statistics core course requirement in the curriculum for thesis and nonthesis paths of 40 MEM programs from R1 and R2 universities in 2021 fall.

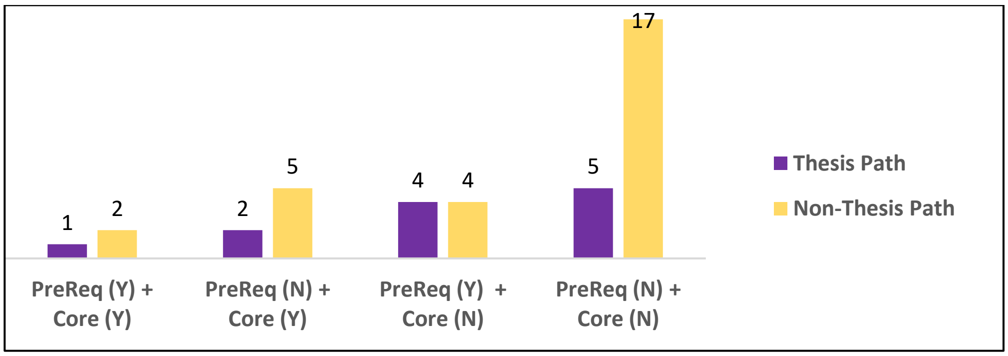

Figure 4: Statistics requirements, prerequisite knowledge of statistics for admission and statistics core course, for thesis and non-thesis paths of 40 MEM programs from R1 and R2 universities in 2021 fall.

Discussion and Conclusion

In the era of big data, the ability to make decisions based on statistical and data analysis is required in almost every engineering field. Including statistics courses in order to increase the level of statistics coverage in the curriculum has become more challenging with the continuing demand to reduce the total credit hours to fulfill the graduation requirements for engineering degrees. Some creative ideas are required to improve the statistics content in the curriculum if adding a statistics course is not possible such as increasing the discussion hours for the existing statistics courses and covering statistics topics in other courses.

In general, R1 engineering programs (mechanical, civil, and industrial) cover on average more statistics than the R2 ones. The average required credit hours of statistics of the surveyed mechanical engineering programs is significantly less than the surveyed civil or industrial engineering programs. Mechanical engineering programs need to increase the statistics content in their curriculum to prepare their students to the new trends in industry. Data analysis is becoming more important topic for civil and industrial engineering programs and has to be included in the curriculum within a 4-hour statistics course (1 cr. hr. for data analysis topics) or as an independent course to cover subjects such as sampling techniques, decision tree, and decision under uncertainty. Surveys of statistics syllabi and questionnaires for current students, instructors, industries, and alumni can be the next steps of the evaluation phase of the inputs and outputs of teaching statistics for engineering students. The next phase, improvement, requires more institutional efforts and brain storming to adopt the required changes.

Statistics is an important tool for managers with engineering background. More focus on statistics is needed for MEM programs in R1 and R2 universities. Statistics is more important for the thesis path of engineering graduate programs including MEM as more experimental work and analysis are expected. It seems that there is no relation/connection between the statistics coverage in the MEM programs and the thesis/non-thesis option available in these programs. However, it is more obvious the relation between the statistics coverage and the offering method. The in-person MEM programs tend more than other MEM programs to require prior statistics knowledge for admission and to include statistics in the curriculum plans.

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Mazen Hussein

Mazen is an Associate Professor in the General and Basic Engineering Department at Regional University. His research interests include: Freight modeling and logistics, facilities planning and material handling, optimization and simulation modeling, production planning and control, reverse logistics and recycling, modern manufacturing systems, microalloying and mechanical behavior, teaching statistics and increasing the data analytics content in engineering curricula, and the impact of the administrative policies on the engineering education. Memberships: Institute of Industrial and Systems Engineers, American Society for Quality, Institute for Supply Management, and Institute for Operations Research and the Management Sciences.