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Uncertainty Management in Advanced Manufacturing Implementation: The Case for Learning Factories

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Abstract

Novel manufacturing concepts and technologies emerge in the environment of the fourth industrial revolution, also known as Industry 4.0, thus requiring new skills and abilities. However, technologies are associated with uncertainties related to technical specifications of products and production processes. Being able to identify and create strategies to overcome uncertainties is still a challenge to Industry 4.0. In this paper, we argue that Learning Factories are an effective solution to deal with new technologies and learning how to mitigate uncertainties. Learning Factories are testbeds and educational spaces that operate as a prototype for new concepts and technologies. Therefore, the questions that guide this paper are: What are the main uncertainties in Advanced Manufacturing? How can Learning Factories mitigate them? By describing a case, we will discuss concepts to mitigate uncertainties in a Learning Factory implementation.

Keywords: Industry 4.0; Technology uncertainties; Uncertainties mitigation

1. Introduction

The adoption of Advanced Manufacturing techniques in connected environments, creating smart factories, is triggering a constant change in industrial technologies, demanding new strategies to deal with uncertainties [1]. According to Abele et al. [2], companies are finding a volatile and dynamic environment undergoing major transformations, as a consequence of the new scenario brought about by Industry 4.0. In this new environment,

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several challenges emerge, related to connectivity, regulation, information analytics, etc. To overcome the challenges, companies need to quickly adapt to new conditions, learning how to deal with uncertainty.

The business focus that was mainly directed to quality and operational efficiency may now shift to transforming uncertainties in useful learnings that contribute to the evolution of new technologies. The model of learning-oriented planning encourages teams to systematically and continuously examine different categories of uncertainty. The practice allows managers to identify gaps in knowledge and record what is known to prioritize which uncertainties are most critical, to propose alternative hypotheses and ways of testing them to solve uncertainties [1].

In both academia and industry, Learning Factories are considered to be very similar to reality, i.e. a real factory environment, aimed at promoting education and training for manufacturing professionals. Therefore, Learning Factories integrate different teaching methods that aim to leave teaching-learning processes as close as possible to real industrial problems, supporting the application of the learning plan [3].

According to Abele et al. [2], there are two main objectives for Learning Factories, namely: technological and/or organizational innovation; and the effective development of competencies of their participants to become accustomed to complex and unusual situations. Learning Factories place a production environment as a learning environment. How to use Learning Factories to mitigate the uncertainty in Advanced Manufacturing implementation is an open space in literature. In order to deal with this issue, the article is structured in six sections, as follows. Section 2 describes the literature review. Section 3 highlights the research procedures. Section 4 presents the proposed uncertainty mitigation model. Section 5 presents a case application. Finally, Section 6 draws some concluding remarks and recommendations for further research.

2. Literature review

2.1. Advanced manufacturing technologies

The application of Advanced Manufacturing Technologies is characterized by: deployment of cyber-physical systems in product creation and usage; information exchange and communication based on Internet technologies; components as information carriers; and holistic concept of safety and security. To apply these new capabilities, a suitable information and communication technology (ICT) infrastructure is necessary, which enables to network people, resources and machines in cyber-physical production systems (CPPS) [4-6].

The rise of connectivity and the use of communication pattern protocols brought by Industry 4.0 increases the need for protection of industrial systems and manufacturing lines. Companies are in an environment of high volatility and transformation [2, 7] – a place of uncertainty.

2.2. Uncertainty management

Uncertainty is a fundamental concept applied in economics and administration [8]. It is an inevitable aspect of most projects [9]. Learning is the ability to conduct new and unique plans in the middle of the project. Learning comes from signals that are incompatible with the project team's predictions [9]. The project is redefined as new information emerges. This approach requires constant questioning of what is known and flexibility for fundamental changes throughout the project, if necessary [10].

2.3. Learning factories

Jaeger et al. [11] state that "[...] the lack of practical experience and the inability to cope with the greater complexity and dynamism that is present in today's workplaces create major problems for new employees" and continue to require changes that support a faster transfer of students to realistic situations as protagonists of the process.

The description of the characteristics of the Learning Factories in the literature emphasizes the realism of the configurations and the students' exposure to practical activities. The terms "production environment in accordance with reality" and "high degree of contextualization" are used by Abele et al. [2]. Tisch et al. [3] cite as characteristics the practice-oriented approach and the acquisition of competences through a self-directed process, which involves the integration of different teaching methods to make the teaching-learning process as close as possible to real industrial problems. The differentiation for real factories appears in Wagner et al. [12], listing among the limitations the physical size, spaces and groupings of machines, types and numbers of workstations included, and material handling systems.

3. Methodology

In order to acquire a broad knowledge of uncertainty management for the implementation of Advanced Manufacturing, we first took into consideration the possible ways a literature review can be developed [13]. The research design combines quantitative and qualitative strategies. It merges bibliometric and content analysis, to investigate a research topic, as these are complementary methods [14]. Decisions on which research method to apply are mainly taken based on the results from the databases, particularly the sample size to be reviewed [14]. The bibliometric approach is particularly useful for large sample sizes since they focus on metrics based on the number of publications and the publications metadata. Content analysis, on the other hand, focuses on an in-depth review of the sample but allows analytical flexibility [15, 16].

For this paper, an initial literature review paper sample was selected based on the ISI Web of Science (for uncertainty in manufacturing). The literature search for uncertainty in manufacturing was performed in April 2018. The following search string was applied, and no restrictions but the type of documents (Articles and Review) were considered: “Uncertainty management” and ("Industry 4.0" or "Advanced Manufacturing" or "Learning Factory") producing none results, and “Uncertainty management” and ("manufacturing" or "learning" or "factory"). This search resulted in 164 entries in ISI Web of Science main collection.

The first exclusion criteria were based on keyword selection. For the first keyword, the strings related to uncertainty management were considered for the filtering, resulting in 103 papers. For the second keyword, the strings related to Advanced Manufacturing Technologies were considered for the filtering, reducing the analysis in additional 7 papers. The remaining 96 papers were filtered according to the title analysis, with no exclusion. The second exclusion criteria were based on the content of the abstract. The 96 papers had their abstracts read for identifying those that did not fit within the scope of the study, excluding them from the final list, resulting in 60 papers. It was possible to have access to the full paper for 33 papers. These 33 papers were considered in the content analysis.

4. Results

4.1. Uncertainty factors for the implementation of Industry 4.0

The numbers of factors that characterize “Industry 4.0 implementation uncertainty” are numerous. The term “Technology” was mentioned by 14 documents among the researched paper sample, being the most cited factor to be monitored for mitigating uncertainty. For instance, systems in a very early phase of commercial development, require a lot of additional research and prototype implementations, the interests and hopes associated with these technologies are very high [17]. For additive manufacturing, for example, uncertainty management is required for identifying the sources with the largest relative contributions to the overall prediction error [18, 19].

“Resource” is the second most cited factor. In reality, implementation projects are usually limited by the available resources both people and machines [19]. Although the existing literature indicates the use of networks to access resources to cope with uncertainties [20], it is necessary “to formulate and execute future strategies, and achieve particular business objectives through the merging and coordination of resources and capabilities that exist both inside and outside of the company, including its customers’” [21].

“Market” is the third factor. In today’s market, to differentiate from rivals and to leverage competition capabilities, companies try to provide better pre and after-sales services for their customers [22]. The market environment is exposed to more and more degrees of uncertainty that is a critical agenda for operations managers in almost all industries [23]. Besides, the uncertain nature of the market demand makes the remanufacture planning even more complicated [24]. Therefore, it is one of the points to be analyzed to mitigate uncertainty.

4.2. Learning Factories as a mitigation tool

Based on the three main factors to be used to mitigate uncertainty (Technology, Resources, and Market) and on the implementation and transition characteristics of a Learning Factory, it is possible to propose the model described in Figure 1.

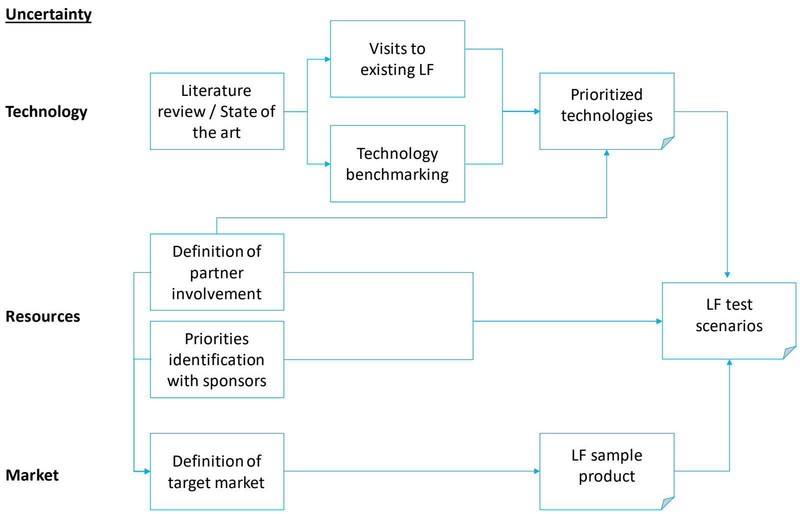

Fig. 1. Proposed model.

On the model, Technology uncertainty is mitigated through a literature revision of state of the art in manufacturing technology combined with a benchmarking of technologies in different Learning Factories and meetings with various partners from industry. Resources uncertainty is mitigated by the definition of the budget involved on the project and by the resources that are provided by the partners and the university that hosts the Learning Factory. Market uncertainty is mitigated by a definition of the target market and by regular meetings with the industry partners, the university representatives, and the financial sponsors of the Learning Factory (e.g. government or industrial sector associations).

5. Case application

With the model developed, it was possible to apply these concepts to mitigate uncertainties in a Learning Factory in Brazil. The selected Learning Factory is based on the assembly of a skateboard. The assembly station includes continuous production flows of standardized products as well as individualized production in the context of Industry 4.0 for personalized manufacturing and assembly, digital representation of the components, and production mapping. For this, simulations are developed considering different levels of standardization of the final product and different lot sizes, leading the students to reflect on different production arrangements. Each situation may require changes in layout, workflow, and division of tasks and application of production technologies, such as RFID (Radio Frequency Identification), among others. Considering that there was limited resources for the Learning Factory implementation, the model to mitigate uncertainties was applied.

Uncertainty mitigation applied in a Learning Factory

A research of Learning Factories around the world, based on articles from the previous CIRP Learning Factory Conferences (CLF) was conducted to understand the technology developed in various Learning Factories. CLF conference has proved to be one of the most relevant in this theme. According to Vogt [25], since 2011 this conference has been positioning as one of the most famous international forums for the sharing of research and new visions in the area of Learning Factories.

To understand and define the concept of Learning Factory, the CLF database was analyzed, aiming to cross-check their results and understand the challenges in the technology implementation of Advanced Manufacturing in Learning Factories and how to deal with related uncertainty.

The article search for technologies in Learning Factories considered all papers available online from previous CIRP Conference on Learning Factories. By 2017, there have been seven editions of the CLF conferences. Here, the proceedings of the 5th, 6th and 7th editions have been used, since these are all editions of the conference that have their articles available online. The Annals of the 1st, 2nd, 3rd and 4th editions could not be found and considered for this survey. Therefore, 86 papers from three past conferences were analyzed. The research indicated 77 demonstrators around the Learning Factories. Then it was counted the number of times each technology was employed. The resulting ranking of technologies is presented in Table 1.

The main technologies employed were Cyber-Physical Production System (for digitalization and information exchange between physical and digital), automation of processes, smart tracking of equipment, smart assembly of products, internet of things for data collection, and Additive Manufacturing.

Table 1. Technologies appearances and ranking of the most recurrent – 5th, 6th and 7th CLF Conferences.

Technologies	Count	Ranking
Cyber Physical Production Systems	**29**	**1**
Automation	**18**	**2**
Smart tracking	**14**	**3**
Smart Assembly	**11**	**4**
Internet of Things	**10**	**5**
Additive Manufacturing	**10**	**5**
Lean Production	8	7
Modular Manufacturing	7	8
Logistic Processes	7	8
Cloud	5	10
Artificial Intelligence	4	11
Big Data	4	11

Source: The Authors

To work on the other uncertainty factors – Resources and Market – it was necessary to understand the partners considering their core business and the solution that the partner were going to provide for the Learning Factory. Besides, foresight meetings were realized between the different partners in order to propose a list of technologies that are going to be dominant in the following years. Our Learning Factory currently has 10 partner companies from software, services, and hardware technology areas.

6. Conclusion

This paper provides a description and analysis of factors that compose uncertainty in Advanced Manufacturing in the literature. An analysis of the most frequent related topics reveals that Technology, Resources, and Market are the factors to be studied to mitigate uncertainty in Industry 4.0 implementation. They act as a guideline for implementation models. Learning Factories, as vivid models can, in its constitution or updating process, consider these factors to mitigate uncertainty in Industry 4.0.

This research has limitation due to the methodological choices, particularly related to the sample analyzed. The database choice, the search strings applied and topic examined have a possible bias; hence, essential articles can be missed in the process. The future of the research into the field is still open, and new technologies should be tested on the model proposed in this paper.

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