International Journal of Industrial Engineering and Management (IJIEM), Vol. 8 No 1, 2017, pp. 39-45
Available online at www.iim.ftn.uns.ac.rs/ijiem_journal.php
ISSN 2217-2661

UDK: 62:005.3

An Empirical Study of Industrial Engineering Curriculum

Ammar Aamer
Ph.D., Assistant professor at the Faculty of Engineering, Sana'a University, aaamersu@gmail.com

Bradley Greene
Ph.D., GridWell Management Consulting, Knoxville, Tennessee

Chad Toney
Ph.D., Plant Leader at General Electric, Louisville, Kentucky

Received (04.11.2016.); Revised (28.02.2017.); Accepted (20.03.2017.)

Abstract

The purpose of this paper is to identify current and future Industrial Engineering (IE) trends in graduate-level course curriculum. Top ten US industrial engineering schools were benchmarked, as indicated by US News and World Report. Different IE topics were categorized into several categories- Engineering Economics, Human Factors, Information Technology, Manufacturing Processes, Manufacturing Systems, Operations Research, Quality Control, Simulation, Statistics, and Integration of subject areas. The study of the Top Ten Graduate Programs in Industrial Engineering, according to US News and World Report, showed that these schools are focusing on Manufacturing Systems and how the other tools of Industrial Engineering relate to manufacturing. The implication of this study is that teaching methods should reflect the emphasis on Manufacturing Systems and incorporate real world problems.

Key words: *Industrial Engineering, Benchmarking, Curriculum Trends*

1. INTRODUCTION

Over the last years, industry has witnessed a major change in the roles of Industrial Engineers (IE). Industrial Engineering has been defined by the Institute of Industrial & Systems Engineers (IISE) as a field of study that is "concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy" [1].

Industrial Engineers were once thought of solely as shop-floor efficiency experts.

However, they are now being asked to perform a diverse set of roles within organizations, from production planning and scheduling to the development of information systems. Industrial Engineers are being hired for jobs in hospitals, distribution centers and other service organizations. The diversity of roles that Industrial Engineers are capable of playing has led to the diversification of curricula within Industrial Engineering departments across the world [2, 3]. One of the challenges for these departments is to determine what to offer and what to exclude.

The Faculty of Engineering at Sana'a University has been looking toward the future and trying to decide where it wants to be in ten years' time. One of the objectives of the faculty is to establish an IE graduate program based on quality and accreditation standards. More emphasis is placed on quality educations the region as well as internationally [4].Therefore, for the faculty of Engineering to be positioned similarly to other IE graduate programs, there was a need to understand what other schools teach during the graduate IE programs to ensure the development of innovative ideas and appropriate goals for the future. The purpose of the study was to identify current and future trends in IE graduate-level course curricula.

Understanding the need to have well-prepared students who go out to industries and perform effectively, school curriculums have begun to mirror industries.

Therefore, the benchmark process in this paper was built from the vantage point of the students being the customer implicitly. As witnessed by Lohmann [5], when a department changes its curriculum or focus, the students in such a department are affected the most. This is why the students are determined to be the customer.

2. LITERATURE REVIEW ON IE TRENDS

The literature review on IE education has revealed a limited number of researches on the topic of IE trends. In a study by Elsayed [6], the author stressed the fact that courses taught in traditional IE programs included manufacturing processes, manufacturing systems engineering and design of production as core courses, in addition to natural sciences courses. Therefore, Mummolo [3] suggested the need to combine innovation and knowledge-based sectors with traditional IE disciplines. The author emphasized the necessity of bridging the gap between innovation and IE programs, to allow IE to compete in new emerging areas such as Nano-bio technologies, new materials, digital factories, energy and environment, safety, security and health.

The diversity of roles that Industrial Engineers are playing and the rapidly changing industrial environment drove the need to change the IE curricula. One of the factors reported in the literature affecting the need to change IE curricula is the ongoing technology evolution as confirmed by a recent study by Paté-Cornell and Chen et al. [7, 8]. According to the authors, this should help industrial engineers be abreast with recent development.

Another factor reported in the literature was the limited emphasis being placed on engineering problem solving in the IE curricula, as confirmed by Elsayed, Grimson, Acar, Baillie et al., Mitchell, and Chen et al. [6, 8, 9, 10, 11, 12]. Also, industrial engineers need to develop the skills of engineering problem solving, which are critical for industrial settings. This is supported in the literature by Kuo et al. [13] where the authors stressed the importance of the reform of the IE curricula and that of engineering problem solving.

Moreover, a number of studies in the specialized literature discussed that industrial engineers need to develop their communication abilities by being introduced to other business disciplines, such as management, finance, economics, organizational psychology and communication [7, 10, 12, 14].

As an example, according to Paté-Cornell [7] Stanford moved toward the integration of other business disciplines in the IE curriculum to prepare students to face the increasing challenge imposed by globalization and the complex business world.

Chen et al. [8] also argued that creativity should be introduced in IE programs in the form of industrial communication, creative problem solving and scientific research methodology. Another study conducted by Eskandari, et al. [2] focused on the emerging topics that should be integrated in the IE program.

The study concluded that emerging important topics, such as management and leadership, quality engineering, and Supply chain management were important topics that needed to be incorporated in the IE curriculum.

One can conclude from the literature review that the IE program is a diversified discipline that needs to be balanced by technical and soft skills. These skills are required from IEs in today’s world to keep up with the rapidly changing industrial and business environment.

3. METHODOLOGY AND DATA COLLECTION

The researchers set out to find information about other industrial engineering schools. Supported by Fisher et al. [15], a conclusion was made that the best source for determining the top ten industrial engineering schools was US News and World Report, which listed the top ten schools in alphabetical order [16]:

- Cornell University
- Georgia Institute of Technology
- Northwestern University
- Pennsylvania State University
- Purdue University
- Stanford University
- University of California—Berkeley
- University of Michigan—Ann Arbor
- University of Wisconsin
- Virginia Tech

In this research, three industrial engineers were assigned to perform the task of benchmarking against other Industrial Engineering programs. These individuals were highly motivated because the benchmarking effort allowed them to explore other curriculums and investigate how other schools teach their disciplines. Also, the team was qualified due to their knowledge in most areas related to industrial engineering.

A database framework was developed to collect data. The data in the framework was obtained from course catalogs from many universities to understand what subjects are taught in Industrial Engineering programs. From reviewing course descriptions, it was determined that the fundamental unit of analysis should be a topic within a course (example: a course in linear programming would have the Simplex Method as a topic). The determination was made because otherwise there would have been too much variation between subject area and course title of the different schools. For instance, a course titled “Inventory Control” may be taught from a management perspective, while other schools teach the shop floor fundamentals of inventory. Each topic listed in the course description and/or syllabus was then classified into one of ten IE main categories as described in Table1.

Some IE programs were teaching traditional course subjects in the context of another subject area. For this reason, it was decided to classify a topic into a Main Category and a Secondary Category when necessary.

In these cases, the Main Category would represent the overall context of the course and a Secondary Category would represent the traditional classification for the tool or technique. For instance, several schools taught a planning and scheduling course, which utilized operations research methodology to solve problems.

In this example, the Main Category is Manufacturing Systems and the Secondary Category is Operations Research, as shown in Table 2.

Table 1. IE main categories and their definition

IE Main Category	Definition
Engineering Economics	Cost justification of engineering projects, finance.
Human Factors	Integration of humans and machines, designing to work environment to human constraints.
Information Technology	Information management, using computer software and hardware to get the right information to the right person in the organization.
Manufacturing Processes	Understanding the tooling, machines, material handling equipment, and other hardware required to manufacture a product.
Manufacturing Systems	Understanding the organizational systems required to manufacture a product (planning, scheduling, inventory control, etc.).
Operations Research	Use of mathematical modeling tools to solve a variety of problems.
Quality Control	Tools and techniques used to assure quality in a production environment (Statistical Process Control, Design of Experiments, Sampling Techniques, etc.).
Simulation	Development of computer models of real world systems for purposes of studying system behavior (discrete event simulation)
Statistics	Fundamental statistical tools.
Integration of subject areas (Project course)	Use of two or more subject areas in a course, most often occurring in a capstone project course.

Table 2. Main and Secondary Category s for an Industrial Engineering Course

Main Category	Secondary Category	Topic	Course Number
Manufacturing Systems	Operations Research	Theoretical treatment of optimization models for manufacturing system design and control	554

The researchers first ensured that a given topic had not already been recorded in the database. If the topic did not exist, it was assigned a Main Category and a Secondary Category if relevant, as well as the corresponding course number. If the topic did exist, a new course number was recorded under the proper school name, as shown in Table 3.

4. RESULTS AND ANALYSIS

Upon completion of the database, the team reviewed the information for quantitative and qualitative trends. First, the team analyzed the number of topics for each Main Category and Secondary Category.

But after this analysis, the team realized that the data could be skewed as a result of many topics taught in a single class. discuss Just-in-Time, Lean Production Systems, Kanban, 5S, One Piece Flow and Standard Work, while an Operations Research class might only discuss the Simplex Method. T
herefore, the frequency of Manufacturing Systems would be inflated. For that matter, the team decided to compare how many classes were taught within each Main Category and Secondary Category. The resulting trends are discussed below.

Table 3. Example of the database framework and collected data

Main Category	Secondary Category	Topic	North-western	Stanford
Manufacturing Systems		Determination of order quantities and safety stocks		X
Manufacturing Systems		Inventory replenishment systems	X	X
Manufacturing Systems		MRP	X	X
Manufacturing Systems		Functions of inventory	X	X
Manufacturing Systems	Operations Research	Timing and sizing for production capacity expansion	X	X
Manufacturing Systems	Operations Research	Production lot size	X	X

4.1 Observed Trends

There are several results that came from this study. The first trend detected from the study was that the three main topic areas that seemed to be stressed the most were Manufacturing Systems, Human Factors, and Operations Research (see Table 4).
These three subject areas represent 64% to 65% of the topics taught in the curricula at these schools. It is also interesting to note that only Human Factors would be unnecessarily inflated, and even then, the number of topics is almost double compared to those of Engineering Economics, the next most prolific subject area. Therefore, we can say with some degree of certainty that these three subject areas are the major emphasis of the IE programs in this study.
This point is emphasized in Tables 5 & 6. Table 5 presents the amount of Classes per Main Category and Secondary Category. Table 6 presents the comparison between the percentages of topics versus classes offered per Main Category.
From these tables, it seems that the same three Main Categories are taught the most often as courses, but this time Operations Research is deemed the most important, followed by Manufacturing Systems and Human Factors.

Table 4. Number of Topics per Main Category

Main Category	Total Number of Topics	% of Total Number of Topics
Manufacturing Systems	270	25
Human Factors	235	21
Operation Research	202	18
Engineering Economy	98	9
Information Technology	73	7
Quality Control	58	5
Statistics	53	5
Manufacturing Processes	51	5
Simulation	35	3
Integration of Subject Areas	19	2

The second trend observed in the study is that most of these 10 schools would integrate some of the subject areas within course offerings. This is manifested in the number of courses that warranted a Secondary Category to go with the Main Category. The subject that is used most often as a Secondary Category is Manufacturing Systems (in 50% of the situations), as shown in Table 7. Again, this is emphasized by Tables 5 & 8. Table 8 compares the percentage of topics versus classes offered per Secondary Category. The results from these tables confirm that Manufacturing Systems is the Secondary Category used most often. This probably indicates an effort to use manufacturing to set the context for the other subject areas. It also reflects the real world more succinctly and is a direct response to the present industry that students should understand how academic subjects are integrated in a practical environment.

Another interesting observation is that Manufacturing Systems most often serves as a secondary subject to Information Technology and Engineering Economics, as described in Table 9.

Table 5. Amount of Classes per Main Category and Secondary Category

Topic	Main Category	% of Main Categories	Secondary Category	% of Secondary Categories
Operations Research	121	25	30	22
Manufacturing Systems	105	22	58	43
Human Factors	71	15	4	3
Manufacturing Processes	37	8	7	5
Engineering Economics	33	7	1	1
Statistics	28	6	14	10
Information Technology	27	6	13	10
Simulation	22	5	5	4
Quality Control	22	5	2	1
Integration	21	4	0	0

Table 6. Comparison between the Percent of Topics versus Classes Offered per Main Category

Category	% of Topics per Main Category	% of Classes per Main Category	% Points Difference
Operations Research	18	25	7
Manufacturing Systems	25	22	-3
Human Factors	21	15	-6
Manufacturing Processes	5	8	3
Engineering Economics	9	7	-2
Statistics	5	6	1
Information Technology	7	6	-1
Quality Control	5	5	0
Simulation	3	5	2
Integration	2	4	2

Table 7. Number of Topics per Secondary Category

Secondary Category	Total Number of Topics	% of Total Number of Topics
Manufacturing Systems	93	51
Information Technology	26	14
Operations Research	24	13
Statistics	12	7
Manufacturing Processes	10	6
Engineering Economy	7	4
Human Factors	5	3
Quality Control	2	1
Simulation	2	1
Integration of Subject Areas	NA	NA

Table 8. Comparison between the Percent of Topics versus Classes Offered per Secondary Category

Category	% of Topics per Secondary Category	% of Classes per Secondary Category	% Points Difference
Manufacturing Systems	51	43	-8
Information Technology	14	10	-4
Operations Research	13	22	9
Statistics	7	10	3
Manufacturing Processes	6	5	-1
Engineering Economics	4	1	-3
Human Factors	3	3	0
Simulation	1	4	3
Quality Control	1	1	0
Integration	NA	NA	NA

Table 9. Relationship of Secondary Categories with Selected Main Categories

Secondary Category	**Main Category**	**Total Number of Topics**
Manufacturing Systems	Information Technology	34
Manufacturing Systems	Engineering Economics	31
Manufacturing Systems	Operations Research	14
Manufacturing Systems	Statistics	6
Manufacturing Systems	Quality Control	5
Manufacturing Systems	Manufacturing Processes	3
Information Technology	Human Factors	10
Information Technology	Statistics	8
Information Technology	Manufacturing Processes	5
Information Technology	Manufacturing Systems	2
Information Technology	Operations Research	1
Operations Research	Manufacturing Systems	20
Operations Research	Engineering Economy	4

The third trend is the development of Supply Chain Management (SCM) under the Industrial Engineering curriculum. Seven out of the ten top Industrial Engineering schools place significant emphasis on teaching the concept of SCM. For instance, Northwestern University and Stanford offer courses in Transportation and Supply Chain Systems. These courses focus on the design of industrial logistic systems, as well as state of the art planning models and practical tools for inventory controls, distribution management and multi-plant coordination.

A fourth trend observed in the study is that the teaching methods of these 10 schools tended to emphasize the application of the subject areas. Case studies were often used to bring a concept into a real world context. Design projects and team demonstrations were also a major part of the curricula. These methods are dramatically different from the traditional lecture methods of most university courses.

Finally, another trend that was observed in the study is the use of capstone design projects. This differs from the in-class design projects, because the entire class is a design project aimed at integrating some or all of the subject areas within the curriculum. In fact, nine of the ten schools in this study have capstone design projects. Once again, the attempt is to create a realistic context for the learning process, which helps solidify the notions in the students' minds and better prepare them to work in various industries.

5. CONCLUSIONS

In conclusion, this study benchmarked top ten industrial engineering schools, as indicated by US News and World Report. The purpose of this research was to identify trends in graduate level courses curricula, as well as course delivery methods. Different topics were categorized into the following categories:

- Engineering Economics
- Human Factors
- Information Technology
- Manufacturing Processes
- Manufacturing Systems
- Operations Research
- Quality Control
- Simulation
- Statistics
- Integration of subject areas (Project course)

The overall contents of the course were categorized with the Main Category and a Secondary Category being the traditional category for the tool or the technique used in that course. Overall, the study of the Top Ten Graduate Programs in Industrial Engineering, according to US News and World Report, showed that these schools are focusing on Manufacturing Systems and how the other tools of Industrial Engineering relate to manufacturing. The implication of this study is that teaching methods should reflect the emphasis on Manufacturing Systems and incorporate real world problems. These real world problems may be brought forth through projects, labs, integrated curricula or experts in the field presenting to the students. As with many organizations, there is plenty of room for improvement in the academia industry, and a good benchmarking strategy will help develop strategies for this needed improvement.

5.1 **Theoretical and practical implications**

This study offers several important implications to the IE education literature, as well as graduate programs. This study extends previous research in the area of IE education. It also adds to the body of IE education knowledge. In addition, the research contributes to the understanding of IE trends and how they can be utilized to establish new IE graduate programs.

The findings of this paper suggest placing more emphasis on case studies to bring a concept into a real world context. Also, design projects and team demonstrations were also a major part of the curricula. The implication is that professors and instructors must begin to learn how to teach in a new manner.

These methods are more efficient for the student's learning and retaining, although they can be less efficient for the instructor. Similar to the previous trends is the use of industry experts to serve as guest lecturers. These classes are often taught in a seminar format, with a new expert in each class period.

There are several issues to be solved when using this method. How do you grade the students? Can you find 18-20 experts in a subject area with time schedules that match your own? How do you integrate the expert knowledge in the rest of your curriculum? That said, this could be a very valuable method of providing context for the rest of the curricula.

In the practical implication, this study helps schools to forecast what IE topics to offer in their programs. Since companies typically prompt universities to teach specific new initiatives to their employees, these topics should therefore be taught to the students in the universities to make them more marketable when they are applying for jobs.

Current Executive Education courses are identified as shown in Table 10, Manufacturing Systems are taught almost exclusively. Also, we noticed that it is rare for several categories to be taught together in these courses.

This is probably because the courses are more specific and the students already have experience in the marketplace, so they do not need the experience gained from project-based classes.

Table 10. Number of Executive Education Courses Taught per Category

Category	Courses
Manufacturing Systems	49
Information Technology	0
Operations Research	3
Statistics	0
Manufacturing Processes	0
Engineering Economy	0
Human Factors	0
Simulation	0
Quality Control	0
Integration	0

6. LIMITATIONS OF THE STUDY

As with most benchmark studies, there were some difficulties in collecting and analyzing the data in the manner that was chosen. The three areas that contributed most to the error in the data are the following (in order of significance):

- Interpretation of different terminology used by different schools.
- Differences in the level of detail in course descriptions.
- Current relevance of course descriptions.
- Several Main Categories and Secondary Categories per class.

6.1 **Interpretation of Different Terminology**

Each topic within a course description was compared to the other topics in the database to determine whether the topic was new or similar to another one from a course at a different school. Often, different schools would use different terminology to describe a similar concept. In these cases, the researcher had to make a subjective decision as to how to categorize the topic. The researcher’s expertise could affect the decision of how to categorize the topics. In this benchmark, all four researchers' main area of expertise is Manufacturing Systems. This being the case, many topics were probably repeated using different terminology, since the researchers were not aware of the redundant definitions.

6.2 **Differences in the Level of Detail**

Using these research methods, it was difficult to verify what exactly was covered in a specified course. Some course descriptions used more general terms to describe the concepts covered. Other course descriptions used more specific terms. For example, in a Nonlinear Programming course, a general description might read, 'Discussion of unconstrained optimization techniques'. A more specific description would enumerate the techniques used. For the most part, course descriptions were more specific than general, however the only true way to know what is covered in all courses is to obtain the syllabus.

6.3 **Current Relevance of Course Descriptions**

Another limitation of the study was determined by the fact that course catalogues might not be up to date. The research assumed that the courses listed in the catalogues were still being offered. The resulting error in the study is that there are courses and topics that were entered into the benchmark database which are not currently being taught on a regular basis.

Several Main Categories and Secondary Categories per class

During the data collection, the topics were separated and logged in an individual record. The appropriate Main Category and Secondary Category were selected based upon the analysts' knowledge of the topic. Therefore, two or more Main Categories may be represented within the same course. For instance, one course taught about systems for production scheduling (Information Technology), heuristics for scheduling (Operations Research) and management of inventory (Manufacturing Systems). This is not very significant until the observed trends are noted. A comparison is made with regard to the number of classes taught for each Main Category and Secondary Category. Some classes may have two or more Main Categories and/or Secondary Categories. However, this limitation could not be avoided due to the assumption that the smallest unit of analysis would be the topic.

7. REFERENCES

[1] IISE. (2016, mAY). INSTITUTE OF INDUSTRIAL AND SYSTEMS ENGINEERS. Retrieved from http://www.iienet2.org/

[2] Eskandari, H., Sala-Diakanda, S., Furterer, S., Rabelo, L., Crumpton-Young, L., & Williams, K. (2007). Enhancing the undergraduate industrial engineering curriculum: Defining desired characteristics and emerging topics. Education + Training, 49(1), 45 - 55.

[3] Mummolo, G. (2007). The future for industrial engineers: education and research opportunities. European Journal of Engineering Education, 32(5), 587-598.

[4] Aldowaisan, T., & Allahverdi, A. (2015). Continuous improvement in the Industrial and Management Systems Engineering programme at Kuwait University. European Journal of Engineering Education, 1-11.

[5] Lohmann, J. R. (1999). EC 2000: The Georgia Tech Experience. Journal of Engineering Education, 305-310.

[6] Elsayed, E. A. (1999). Industrial Engineering Education: A Prospective. European Journal of Engineering Education, 24(4), 415-421.

[7] Paté-Cornell, E. (2001). Management of post-industrial systems: Academic challenge and the Stanford experience. International Journal of Technology, Policy and Management, 1(2), 151–159.

[8] Chen, C.-k., Jiang, B., & Yiao, K. (2005). An empirical study of industrial engineeringand management curriculum reform in fostering students' creativity. European Journal of Engineering Education, 30(2), 191–202.

[9] Grimson, J. (2002). Re-engineering the curriculum for the 21st century. European Journal of Engineering Education, 27, 31–37.

[10] Acar, B. (1998). Releasing creativity in an interdisciplinary systems engineering course. European Journal of Engineering Education, 23, 133–140.

[11] Baillie, C., & Walker, P. (1998). Fostering creative thinking in student engineers. European Journal of Engineering Education, 23, 35–44.

[12] Mitchell, C. (1998). Creativity is about being free. European Journal of Engineering Education, 23, 23–34.

[13] Kuo, W., & Deuermeyer, B. (1998). The IE curriculum revisited: the development of a new undergraduate program in industrial engineering at TexasA&M University. IIE Solutions, 30, 26–22.

[14] El Maraghy, W. H. (2011). Future Trends in Engineering Education and Research. Advances in Sustainable Manufacturing: Proceedings of 8th Global Conference on Sustainable Manufacturing (pp. 11-16). Springer Berlin Heidelberg.

[15] Fisher, D. P. (2000). Linking Engineering Service Courses with Engineering Design. Proceedings of the Conference of ASEE.

[16] LP, U. N. (2016, May). U.S. News & World Report Education. Retrieved from http://colleges.usnews.rankingsandreviews.com/best-colleges/rankings/engineering-doctorate-industrial-manufacturing/datailibar

Empirijska studija kurikuluma industrijskog inženjerstva

Ammar Aamer, Bradley Greene, Chad Toney

Primljen (04.11.2016.); Recenziran (28.02.2017.); Prihvaćen (20.03.2017.)

Apstrakt

Cilj ovog rada je utvrđivanje trenutnih i budućih trendova u nastavnim planovima i programima vezanim za industrijsko inženjerstvo (II) kao i program kursa na osnovnim studijama. U radu je analizirano 10 najboljih američkih univerziteta i škola u oblasti industrijskog inženjerstva škole su poređen identifikovanih prema „US News and World Report". Različite II oblasti svrstane su u nekoliko kategorija: inženjerska ekonomija, ljudski faktora, informacione tehnologije, proizvodni procesi, proizvodni sistemi, operaciona istraživanja, kontrola kvaliteta, simulacije, statistika, kao i integracija navedenih oblasti. Studija je pokazala je da se ove obrazovne ustanove fokusiraju na proizvodne sisteme, kao i kako su drugi alati industrijskog inženjerstva povezani sa procesmo proizvodnje. Implikacija ove studije jeste da nastavne metode treba da su fokusirane na proizvodne sisteme sa osvrtom na realne svetske probleme u oblasti.

Ključne reči: *Industrijsko inženjerstvo, benchmarking, trendovi nastavnih programa*