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Industrial Management for Industry 4.0 – Simulation System to Support Learning of Opportunities and Challenges of Dealing with Real-Time Data

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Abstract. The fourth industrial revolution brings many opportunities for the exploration of new business models, based on increasing digitalization that ultimately enables the prediction of the behavior of systems. Several challenges may be identified in the Industrial Management (IM) field. One of the most relevant is the opportunity to deal with real-time data and adapt the decision-making processes with agile approaches. IM learners will need to increase their awareness of these opportunities and challenges, both in professional training and in higher education. Thus, this study proposes a simulation system to support the learning process of opportunities and challenges to deal with big data from production systems' sensors. The proposed simulation system implements simple dispatching rules for the jobs entering the production queue. Additionally, the system allows the creation of many coupled machines, each one associated with a one-level bill of materials, and a set of sensors delivering data to an excel file simulating a cloud. The study will show how to use the data in a learning experience for learners to understand the high amount of data delivered by sensors and the type of information and decisions it allows.

Keywords. Industry 4.0, Industrial Management, Engineering Education, Active Learning, Project-Based Learning

Introduction

Industry 4.0 (I4.0) is a technological revolution that is transforming the way companies produce and manage their processes. Using digital technologies such as the Internet of Things (IoT), artificial intelligence, and big data makes it possible to integrate systems, machines, and processes, making them more efficient, flexible, and personalized. However, among the barriers to implementing the fourth industrial revolution are those related to human factors, such as the need for digital competences, new qualifications, and specific workforce preparation for this new context [1].

In that regard, there is a gap between the competences demanded by the job market and engineering education, which becomes more evident with the fourth industrial

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revolution [2], [3]. To remain competitive, companies need professionals capable of dealing with the technologies and processes involved in I4.0. Therefore, engineering education must keep up with market transformations and prepare students to work in this new context, developing not only technical competences but also non-technical competences such as teamwork, communication, and leadership [4].

Gutiérrez-Martínez et al. [5] reinforce that educational models must form adequate human capital for industrial development. Using Challenge Based Learning, the authors were able to demonstrate to their students the challenges of applying the knowledge gained in the integration with the industry. Lima et al. [6] discuss the use of project-based learning in real-world situations exploring partnerships between universities and companies, with gains for the various stakeholders involved. This approach allows students to develop in an active way competences required by the job market, providing opportunities to acquire and use interdisciplinary knowledge [7]. Besides, some challenges such as the lack of communication between the university and the company and the unavailability of companies to interact with students may occur [6]. In this context, simulations can be used to overcome such difficulties and allow students to experience projects that resemble real situations.

In summary, I4.0 brings new challenges and opportunities for engineering education. It is necessary to prepare students not only to work in a technological and dynamic environment but also to be leaders and innovators capable of integrating knowledge from different areas [8]. Thus, this article addresses the use of a simulation system for teaching concepts related to I4.0, in the context of a specific course unit (Production Management Processes), which allows students to simulate the interaction with a production system full of sensors for data collection and manipulation. Smart factories development requires collaboration between academia and companies, completely changing business models [9]. Reducing data security risks and achieving potential benefits are some of the goals of the transdisciplinary approach to system design and development in I4.0 [9]. It is expected that with this activity students will be able to develop competences that will allow them to develop the ability to deal with a large amount of data, as well as to understand that this is a part of the I4.0 transformation, which encompasses the organizational structure and the culture of the company. The transdisciplinary nature is reinforced by the fact that, as referred by Nordahl and Serafin [10], the boundaries of the problem are not the boundaries of the discipline (course unit).

1. Theoretical Background

1.1. Industry 4.0

Industry 4.0 is a term that refers to the incorporation of automation technologies with the potential to improve results in various areas of the production chain, such as meeting specific customer requirements, increasing productivity and efficiency, and creating value opportunities from new services [11]. Internet of Things, cloud computing, cyber-physical systems, Industrial integration, enterprise architecture, and enterprise application integration are some of the enabling technologies of this transformation [12]. These technologies allow real-time connections and integration of different systems as a way to enable the vertical and horizontal integration of companies.

The implementation of I4.0 involves evaluating maturity in several dimensions of companies. Schumacher et al. [13] adopt 9 dimensions: strategy, leadership, customers, products, operations, culture, people, governance, and technology. Although much is said about technology, the dimensions encompass other management aspects of industrial engineering, such as organizational design, teamwork, and leadership. Furthermore, other aspects, such as company culture, are involved thus reinforcing the transdisciplinary approach. Depending on the company's progress, it is possible to identify its maturity level. Schuh et al. [14] adopt six levels of maturity: computerization, connectivity, visibility, transparency, predictive capacity, and adaptability.

In this context, new business models have been developed to meet the needs of companies [15]. To do so, approaches usually start by establishing a common vision among stakeholders, followed by the definition of guidelines and prototyping, and finally understanding the most relevant variants for the company's context [15].

Furthermore, I4.0 still presents several technical, technological, organizational, legal, and socio-economic challenges[16]. Among them, interoperability stands out, as essential for achieving efficiency and productivity gains. In this regard, Lu [17] proposes a framework that considers the integration of things, services, data, and people. In the scope of human resources, there are several competencies that I4.0 will demand from professionals. Analyzing the literature and existing challenges, Hecklau et al. [18] categorize them into four groups: technical, methodological, social, and personal competencies. Some examples of these competencies are programming competences, problem-solving, teamwork, and flexibility [18].

1.2. Engineering Education

Industry 4.0 brings new demands on engineering professionals and impacts the necessary competencies, making it essential to analyze engineering education [19], [20]. In this sense, active learning methodologies become even more important as they prepare students for various real situations, with characteristics such as collaboration, problem orientation, contextual learning, and self-directed learning, as well as allowing the use of multidisciplinary problems [21]. However, the diversity of backgrounds and different levels of knowledge can lead to failures in the teaching-learning process [20]. Moreover, engineering instructors have to develop new competences to deal with effective pedagogical approaches and simultaneously deal with I4.0 new challenges [22]. Thus, teachers aiming for more effective teaching and learning processes use active learning approaches, which require specific competences, with emphasis on teamwork, teacher-student relationships (empathy), feedback about students' performance throughout the learning process, Information and Communication Technology (ICT) competences, and selecting and adapting the teaching-learning methodologies to the class context [23]. Additionally, teachers need to give autonomy and motivate students, not just transmit knowledge.

Several studies analyze the gap and consequences of the fourth industrial revolution on engineering education. Qian et al. [2], in the context of safety education, highlight the differences between the concepts taught in training and the needs of the job market. The authors analyze the curriculum of the chemical engineering course and highlight that the situation tends to worsen with I4.0, given the various emerging technologies associated, suggesting a collaboration between industry and academia, using e-learning tools, simulation software, and project-based learning. Analyzing contexts of maintenance, production, and quality themes, Elkosantini et al. [3] also reinforce the gap between academia and the market, highlighting the need to adjust courses and adopt active learning measures, aiming to meet the needs to transition the market to I4.0.

In this context, there is the concept of Education 4.0, characterized by new learning formats, access to learning content from anywhere and at any time, access to new sources of information and knowledge, interdisciplinarity, individual assessment methodologies focused on competences and learning progress, lifelong learning, individualized study programs, focus on competencies instead of knowledge, application of competences and knowledge to real-world problems, and the teacher as a facilitator [4]. The authors also highlight various tools such as video conferencing, digital exam assessment, document collaboration, game-based learning, and virtual/remote lab and simulation tools. Among the main barriers are difficulty in changing the education system, lack of financial resources, reluctance by teachers, lack of knowledge of digital tools, and concerns about data protection laws.

2. Methodology

The present work is based on a case study, involving the application of active learning methodologies through a simulation model of a digital production system in an Engineering and Operations Management master's degree course on Production Management Processes, to facilitate the learning of concepts related to I4.0. Following the concepts of I4.0, a production system, referred to from now on as a *factory*, composed of four machines in one line and equipped with sensors for data collection, was modeled using Simio software. These sensors generate a large amount of data that is stored in a cloud-based spreadsheet, allowing students to work on data interpretation and manipulation.

The model was presented in a 3-hour class proposing a group activity for students to understand the advantages and challenges of big data for real-time decisions in industrial management. Some concepts based on short-term production management concepts and dispatch rules and Key Performance Indicators (KPI) were developed and discussed during the class.

2.1. Development of the Digital Production System Model

The model was developed using Simio 15 software, which allows for the virtual representation of a productive environment, as well as the definition of parameters and business rules to characterize the factory. The digital production system simulates the production of parts from four linearly positioned workstations. Four types of components can be used in each workstation (machine) in a total of sixteen types of components, each with a per-product custom consumption quantity according to their bill of materials. The system was pre-configured to produce five different types of products. The system may use the following dispatch rules: "first in first out" (FIFO), "Earliest Due Date" (EDD), "Shortest Processing Time" (SPT), or "Longest Processing Time" (LPT). An image of the simulation system is presented in Figure 1.

In total, 43 simulation processes are characterized in the model, including activities such as changing dispatch rules, entering components, and recording generated data. The system uses 18 tables for the configuration of parameters, such as order arrival, product routing, processing times for each activity, and probability of defects. By inputting real data into these tables, various scenarios can be simulated that can significantly impact the results. For instance, if the initial stock of components required for product development is reduced to zero, the system will stop production until new components arrive, in accordance with the defined orders. Finally, each time a simulation is performed, the results are stored in an Excel file, including date and time, product type, product identifier, workstation, event, event complement, and action. This file simulates data storage in the cloud and allows for real-time calculation and visualization of indicators.

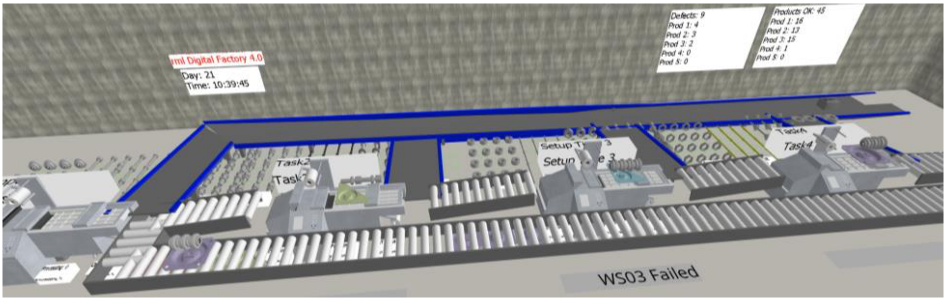

Figure 1. Illustration of the simulation system.

2.2. Classroom application

The application was carried out in the Production Management Processes course, as part of the master's program in Engineering and Operations Management. The class has 24 students and aims to develop their competences in modeling production management processes. The goal is for them to acquire knowledge about production management models, modeling techniques, and modeling languages. The application was led by two facilitators and lasted a total of 3 hours.

Initially, a theoretical foundation was provided on the topic of I4.0, to level the students' understanding of the concepts and facilitate the activity development. Then, the developed system was presented, explaining the production system organization, the products developed their production routings, and their bills of materials. It is worth highlighting that although the parameters can be changed, for the proposed activity, all were defined by the instructors to standardize the students' production system, reducing complexity and enabling teamwork. After clarification of doubts, the students were divided into groups to perform the simulation and work with the data obtained. They were asked to calculate indicators related to the industrial management theme, such as throughput time, work in progress (WIP), and machine utilization. In summary, a set of general instructions were presented to the students: how to run the simulation, and what key measures should they be able to calculate using the results in the Excel file. An illustration of part of the Excel file is presented in Figure 2. It is noteworthy that the resulting Excel file with data from 16 hours of production includes 11209 lines, 5 products, 16 parts, and sensors for machine failure and part processing. In total, the production system depicts 24 different events: Dispatching Rule set to {EDD, FIFO, SP, LLT}, Entered System, Entered Pool, Applied Pool Rule, Exited Pool, Entered WS, Setup Initiated, Setup Finished, Processing Task Initiated, Processing Task Finished, Processing Finished, Defect, Exited WS, Exited System, Product OK, Reached_Reorder_Point, Supply Request Accepted, Supply Initiated, Components Delivered. Current stock, Machine Failed, Out_Of_Stock, Waiting For Component, Resuming Activities, Machine Repaired. Finally, an anonymous questionnaire was applied to the students to obtain feedback on their perceptions, difficulties, and possible improvements for the model and application dynamics.

	A	B	C	D	E	F	G
1	EventDateTime	ProdType	ProdIDName	WSID	Event	EventComplement	Action
11184	23:44:10	Prod4	Prod4.4614	WS02	Processing Task Initiated	Task2	
11185	23:49:04	Prod4	Prod4.4614	WS02	Processing Task Finished	Task2	
11186	23:49:04	Prod4	Prod4.4614	WS02	Processing Finished	All Tasks	
11187	23:49:04	Prod4	Prod4.4614	WS02	Product OK		
11188	23:49:04	Prod4	Prod4.4614	WS02	Exited WS		
11189	23:49:06	Prod4	Prod4.4614	WS03	Entered WS		
11190	23:49:06	Component	Component_02	WS03	Reached_Reorder_Point	Component_02_Wait_For_Replenishmen	Trigger Supply Request for Component_02 @ WS03
11191	23:49:06	Component	Component_02	WS03	Supply Request Accepted	25	Components
11192	23:49:06	Component	Component_02	WS03	Supply Initiated	ETA	44368.99845
11193	23:49:06	Component	Component_03	WS03	Reached_Reorder_Point	Component_03_Wait_For_Replenishmen	Trigger Supply Request for Component_03 @ WS03
11194	23:49:06	Component	Component_03	WS03	Supply Request Accepted	30	Components
11195	23:49:06	Component	Component_03	WS03	Supply Initiated	ETA	44369.00097
11196	23:51:25	System Sensors	Machine Sensors	WS01	Machine Repaired	Machine Status	Monitor Maintenance Plan
11197	23:52:46	Prod5	Prod5.4784	WS03	Setup Finished	Setup Time 3	
11198	23:52:46	Prod5	Prod5.4784	WS03	Processing Task Initiated	Task3	
11199	23:54:36	Component	Component_01	WS02	Components Delivered. Current stocl	37	Components
11200	23:56:59	Component	Component_02	WS03	Components Delivered. Current stocl	114	Components
11201	23:57:15	Prod5	Prod5.9053	WS01	Setup Finished	Setup Time 1	
11202	23:57:15	Prod5	Prod5.9053	WS01	Processing Task Initiated	Task1	
11203	23:58:29	Prod5	Prod5.4784	WS03	Processing Task Finished	Task3	
11204	23:58:29	Prod5	Prod5.4784	WS03	Processing Finished	All Tasks	
11205	23:58:29	Prod4	Prod4.4614	WS03	Setup Initiated	Setup Time 3	
11206	23:58:30	Prod5	Prod5.4784	WS03	Product OK		
11207	23:58:30	Prod5	Prod5.4784	WS03	Exited WS		
11208	23:58:31	Prod5	Prod5.4784	WS04	Entered WS		
11209	23:58:31	Prod5	Prod5.4784	WS04	Processing Task Initiated	Task4	
11210							

Figure 2. Illustration of the resulting data from the simulation and sensors.

3. Results and Discussion

3.1. Students' Perceptions

Initially, 12% of the students who answered the questionnaire considered themselves as beginners regarding I4.0 concepts, 53% as intermediate, 35% as advanced, and zero students considered themselves as specialists, which reinforces the different levels of prior knowledge in the classroom. They answered 6 questions related to the contribution of the activity to clarifying the challenges and advantages of applying concepts and technologies of the fourth industrial revolution in Industrial Management, all with 5 alternatives between "Totally Disagree" and "Totally Agree". The results can be seen in Figure 3.

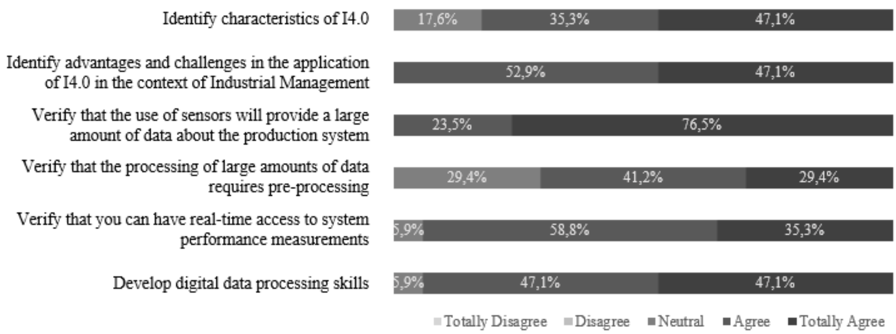

Figure 3. Questionnaire Results.

All responses alternated between "Neutral" and "I totally agree", which demonstrates that, in general, the activity achieved its objectives, in the students' perception. As the focus of the exercise was the interpretation and treatment of the data, the fourth question, related to data management, had a greater number of answers with "I totally agree". In addition, for questions 4 and 5, all students answered "Agree" or "Completely Agree" with the contribution of the class to their knowledge.

Finally, two subjective questions were suggested, asking participants to describe what they learned in the class about I4.0 and what they thought of the class. Several responses show an understanding of the breadth of the topic, going beyond the students' prior knowledge, which was mainly focused on the association of I4.0 with technologies, as shown by the answer of one student: *"That industry 4.0 goes far beyond automation, but encompasses different sectors of the company in a context to seek the improvement of production processes"*. So, they understood that I4.0 also includes the human factor, both in the organizational structure and culture of the industrial companies.

Other feedback positively emphasized the dynamics of the class, the practical activity, and the use of simulation: *"The dynamics of the class were quite interesting, we started with a theoretical approach on Industry 4.0 and then calculated and discussed the production indicators of an industrial unit. The efficient way in which we analyzed the amount of data on the production system and the advantage of systems integration was enriching too, based on performance indicators, make conscious and encouraged decisions"*. As a point of improvement, the lack of prior knowledge of the software was pointed out, which brought difficulties for some of the students: *"I think the feedback remains on the question that a large number of students are still unfamiliar with the platform and may have difficulties in generating satisfactory results"*.

In general, students liked the use of active learning to discuss and practice I4.0 skills, applying knowledge from different areas to improve the capabilities of the digital factory.

3.2. Facilitators' Perceptions

During the application period, two facilitators were available to guide the students, clarify doubts, and provide technical support with the software. After the session, a debriefing was conducted to gather individual feedback, and the learnings were grouped into three aspects for future applications.

- Model presentation: it is important to spend more time navigating the model with the simulation software to explain the positioning of the sensors, the applied business rules, and the simulation possibilities. It is also worth encouraging students to explore parameter changes on their own, identifying their impact on the system's exported results.
- Activity definition: when faced with the model and the results exported in table form, many students had difficulty defining how to calculate the indicators. In this sense, it is interesting to clearly define the steps for interpreting and handling the data, suggesting, for example, that they isolate the records for a single product and start by interpreting the events that occur in the factory.
- Support material: despite one of the study's objectives being the interpretation of the model and the perception of difficulties related by the students, it is important to provide support material for consultation after some time has passed since the activity begin. The creation of data dictionaries and formulas for manipulation is suggested to ensure that all students can reach the final stages of the activity.
- Data visualization: as the next step of the system, the exported data must be integrated with business intelligence software, and modeled to automatically calculate the performance indicators. This can be used to discuss real-time data analysis and real-time connections between systems.

In summary, the practical activity focused on the interpretation and handling of data, which revealed the different levels of experience among students. Other studies highlight that students' prior knowledge can be a challenge during learning activities [20]. The facilitators noticed a reluctance to interpret and manipulate the tools, which took up a lot of time in the activity. Additionally, the impact of student engagement and their learning profiles on the dynamics' progress is evident, limiting some groups' results.

4. Conclusion

The present article explored the development and application of a digital simulation model of a production system to facilitate the understanding of concepts related to I4.0 in a master's degree class. The tool used allowed students to simulate the interaction with data acquisition from sensors, data analysis, and industrial management concepts such as the application of KPI calculation and dispatch rules in real-time. The transdisciplinary nature of this learning experience was evidenced by the fact that it went beyond the boundaries of the course unit itself.

Difficulties in high amounts of data interpretation and manipulation by students were noticed, which is one of the characteristics of I4.0. In addition, there are challenges regarding the balance between theoretical activities and practical activities, mainly due to the limited time for the activity. Suggestions for future applications were listed related to three aspects: model presentation, activity definition, and support material.

The developed model will be adjusted for new applications, as well as complementary materials. The authors suggest that applications should be made with different profile classes and varied formats, such as longer workshops. Furthermore, the use of simulation has shown to be an effective way to enable students to have contact with real situations, developing competences for the different activities that will be demanded by I4.0.

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