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Data Analytics in an Industrial and Systems Engineering Curriculum

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Abstract

The last two decades have seen a mass digitalization of manufacturing. Sensors and wireless monitoring within this digitation provide opportunities for vast collections of data. This data can be collected from various areas throughout the production cycle: design, assembly, quality control, maintenance, etc. Value can be extracted from this data which can benefit company's manufacturing processes. Therefore, the need exists for analytical knowledge to explore these data sets to uncover information with the goal of improving efficiencies. Industrial engineers already have a strong statistics background as well as linear algebra. Some of the areas that traditional IE programs may be lacking are unstructured data analysis, advanced machine learning techniques, and programming skills. In response to this burgeoning need, Stevens Institute of Technology created a brand new Industrial and Systems Engineering program heavy in data analytics. The first students graduated in May 2020. A paper addressing the initiation of this topic was previously brought before ASEE IED Division in 2018 and this article is meant as a follow up. One purpose of the paper is to demonstrate the final curriculum outcome for the program. However, the global goal of this paper is to demonstrate the growing need for the topic of data analysis in Industrial Engineering curriculums across the country.

Background

Industrial Engineering has much of its history intertwined with the Industrial Revolution; a time when what had been done manually was being mechanized through technology. In the roughly 200 years since the first industrial revolution began, bringing on the second and third Industrial Revolutions as well, a lot has changed and Industrial Engineering has changed along with it. With the transition from craftsman production to mechanization; to mass production to power-steam, petroleum, and electric; to electronic and IT systems and automation, industrial Engineering has expanded and morphed to include relevant areas as they developed.

According to Encyclopedia Britannica, we are currently in the beginnings of the 4th Industrial Revolution; data, artificial intelligence, augmented reality, 3D printing, etc. (1) This makes sense given over the past two decades, industrialization has become increasingly digitized. This digitization has led to immense data sets within and around the production process. Industrial Engineers being efficiency experts can analyze these data sets and improve the production system. Given such, it is a logical step for Industrial Engineering to be data science heavy.

In 1948, the Institute of Industrial Engineers (IIE) was formed. In 2015, IIE changed its name to the Institute of Industrial and Systems Engineers (IISE). The IIE CEO Don Greene explained that this was done since, "The name change aligns IIE with the changing scope of the profession that, while keeping its industrial base, has seen more industrial and systems engineers working with large-scale, integrated systems in a variety of sectors. The change also is consistent with department names in many universities, as two-thirds of the top 65 schools ranked in U.S. News & World Report have incorporated 'systems' into their department names".(2)

Colleges have also modified their Industrial Engineering curriculums over the decades to reflect areas of Industrial Engineering relevant to industry, moving from strictly manufacturing to time studies, logistics, supply chain, ergonomics among others. In the recent decades, colleges have added a newer discipline, Engineering Management, to their offerings. Often these Engineering Management programs are housed in the same department as Systems Engineering, Industrial Engineering and/or Industrial and Systems Engineering programs. More recently another program has been added to this grouping; that being Software Engineering. For example, Stevens Institute of Technology and Arizona State have these three programs, Engineering Management, Industrial/Systems Engineering, and Software Engineering, in the same schools. Stevens has them in the School of Systems and Enterprises. Arizona State has them in the School of Computing Informatics and Decisions Systems Engineering. A natural progression, then is the incorporation of software/data science knowledge into the Engineering Management, Industrial and Systems Engineering Programs.

From the benchmarking done in 2017 while reviewing leading ISE programs (3), IE/ISE programs at leading universities across the country appeared to fall into one or more of the following focus areas

- Manufacturing
- Supply Chain and Logistics
- Ergonomics and Human Factors/Industrial Behavior
- Information and Service Systems
- Statistics and Quality Control
- Operations Research

Historically, as indicated above, Industrial Engineering has traditionally included concentrations called “Operations Research”. However, since the 2017 benchmarking, titles appear to be changing or being added to. Georgia Tech is an institution which has a long history and very good ranking as an industrial engineering educator. For example, US News and World Report has ranked Georgia Tech number one in Industrial Engineering since 1991 (4 & 5). At Georgia Tech today, you can get a Bachelor of Science in Industrial Engineering with a concentration in Operations Research, or a concentration in Analytics and Data Science, among others. (6) This second concentration in data analytics was not available just a few years ago. At another highly ranked US news and World Report industrial engineering program, Columbia University, one can get an undergraduate degree in Operations Research with a concentration in Analytics.

Additional research at the time of the initial benchmarking in 2017 showed the University of Colorado at Colorado Springs performed an analysis in 2016 to determine the market demand for an Industrial and Systems Engineering bachelors degree. (7) Their report highlights benchmarking that is comparative to what was reported in author’s previous ASEE submission (3). Specifically, a recommendation from the report was to “consider specializations in Health systems and analytics”; again, this data focus was the one chosen by Stevens.

At Stevens, data science (specifically Python related) was added to the existing Engineering Management program in 2015. However, in 2017, when it was decided that there would be the creation of a new Industrial and Systems Engineering (I&SE) Program at Stevens, the answer

was clear that the new I&SE program would not just have a component in data science, but that it would be data science driven.

This seems a trend in other places as well. University of Arkansas faculty member Haitao Liao was "featured" in the "2018-2019 State of the (Industrial Engineering) Department Report" under the title "Can an Industrial Engineer Be a Player in Data Analytics?". In the same report, Xiao Liu had an article titled, "Next-Generation Data Analytics for Large Scale Recurrent Event Processes". (8)

Other Industrial and Systems Programs are also addressing the change. Rensselaer Industrial and Systems Engineering program has added a course in applied data science (9) and a minor in Data Science and Engineering. (10)

Colleges and universities are not the only ones seeing the connection between Industrial Engineering and Data Science. At Viasat, the company behind the world's fastest satellite internet service, they are looking to hire what they call "Industrial Engineer – Data Scientists" as of their July 2019 posting. This job description states, "This role's core responsibility is the data analytics that enable the identification of opportunities for improvement... [applicants should have an] aptitude and understanding of data analysis techniques supported by a holistic knowledge of continuous improvement and manufacturing operations…. programming expertise in Python, R, MATLAB, or other Data Science specific language …. [and a] strong understanding and historical application of Lean Manufacturing, Six Sigma, and other Industrial Engineering methodologies." (11)

However, it is worried that educational institutions are not ready to educate students for the 4th Industrial Revolution. David Pistrui is a clinical professor of Engineering at Detroit Mercy and a chief researcher and academic liaison at Automation Alley. The 4th Industrial Revolution is not about any of the new technologies in isolation, but about using them in tandem with the IoT. According to Pistrui, "It is the intersection of these [new] technologies [that is critical]… Engineering Schools are still operating in an Industry 2.0 or 3.0 mindset, and the old silos remain. And they are not relevant to industry." He continues that industries complain that newly hired graduates know the theories behind the technologies, but not how to combine them. (12)

Population and ISE Program Objectives

The current article takes place at Stevens Institute of Technology, a small, private, urban campus across the Hudson River from Manhattan in New Jersey. Approximately 4000 undergraduate students are enrolled, of whom about 3000 are engineering students. The Engineering Management, Industrial and Systems and Software Engineering programs are all housed in the School of Systems and Enterprises and EM has been ABET accredited since the early 1990's. It is this School of Systems and Enterprises that embarked upon the addition of a new undergraduate program in Industrial and Systems Engineering and will graduate its first students in May of 2020.

This Stevens ISE program's objective is to provide a rigorous general engineering undergraduate education, with depth in both industrial and systems engineering topics focusing on data, in order to nurture technical leaders of tomorrow who will be able to engineer, develop, and maintain

increasingly complex systems with cross-discipline content and socio-technical system dimensions.

The curriculum is designed to teach the student many skills. The goal of the curriculum's design is not just to teach students to think about the ways in which technology can help organizations accomplish goals, but also to apply systems analytics and data science to engineering design. This creates engineers who bring a larger perspective on systems, with a capability to use data to develop a big picture model of systems, analyze problems, and optimize system quality and performance. (Employment data of the seniors was not available at the time of this submission.)

Given the data centric focus of the ISE program, the Industrial & Systems Engineering program-specific content at Stevens is delivered via the following courses. Almost all of the courses were created specifically for the new ISE program and were created around the use of Python, R and Excel. However, courses with call letters other than ISE existed already. The curriculum was continuously reviewed by the faculty during its creation and was brought before the Advisory Board multiple times for comment. Please see the Appendix for a brief description of each course. Note that all two hundred level courses are supposed to precede the three hundred level courses and so on. The only two courses which do not follow this format are SYS 501 and SYS 581 which are taken in terms 5 and 6 respectively.

Course Number	**Required Course Name**	**Credits**
ISE 224	Informatics & Software Development	3
ISE 225	Data Infrastructures	3
ISE 322	Engineering Design VI	2
ISE 345	Modeling & Simulation	3
EM 365	Statistics for Engineering Managers	4
SYS 501	Probability & Statistics for Systems Engineers	3
ISE 350	Logistics and Supply Chain Management	3
SYS 581	Intro to Systems Engineering	3
ISE 357	Elements of Operations Research I	3
ISE 457	Elements of Operations Research II	3
ISE 451	Analysis of Networks and Strategies	3
ISE 490	Data-Mining & Applied Machine Learning	3
ISE 423 & 424	ISE Senior Design	3 & 3

The Stevens ISE curriculum also includes a broad core math and science foundation spanning chemistry and physics, calculus, thermodynamics, computer science, and electronics/circuits.

These portions of the curriculum for the ISE Program will be from the standard engineering curriculum that all engineering programs are required to follow at Stevens.

The above Stevens courses align quite closely with the requirements of the newly formed Data Science and Analytics concentration at Georgia Tech. Georgia Tech describes their Data Science and Analytics concentration as "a fast-growing field focused on using data and models to discover relevant insights for making better decisions in business, healthcare, and other disciplines. The depth courses in this concentration are selected from data analytics for decision making, machine learning, and selected advanced courses in operations research and statistics. This concentration prepares students for some jobs as analysts or consultants, or for Master's-level studies in analytics." The 15 hours of "analytics elective" requirements for Georgia Tech's concentration are to be from those listed below (13). Although comparison in some cases may not be truly direct, there is enough similarity to show a trend. In both curriculums listed below, there is an obvious focus on data and data analysis building to a body of knowledge where graduates will be able to use such analysis for "Decision Making".

Course Number	**Required Course Name (3 to 6 hours)**	**Similar Stevens Course**
ISYE 4133	Advanced Optimization	ISE 457 – OR II
ISYE 4045 or 4803	Advanced Simulation	ISE 451 - Analysis of Networks and Strategies
ISYE 4232	Advanced Stochastic Systems	SYS 501 – Prob & Stat
ISYE 4134 or 4803	Constraint Programming	ISE 224 – Informatics & Software Development
Course Number	**Required Course Name (6 to 9 hours)**	**Similar Stevens Course**
ISYE 4034 or 4803	Decision and Data Analytics	ISE 225 – Data Infrastructures
CX 4240	Computing for Data Analytics	ISE 224 Informatics & Software Development
ISYE 4803 or CS4641	Machine Learning	ISE 490 – Data Mining & Applied Machine Learning
ISYE 4803	Special Topics - Online Learning & Decision Making	ISE 451 - Analysis of Networks and Strategies
Course Number	**Required Course Name (3 hours)**	**Similar Stevens Course**
Varied	An additional course from list mostly consisting of the courses indicated above	

Alignment with ABET Program Criteria

The curriculum component of the ABET Industrial and Systems Engineering Program Criteria reads as follows with text below showing the way the courses and curriculum satisfy the IE criteria.

"The curriculum must prepare graduates to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy."

The strength of the Stevens Industrial and Systems Engineering program is in relating the technical components of industrial engineering with critical systems skills. This strength is developed in almost all of the technical elective courses in the program. Behind this overall strength is the idea that if students are well-prepared to analyze and design processes in general, they will be well-prepared for any situation they may encounter in their careers, beyond the particular technologies and theories that are being taught today.

"The curriculum must include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices."

Throughout the curriculum, students are the application of tools to stochastic and "real world" nature Industrial and Systems Engineering problems through a variety of means. First and foremost, the capstone/ senior design courses provide a real-world laboratory for the students to practice the theory learned in the classroom. By solving actual problems, for real clients, the students experience the difficulties of dealing with changing requirements, project creep, variability of input, choosing appropriate analytical methods and tools, etc. and putting it all into practice. They also are exposed to the mathematical nature of problems in the classroom in courses dealing with statistics, modeling and simulation, operations management, big data and informatics.

Finally, in discussions with the ISE Advisory Board and the ISE senior classes since implementation, it was clear that the above curriculum was well received. Feedback was overwhelmingly positive from the Advisory Board, employers, and Senior Exit Surveys. Stevens is not allowing publication of specific ISE data at this time since the number of graduates within the ISE program is not large, and thus could be related back to individuals. In May of 2022, the first large class is anticipated to graduate and allow for publication of employment and starting salary data.

Data Science vs. (or in combination with) Operations Research

Some may say that Operations Research contains data science so does this discussion even matter? The answer in today's marketplace is yes because the rest of the world does not see an Industrial Engineer as a mathematician. If we want our IEOR's to get hired, then we need to transition the IE degree to something employers understand that they need in their employees. Specifically, Operations Researchers and Data Scientists are both mathematicians that fit data into advanced mathematical models that predict future behavior. Operations Research traditionally uses optimization and simulation tools like linear programing, discrete event simulation, etc., while data science uses computer science tools like programming and database tools. However, in today's world the separation between the two areas is blending away and they generally overlap today. Though modeling and simulation have been around for decades, integrating sophisticated, inexpensive sensors into existing production machinery would allow

the collection and analysis of real time data right on the shop floor. Thus, data science is an interdisciplinary field about extracting knowledge and insight from data. Isn't this just what OR is – using advanced analytical methods toward the end of making better decisions? To optimize? The dezyre.com website put it nicely by saying, "If operations research is the metal detector that guides to the right area of business then data science is the spade to dig into the data and extract value." (14)

Conclusion

The Stevens ISE program has been designed to prepare students with a broad-based engineering education, a systems thinking perspective and a strong set of data analysis skills. This set of talents will enable students to design new and innovative systems and improve existing systems in response to market needs and opportunities

The aim of the program is to teach students to take a systems approach to ensure the right problems are addressed, and complete solutions are developed. A broad-based engineering education enables understanding of how various technologies can be applied to realize solutions. Data Science knowledge helps students develop a deep understanding of problems and provides tools useful in optimizing solution designs.

As data science continues to become a relevant and almost necessary part of engineering education, adding an IE focus or concentration in data analytics makes sense for the future of Industrial Engineering.

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Appendix

ISE 224 Informatics and Software Development (3 - 3 - 0)

This course deals with the challenges associated with the variety and volume of information encountered in today’s workplace, and working with others in a software development environment. Students will analyze and work with both structured and semi-structured data, using the python programming language. Students will learn about the types of software development environments they are likely to encounter in their careers. The capstone of the course is a small-group project that analyzes real-world data to answer a business or research question.

ISE 225 Data Infrastructures (3 - 3 - 0)

This course provides an introduction to Data Engineering. Data Engineers gather and collect the data, store it, do batch processing or real-time processing on it, and serve it to a data scientist who can query it. This course is designed to give students a broad understanding of modern storage systems, data management techniques, and how these systems are used to store, access and analyze Big Data. Topics include data modeling; storage system design of disk arrays, network attached storage, clusters and data centers: relational databases and techniques for data analytics; no-SQL databases and their advantages; cloud data storage and the use of clouds for big data; data warehouses and data mining; the Apache ecosystem for data management with focus on hadoop file system and the mapreduce paradigm for data analytics; graph database management systems, such as Neo4j. Homework assignments will give students practical experience with important topics covered in the course, including the use of cloud storage, relational databases, NoSQL databases, and hadoop/Map Reduce.

ISE 322 Engineering Design VI (2 - 1 - 2)

This course provides students with experiences and tools for new product and process development. Students will become familiar with systematic approaches to design, and they will explore the design process from problem identification through detailed design, validation, and economic analysis. Tools that have been introduced in earlier industrial and systems engineering courses may be brought together as part of this pre-senior design experience. Discussions of contemporary design issues and class projects will provide experiences and insights that will serve to improve their senior project experience. Prerequisite: E 232

ISE 345 Modeling and Simulation (3 - 3 - 0)

This course emphasizes building analytical skills for developing mathematical models and running computer simulations for decision-making. The course provides an introduction to modeling and simulations concepts and analysis techniques for mathematical programming and decision making. Basic computers skills and knowledge of statistics are necessary to solve the problems discussed in the lectures and any assigned for homework. The course emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems. Modeling and simulations techniques and methods for decision analysis in this course will investigate discrete event modeling, and agent-based modeling in depth. Prerequisite: EM 365 Statistics for Engineering Managers

ISE 350 Logistics and Supply Chain Management (3 - 3 - 0)

Supply chain management is integral to increasing an organization's efficiency, capacity, and cash flow. This course will provide an introduction to supply chains, logistics & supply chain management and provides mainly mathematically based techniques used to analyze various aspects of logistics systems. Topics covered include supply chain performance and metrics related to demand forecasting, facilities location, inventory management, transportation, sourcing, pricing and information. Design of distribution networks, forecasting, and planning of demand & supply would be covered. The course has a strong emphasis on providing analytical skills, critical thinking and managerial insight. Co-requisite: E 243 or EM 365 or BT 221

ISE 357 Operations Research I (3 - 3 - 0)

This course emphasizes building analytical skills for developing mathematical models for decision-making and optimization. The course provides an introduction to deterministic operations research (OR) concepts and analysis techniques for mathematical programming and decision making. Basic computers skills (Excel) and knowledge of statistics are necessary to solve the problems discussed in the lectures and assigned for homework. The course emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems. Modeling techniques and methods for decision analysis including linear and integer programming, transportation and network models, dynamic programming, goal programming, classical optimization theory, and non-linear programming. Prerequisites: EM 365 Cross-listed with: EM 357

ISE 422 Data Analysis and Visualization Techniques for Decision-Making (3 - 3 - 0)

Data has the potential to inform decision ¬making and influence public and policies. When situated with appropriate context, visualized data has the power to change the world. This course provides the essential and practical skills necessary to communicate information about data clearly and effectively through graphical means. In this hands-¬on introduction to data visualization, student will learn basic types of plots such scatterplot, bar chart, heatmap, parallel coordinate, geographic map, and word clouds. Advanced and interesting topics such as interactive web application and Chernoff faces will also be introduced. Additionally, this course covers basic data manipulation techniques and machine learning skills. An individual does not necessarily have to be a programmer.

ISE 423and ISE 424 Senior Design VII and VIII

This year long, two-course sequence involves the students in a collaborative design experience in an area relevant to Industrial & Systems Engineering. The need for the project is taken from industry, business, government, not-for-profit organization, or a student-defined project approved by the course instructor. The need expressed by the Client must lend itself to apply the knowledge, tools and methods the students are exposed to in the ISE curriculum to come up with a viable design. The teams will develop a set of alternative conceptual solutions based on deep analysis of clients' and other stakeholder's needs and expectations as well as gather data and knowledge from relevant sources. They will propose a preferred concept based on a thorough assessment of the alternatives. The proposed conceptual solution will be detailed further into a preliminary design by the end of the fall semester. The second semester will focus on iterating detailed design, implementation and testing to refine the design to fulfill the intent of the design(depending on scope and complexity, this could be ranging from a "proof of concept" prototype, to a solution that the Client can put into production). Throughout the year, the teams will submit written reports at key milestones, and formally present it to clients, faculty, subject matter experts and peers.

ISE 451 Analysis of Networks and Strategies (3 - 3 - 0)

This course is designed to help students understand the complexity, structure and dynamics of a highly-connected world. The course is comprised of two basic parts: complex network analysis and the social and economic factors that affect decision-making in networked systems. It takes a mathematically rigorous and interdisciplinary look at economics, sociology, information science and applied mathematics to discuss some of the fundamental features of networks and their behavior. Topics such as diffusion and cascading, voting, emergence and evolving networks, and economic and market implications will be explored. Prerequisite: EM 365.

ISE 457 Operations Research II

This course emphasizes building analytical skills for developing mathematical models for decision-making and optimization, in many cases under uncertainty. The course is an introduction to stochastic operations research (OR) concepts and analysis techniques for mathematical programming and decision making. Basic computers skills (Excel) and knowledge of probability and statistics are necessary to solve the problems discussed in the lectures and assigned for homework. The course emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems.Modeling techniques and methods for decision analysis Markov processes, dynamic programming, metaheuristics, queueing, inventory theory, and forecasting models are covered. Prerequisites: EM 365 and MA 227

ISE 490 Data-Mining and Applied Machine Learning (3 - 3 - 0)

This course will use tools and techniques which have proven to be of value in recognizing patterns, making predictions and supporting the decision making process based on data. Using these tools and techniques, the student will develop applications, and have hands-on experimentation with data/text mining, applied machine learning and network construction, using real-world examples and situations. Prerequisite – Must be an ISE student