Smart Manufacturing Enterprise Curriculum Development: Financial Analysis for Smart Manufacturing Opportunities

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Abstract

Recent advancements in microelectronic systems allow for the rapid collection, storage, and processing of data. In industrial settings, these capabilities have tremendous potential in increasing automation in manufacturing processes with computerized vision and artificial intelligence. Using sensors, distributed computing, and smart robots, an automated system can both operate and actively monitor a process with greater accuracy and precision than a human operator. This collected information can also be sent to and stored in a cloud server, where it can be automatically, or manually, analyzed to provide insights into how to improve that manufacturing process.

However, capital outlays for such manufacturing systems can be significantly high in cost, especially for large systems. Further, some subprocesses may be too complex or currently have too low of demand for a cost-effective, automated solution. As such, financial analyses are critical to ensure such investments have viable return. To address this problem, we have developed a graduate-level, online course for Industry 4.0 technologies with a focus on financial performance, including risk and capital budgeting assessment. This course was designed to be centered around a course project which involves a mock industry scenario complete with financial data and strategic goals. Students will be required to work in small groups to develop three alternative strategies for smart technology implementation.

Students will be exposed to various Industry 4.0 technologies through weekly lectures, supplemental readings, and discussions to inform their strategies. Each week, students will be given a case study over a smaller mock industry scenario along with practice problems. The goal of the course is to provide students with the tools they need to demonstrate how project investments in Industry 4.0 technologies can generate new business opportunities and improve productivity to benefit a company's overall financial performance. Through these improvements, the company monetarily benefits while the student gains recognition to further the student's career. This course will be offered for the first time in spring of 2023. Both formative and summative assessments will be made of the course for potential improvements.

Introduction

Manufacturing processes generate a large, continuous stream of valuable temporal data during operation. These data contain vital insights about the state of the machinery involved and the quality of the product. For the machinery, some examples of recordable data may include the temperature of the machine over time, the wearing of tools over time, radiographic imaging to assess the internal state of the machines, vibration analysis, the speed of tool movements, various settings that may be enabled, and so forth. For the product, any imaginable product dimension, which may be measured using a nondestructive method, such as resonance imaging to assess internal structure, height, width, depth, weight, surface roughness, etc., may all be recorded. Most of these data are not likely recorded, primarily due to the cost considerations associated with the purchase, installation, and calibration of the necessary sensors along with the costs associated with the storage and processing of those acquired data.

In high-production environments, the presence of these data would allow a company to parametrically sweep through controllable inputs to determine the optimal configuration for product quality or total cost of production, in accordance with a defined optimization function. This process is commonly referred to as reinforcement learning, defined by Sutton and Barto [1] as, "the optimal control of incompletely-known Markov decision processes." While the optimization function for the total cost of production is a straightforward minimization, for product quality, an example optimization target may be to minimize the penalties applied to a particular input configuration with respect to the deviations of the product dimensions from their desired values.

In comparison, low-production environments are much more sensitive to the costs of such perturbances to the system and an exhaustive search through the parameter space may be monetarily infeasible. In such cases, the natural variation of the processes may lead to useful insights regarding the input configurations, or fewer perturbances of a lower magnitude may be tested. Low production-environments which produce expensive products further benefit from the recording of these data due to the additional quality control which is enabled through active capture and monitoring.

These sensing data are also paramount to increasing the level of automation of a process when mechanical means alone are not sufficient or too costly, i.e., when a decision is required to be made for a process which may have varied states. For example, if parts need to be identified, it is possible to manufacture a long, flat plane with holes of increasing size across the plane and storage vessels underneath each hole. Dragging or pushing the parts across the plane until they fall through the desired hole may be an effective means of sorting them into recognized bins. However, if the number of parts to sort becomes too numerous, or if the parts are similar in size and shape, computer vision, using open-source toolkits like OpenCV [2], becomes a practical alternative to classify those parts.

As the amount of data will rapidly increase over time, serious consideration must be given to how much and what type of data to collect and store, as monthly costs for cloud storage depend directly on the amount of stored data. The significance of these data types and the frequency of their capture may be determined by a pilot study. Significant data can be stored remotely on cloud servers, to which the data can be sent directly after measurement by microcontrollers, which are compact, single-board computers, such as a Raspberry Pi [3]. Such sensors or other devices fit with these single-board computers are referred to as "smart" devices and this ability to fit microcontrollers onto these devices drives the fourth industrial revolution, known as Industry 4.0 [4]. If the data are not analyzed, which can be processed directly on the cloud servers, the collection and storage costs are wasted. The required computing power for these analyses is also determined by the type and size of the data.

The intended data analyses will heavily impact the amount of data that must be stored. For example, periodic aggregates, such as for a day or a shift, may be sufficient to compare performance between each period, and, as such, the corresponding data may be discarded after the aggregations of that period have been performed. If the use of the data is more sophisticated, such as for the building of a digital twin to train a deep neural network for an industrial robot, a more substantial investment into data storage is necessary due to the reliance of the network on training data.

Cloud storage may not be necessary for all data collection. Other uses of sensor data may not require that the data be stored for a significant length of time, such as sensors used in active monitoring. For example, in the transportation of materials between processes, it may be possible for an item to become lodged in an opening. This situation may happen at a seemingly random interval of time due to an undiscernible cause; in which case a camera may be utilized to detect the presence of the obstruction. When an obstruction is detected, a signal may be sent to a robotic arm, which may remove the obstruction using that camera to guide its own motion. For this example, there is no need for long-term data storage, as the data need only to exist in random access memory (RAM) for as long as required by the microcontroller to decide on an action before being discarded.

With the high variance between different manufacturing processes, simple solutions may outperform a more automated process, despite the excitement brought by the prospect of utilizing machine learning and these newer technologies. Each process requires careful analysis and an assessment of the benefits that the more complex solution may produce. To this end, data capture is also important, but the capture of such data itself represents an investment.

Due to the rapid innovation introduced through Industry 4.0 technologies, familiarity with these technologies and financial literacy are crucial to the success of their implementation. Students must be exposed to these technologies to be able to make any sort of recommendation about their use. Financial literacy is necessary to be able to determine the present monetary value of a proposed solution. To address these problems, Purdue Polytechnic Institute is designing a graduate-level, online certificate program called Smart Manufacturing Enterprise Graduate Certificate Program. The certificate program consists of four courses pertaining to different aspects of Industry 4.0 technologies. The course described in this paper will be the third course in the program and focuses on new opportunities for growth, productivity, and financial performance using Industry 4.0 technology. This class is scheduled to deploy in the spring of 2023.

Course Learning Objectives

The course was designed for working graduate students enrolled in the online Smart Manufacturing Enterprise Graduate Certificate Program. As the students are working professionals, it is important to also review foundational material, due to the gap that may exist from the last time students were exposed to these foundational concepts. It is further possible that some students may have never been exposed to those foundational concepts in their higher education due to varying core curriculums between institutions. To inform the design of the course, eight learning objectives were defined through consultations meetings with Dr. Adam

Barragato and Dr. Elizabeth Beese, two instructional design experts from the Course Design and Development department at Purdue University.

The first concept was to learn how to use key financial statements including income statements, balance sheets, statements of retained earnings, and statements of cash flows [5]. It is important for students to understand how to pull information from these basic statements to understand how an organization is performing financially. It is from these statements that metrics of comparison can be initialized.

From the understanding of financial statements, comes the second learning objective. This objective is to help students learn how to identify the impact of an application of Industry 4.0 technologies on both the balance sheet and income statement of an organization. An ability to communicate these changes helps secure the funding from the organization's decision makers so that the proposed Industry 4.0 application may be implemented.

To supplement this communication, the third and fourth learning objectives were defined. The third learning objective was to learn how to calculate a variety of financial ratios important in manufacturing productivity and asset management. The fourth was to learn how to analyze those ratios, common-sized statements, pro-forma statements, and the time value associated with money. The time value of money is particularly important in the case of investments into fixed assets, as is the case in increasing automation, as it may take a prolonged period of time before the investment reclaims its value.

The next two objectives are closely related. The fifth objective is to analyze how information is acquired, exchanged, managed, and leveraged across manufacturing and supply chain processes. The sixth objective is to demonstrate how digital and data-assisted systems in manufacturing are used for decision-making and augmenting human capabilities in manufacturing.

The seventh objective is to analyze the socio-economic impact that industrial internet of things (IoT) and cyber-physical manufacturing systems will have on the human workforce and the manufacturing industry.

Along with the prior learning objectives, the final learning objective is to learn how to evaluate and select the best application of Industry 4.0 technologies and finance it using appropriate capital investment opportunities. As each manufacturing process presents its own unique opportunities for improvement, there are numerous investments which may prove favorable. Identifying the most profitable investment from that set proves a difficult task and relies on the estimated value of the improved process. There can also be substantial variation between the estimated effect and the actual outcome, but the goal is to give students the tools required to keep their analyses as objective as is possible to minimize that discrepancy.

Course Design

Before any course content was generated, the textbook and accompanying software were selected. Foundations of Financial Management, 18th edition [5] was selected as the textbook for the course. Purdue University uses Brightspace for its learning management system. As such, all course content is housed on a Brightspace page. Piazza was selected for students to be able to ask questions and receive peer feedback along with instructor answers. All Purdue University students also have licensing to Microsoft Office with their career accounts, with which Microsoft Excel is recommended to students to build financial statements. Zoom was selected for teleconferencing use in virtual office hours, also due to the licensing that Purdue University grants.

As the course is an online course designed for working professionals, all content was prerecorded except for two weekly virtual office hour sessions to ensure an asynchronous modality for the students. These virtual office hour sessions would be recorded and uploaded to Brightspace for students who are unable to attend the sessions due to scheduling constraints.

Each week, students are given a chapter from the textbook to read along with occasional articles describing smart manufacturing technologies. When articles are assigned, there is a weekly discussion forum housed in Brightspace where students are to discuss the article. The article reviews are approximately assigned every other week. In other weeks, students are required to identify new technologies and perform a product review for a discussion post.

Each week also has accompanying lecture videos, which are around fifteen minutes each, with the number of videos per week ranging from one to three. The lecture videos relate directly to the chapter content from the textbook, longer chapters require more lecture videos to adequately explain all concepts. There is also a weekly podcast, proposed by Dr. Barragato, which is in a conversational, question-and-answer style that is approximately thirty minutes in length. The podcast is designed to relate the chapter material to Industry 4.0 technologies and to provide students flexibility to listen to the podcast during their commutes, on a lunch break, or whenever else they might have spare time throughout the day.

Mastery quizzes and case studies are also assigned weekly. Mastery quizzes are short quizzes for students to practice the calculations necessary for the chapter. These quizzes may be taken as many times as the student desires until the student masters the content. The weekly case studies are also tailored to the content for a particular week and describe an industry scenario that the students must solve. The weekly modules were developed by the authors in collaboration with Dr. Barragato and Dr. Beese.

The overarching focus of the course is on a capital investment project. An extensive background is provided to the students for a fabricated company. Also provided are fabricated financial and manufacturing data for the company. Students are tasked with providing three alternative strategies regarding the implementation of Industry 4.0 technologies. For the rationale behind each strategy, students are required to provide pro forma statements, provide key financial ratios before and after implementation of the strategy, financing decisions using currently market rates, net present value of the investment and the average return on investment per year, best- and worst-case scenarios for the investment, and conditions that underlie the feasibility of the investment. Students are required to submit a written report of the strategies along with a recorded presentation. Students are also required to submit a peer review of other teams' presentations.

Conclusion

In this paper, we introduced a myriad of transformative benefits that Industry 4.0 provides. The capabilities provided by the ability to fit microcontrollers onto any device provides powerful automation opportunities for equipment. This allows increased standardization of work and can reduce the potential hazards for employees by using industrial robots for dangerous tasks.

We also described a course designed to help students develop the skills they need to financially assess Industry 4.0 solutions. This course will be offered in the spring of 2023 through an online modality to graduate students within Purdue Polytechnic Institute. It is imperative that students be exposed to these new technologies so that they can apply those technologies to solve problems. Equally important is the ability of students to be able to financially analyze these investments to not only procure funding, but also to ensure that the investment itself is viable. Through this knowledge, students increase their company's performance while advancing their career prospects. We seek to assess the effectiveness of the course using formative and summative evaluations of the first offering.

Acknowledgments

The authors would like to thank Dr. Adam Barragato and Dr. Elizabeth Beese for their substantial contributions to the building of our Brightspace page, the hosting and editing of the podcasts, planning efforts, and assistance with brainstorming and design choices. The two were instrumental in the construction of this course. The authors would also like to thank Vincent Hornbach for his help with the editing of the lecture videos as well as assuring the accessibility of those videos.

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