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Bernd M. Zunk
Amila Omazic

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Preface

Dear EPIEM conference participants!
Dear IEM colleagues & friends!

In order to initiate and foster collaboration in the scientific community of IEM academics, students and practitioners, the regular organization of international conferences and workshops is crucial.

It is therefore a great honour and pleasure for me to present the proceedings of the 15th EPIEM Conference, hosted by Graz University of Technology. I am all the more pleased that you, authors of this EPIEM conference volume and participants of this in-presence conference, have chosen to take the opportunity to…

- …submit a research/working paper,
- …present your research and
- …discuss the implications of your research with the conference participants.

I would particularly like to emphasize that conferences of this kind, which enable us to exchange knowledge and share experiences, are very important for us to grow as a scientific IEM community. We are convinced that this growth can be fostered by opening the doors to (new) interested network partners. These network partners will serve as multipliers, supporting the development of the IEM network and building bridges among motivated professors, lecturers, scientists and mindful thinkers in the IEM field.

At this point, I would like to take the opportunity to thank the members of the EPIEM programme and scientific committees for their excellent help, input and contributions. Furthermore, I would like to thank the representatives of Graz University of Technology and the Austrian Association of Industrial Engineering and Management for extending an invitation and giving us the opportunity to hold the 15th EPIEM Conference in such a dignified setting. Finally, my special thanks go to Ms. Amila Omazic BSc MSc, whose tireless work, renowned organisational talent, cultural awareness and personal skills have made the success of this in-presence conference uniquely possible.

Graz, 3/6/2022

Prof. Dr. Bernd M. Zunk
President of the EPIEM network

Industry 4.0 – Between Vision and Reality

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Abstract

Industry 4.0 is currently a frequently used keyword (hype) as well as a concept that is slowly taking shape and that supports basic changes in the sector of industrial production. Many of the assumptions, forecasts, and expectations regarding Industry 4.0 are unclear or hypothetical in nature. The known experiences often cannot be generalised enough; therefore, the potentials and effects can hardly be assessed. In addition to expectations and hopes, scepticism and fear have been expressed. In this context, the article presents fundamental insights into the (contradictory) “conditions of possibility” (Kant) of Industry 4.0, especially from the point of view of the technological impact assessment. Industry 4.0 is based on smart objects, comprehensive networking and convertible, agile production systems. This is associated with a wide range of economic expectations: reduction in throughput time, cost reductions, increased sales, increased quality and more flexible reactions to customer requests. For the participating individuals, the use of these largely “autonomous” technologies sometimes result in profound changes in their working environments and, thus, inevitably in their living environments (“Society 4.0”?), as well as the associated cultural patterns and practices (“Culture 4.0”?): People’s positions and roles are changing dramatically, both in terms of the workplace and the workload. Industry 4.0 extends far beyond the immediate technical and economic aspects and into social, cultural and human-mental (i.e. the individual) dimensions of production. The background presented in this article is based on the results of a corresponding scientific project, conducting in recent years. Insights which are derived from these results are summarized in the conclusion.

Keywords: Industry 4.0, Scepticism, Smart objects, Technological impact assessment, Working conditions

Background[1]

Industry 4.0 is a vision that is (slowly) taking shape currently, extending far beyond the directly technical and economic dimensions and into the social, cultural and human-mental (that means the individual) dimensions of production: ‘Previous industrial revolutions have energised national economies and increased the standard of living of millions of people. Likewise, the next production revolution could have far-reaching impacts. on productivity, income distribution, well-being and the environment. These impacts are likely to vary across industries, countries and sections of the workforce and some impacts may be hard to foresee’ (OECD, 2015, p. 3). In this context, this is probably why it is spoken of as the ‘fourth

[1] The following statement is based on Banse, 2020, 2021; Banse et al., 2019.

industrial revolution' (see the overview in Schwab, 2017). The innovation (hypo)thesis regarding Industry 4.0 states: Intelligent factories, in which highly qualified and flexible employees use intelligent automated, self-organized and optimized processes (in the form of cyber-physical systems: CPS), master the increasing complexity. The expectations as well as the fears are great, both in terms of the technical and associated economic, social and individual (transformational) effects. Thus, scholars refer to Work 4.0, Culture 4.0, or even Society 4.0. As a result, it is necessary to reflect on the associated changes comprehensively and systematically; these are technology-based, but affect all of society, especially in the form of technological impact assessments (and vision assessments).

The technological impact assessment (TIA) is included as a systematic procedure:

1. to bundle available knowledge based on the topic and decisions to be made;
2. to identify technological consequences that affect people's individual and social lives, including addressing knowledge problems that arise;
3. to assess these technological consequences regarding their acceptability (desirability) and including addressing any ethical questions that arise.

From the perspective of TIA, it becomes clear that Industry 4.0 primarily involves the analysis of the relationships between risk, risk knowledge and risk trading as well as refers to security in general, to information technology security in particular. One commonly and primarily accepted point is the questionable status of future knowledge. Niklas Luhmann formulated the associated dilemma by commenting 'The more rational you calculate and the more complex you make the calculation, the more facets come into the view with regard to uncertainty about the future' (Luhmann, 1991, p. 37).

A vision is born: Industry 4.0

Industry 4.0 is a concept that was developed only a few years ago, especially in Germany: 'Industry 4.0 is a term that goes back to the research union of the German federal government and a project with the same name in the high-tech strategy of the federal government' (Forschungsunion, 2012). The term Industry 4.0 itself was coined in 2011 and appeared in an article with the headline Industry 4.0: On the way to the 4th industrial revolution with the Internet of Things, which was written by the Co-President of the National Academy of Technology Science (acatech) Henning Kagermann among others. He wrote that 'In the next decade, new business models, based on cyber-physical systems, will be possible. […] The third industrial revolution […] will be detached in the next decade with the Internet of Things based on cyber-physical systems' (Kagermann et al., 2011).
In 2013, the theme Industry 4.0 was announced at the Hannover Fair for the first time (and, from then on, every year) as a guiding device. The Association of German Engineers (VDI Wissensforum GmbH) sent an important signal by holding this first major event about Industry 4.0 in Germany in 2013.

Industry 4.0 is nothing less than a new qualitative level in the computerization and digitization of material goods production: 'The term Industry 4.0 describes the fourth change of paradigm in production – from mechanization (steam engine), by electrification (assembly line) and computerization (programmable logic controller / PLC) to the network of intelligent production engineering' (Bosch, 2015, p. 5). In order to be able to capture the social change which will be, is, or can be associated with Industry 4.0 (e.g. opportunities, potentials), it is necessary to assign these technical and technical-organizational changes to larger historical periods or relations. However, this cannot be done at this point.

In theory and practice: Industry 4.0 will be reality?![2]

In the meantime, Industry 4.0 has become more than an idea or (mere) vision: It is gradually becoming reality. Initially applied as a theory, it has become increasingly applied in practice. Currently, in all developed and industrialized countries – but not only there – highly numerous and variegated initiatives, activities, projects, statements and publications on Industry 4.0 are becoming steadily more common, especially in areas of politics, economy, science and education as well as increasingly in areas of civil society. Indeed, the hype that began around 2012 has simply gained speed: Industry 4.0 is not being applied theoretically, but is becoming more frequently part of the practical reality. Correspondingly, the problems or obstacles associated with it are becoming clear(er). The numerous considerations and explanations are certainly related to the fact that numerous (country-specific) strategies (see below) and players in political, economic and scientific arenas have existed for several years. In particular, players such as ministries, research and development institutions as well as engineering associations and companies play important roles.

Surveys demonstrate rudimentarily the extent to which Industry 4.0 has actually 'arrived on the ground-floor' (see Schlund and Pokorny, 2016, 2017, for a more in-depth analysis):

- the majority of the surveyed companies (> 50%) have an Industry 4.0 strategy;
- Industry 4.0 projects focus heavily on central aspects of creating value: manufacturing, assembly, logistics as well as production planning and control;
- most of the companies needed six to twelve months to implement Industry 4.0 projects;
- the main obstacles reported are uncertainty about the economic benefits (> 60%) and a lack of expert knowledge, respectively, skilled workers (approx. 58%).

Another example is the so-called Industry 4.0 Index 2018 measurement, which has been collected by the business consultancy Staufen AG for several years (see Pinnow and Pinnow, 2019, pp. 342f.). In 2018, the measurement revealed that 52% of the 450 investigated industrial enterprises had applied Industry 4.0 in the current year, either in individual projects or even comprehensively throughout the enterprise (in 2014, the percentage was 15%). The measurement also revealed that around every tenth company completely blocked itself off to this technological trend (Staufen, 2018a): 'There are still hesitant companies which continue to analyse the developments of the markets and applications. But there is only a little doubt that these companies also will enter into the active phase soon – even because they have to match with their competitors or with their own network' (Staufen, 2018b). The expectations for Industry 4.0 are extremely high. Comprehensive (especially positive evaluative) political, economic, social and individual effects have been forecast. Therefore, some scholars refer to Work 4.0 or Society 4.0:

- *political*: high (national) chances in (international) competition for digital domination;
- *economical*: reduction of time, cost-cutting, sales increases, quality intensification and more flexible reactions to customer requests;
- *social/cultural*: profound changes in the working environment and, beyond that, in the entire living environment – (dramatic) changes in working life (especially with regard to working hours, work spaces, work environments and the workload: Work 4.0?), as well as in the daily cultural patterns and practices (Culture 4.0?);
- *individual-mental*: diverse changes in terms of health and employability, respectively, efficiency, as well as in the freedom of decision and individual readiness to take on responsibility.

[2] https://www.vdi.de/index.php?id=58659 [26.07.2018].

It is clear that Industry 4.0 has a comprehensive transformative potential and that it is still uncertain which effects will become reality. Accordingly, it is normal for expectations and hopes, but also discomfort, scepticism, or even fears to be expressed. Specifically, many of the assumptions, forecasts and expectations are (still) uncertain or are hypothetical in nature, and the known experiences often cannot yet be sufficiently generalized. This makes it difficult to assess the requirements, potentials and effects fully. This is also associated with at least the following three dilemmas regarding Industry 4.0: the so-called “Forecast Dilemma”,[3] the so-called “Technology Policy (Collingridge) Dilemma”[4] and the “Ironies of Automation”, first described in 1987 by Lisanne Bainbridge[5].

In the last years, further considerations in this direction were made. Two examples: (i) The European Commission issued a report on “Industry 5.0” (see EC, 2021, 2022) and (ii) Keidanren (the Japan Business Federation) published the concept of “Society 5.0” (see Keidanren, 2018). The European Commission oriented on sustainability, human-centricity and resilience for Europe and European industry, as well as benefits for all concerned. Keidanren developed “Society 5.0” concept to create ‘a society where anyone can create value anytime, anywhere, in security and harmony with nature, and free from various constraints that currently exist’ (Keidanren, 2018). The technical basis for this concept is especially the Internet of Things, artificial intelligence and robotics. In my opinion, both approaches are based on the Industry 4.0 concept, but these drive its development in two certain directions:

I. *The views are not narrow technology- and economy-centric views, but are focused on social contexts.*
II. *The future must be shaped in a creative transformation process (see also Schwab 2018).*

Conclusion: Multi-Perspective Industry 4.0

Some years ago, the EA European Academy of Innovation and Technology Assessment Bad Neuenahr-Ahrweiler (Germany; currently the Institut für qualifizierende Innovationsforschung und -beratung), implemented a project called Industry 4.0 in Central, Southern and Eastern Europe from the perspective of technological impact assessment and vision assessment.

One result is a report which indicates the status of Industry 4.0 in the following countries: Germany, Austria, Poland, Romania, Slovenia and the Czech Republic (Banse et al., 2019). These country reports contain a wealth of relevant information about the countries and Industry 4.0 in general. So far, the conclusions that can be reached about Industry 4.0 can be summarized as follows:

[1] Industry 4.0 and digital change have a disruptive and transformative potential (social perspective).
[2] Industry 4.0 includes more than technology and economy (socio-technical perspective).

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[3] Prediction dilemma: To what extent are statements about opportunities such as dangers due to the complexity of the object, the openness of the future and the change of conditions possible or appropriate? To what extent can “complete information” be generated? (Banse and Friedrich, 1996. pp. 156ff.).

[4] Technology-political dilemma: The more highly developed the technology and the more familiar the contexts of its use, the better the prospects for reliable knowledge of the consequences. However, there is no other way to influence the technology formative because the development is then completed or so advanced that it is hardly possible to change direction for economic reasons (Collingridge, 1980; Wagner-Döbler, 1989).

[5] Ironies of automation: As automation is taking away the easy part of the job from humans, automation can make the difficult part of a human’s job even harder. Even a highly automated system needs people to monitor the system and to respond to incidents. System designers try to eliminate the human factor as a source of errors, but system designers are also humans (Bainbridge, 1987; Lüdtke, 2015, p. 127).

[3] No quick and easy solutions can be expected (time and design perspective).
[4] Industry 4.0 solutions require multi-disciplinarity and internationality (research perspective).
[5] Industry 4.0 requires adequate basic education, training and further training (educational perspective).
[6] Culture needs to be considered, especially with regard to
- the culture of everyday life (usage practices and patterns)
- error culture (enacted executions/assessments as part of the corporate culture);
- safety culture (as part of human-machine interaction at the micro and meso levels);
- culture of innovation (as the implementation practice of innovations).

[7] Necessity of technical ethics: It is essential for people to always be able to do more than they are allowed to do. But in order to determine which technical options they have to act, some may (should) be pursued and some should not. Ethically formulated, this means that good reasons must be named (i.e. the so-called technological imperative does not apply).
[8] Technology assessment and vision assessment serve as the basis to formulate these good reasons. The topic Industry 4.0 includes many spheres (of activity); thus, it is not constructive to maintain a purely disciplinary view of the effects. In the meantime, Industry 4.0 has become more than just an idea, because it has already been gradually implemented. At the same time, the application of Industry 4.0 is resulting in more than just technical changes, because it is causing transformations in society, i.e. it also has potentials that extend across national borders. Therefore, Industry 4.0 requires solutions to a number of problems which can only be developed an inter- and transdisciplinary basis and otherwise only in international cooperation.

References

Bainbridge, L., 1987. Ironies of Automation. In: Rasmussen, J., Duncan, K., Leplat, J. (Eds.). New Technology and Human Error. John Wiley & Sons, Chichester a.o., pp. 271–283.

Banse, G., 2020. Industry 4.0 and Culture 2.0. In: Erdmann, J., Egbert, B., Ruda, S., Machleidt, P., Mraček, K. (Eds.). Industry 4.0, Culture 2.0 and new Media – Realitys, Tendencies, Myths. trafo Wissenschaftsverlag, Berlin, pp. 23–36 (in German).

Banse, G., 2021. “Industry 4.0” – Expectations and Development in Germany. A Technology Assessment Point of View. In: Egbert, B., Erdmann, J., Merejo, A. (Eds.). Digitisation and Transformation – Society, Technology, Education. trafo Wissenschaftsverlag, Berlin, pp. 27–40.

Banse, G., Friedrich, K., 1996. Socially Oriented Technological Design – Reality or Illusion? – Dilemmas of an Approach. In: Banse, G., Friedrich, K. (Eds.). Technology between Knowledge and Design. Philosophical Views of Engineering Sciences and Technological Action. Edition Sigma, Berlin, pp. 141–164 (in German).

Banse, G., Thelen, J., Lingner, St. (Eds.), 2019. Industry 4.0 between Idea and Reality. A Country Comparison. trafo Wissenschaftsverlag, Berlin (partially in German).

Bosch Software Innovations GmbH, 2015. Industry 4.0: From Vision to Practice. Berlin. – URL: https://www.bosch-si.com/media/de/bosch_si/manufacturing/whitepaper/final_whitepaper_vision_into_practice_de.pdf [26.07.2018] (in German).

Collingridge, D., 1980. The Social Control of Technology. Continuum International Publishing Group, London a.o.

EC – European Commission, 2021. Industry 5.0 – Towards a Sustainable, Human-centric and Resilient European Industry, Brussels (Publications Office). – URL: https://data.europa.eu/doi/10.2777/308407 [05.04.2022].

EC – European Commission, 2022. Industry 5.0, a Transformative Vision for Europe: Governing Systemic Transformations Towards a Sustainable Industry, Brussels (Publications Office). – URL: https://data.europa.eu/doi/10.2777/17322 [05.04.2022].

Forschungsunion, 2012. Secure Germany's Future as a Production Location. Recommendations of Implementation for the Future Project Industry 4.0. Final Report of the Working Group Industry 4.0, Berlin. – URL: http://www.forschungsunion.de/pdf/industrie _4_0_umsetzungsempfehlungen.pdf [11.02.2017] (in German).

Kagermann, H., Lukas, W.-D., Wahlster, W., 2011. Industry 4.0: With the Internet of Things on the Way to the 4th Industrial Revolution. In: VDI-Nachrichten, 1. April. – URL: http://www.vdi-nachrichten.com/Technik-Gesellschaft/Industrie-40-Mit-Internet-Dinge-Weg-4-industriellen-Revolution [26.07.2018] (in German).

Keidanren, 2018. Society 5.0 – Co-creating the Future. – URL: https://www.keidanren.or.jp /en/policy/2018/095.html [05.04.2022].

Lüdtke, A., 2015. Pathways from Irony towards Serious Automation. In: Botthof, A., Hartmann, E. A. (Eds.). Future of Work in Industry 4.0. Springer Verlag, Heidelberg a.o., pp. 125–146 (in German).

Luhmann, N., 1991. Sociology of Risk. De Gruyter Verlag, Hamburg (in German).

OECD – Organisation for Economic Co-operation and Development, 2015. Enabling the Next Production Revolution: Issues Paper. Paris, March 09 (DSTI/IND(2015)2). – URL: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/IND%282015%292&docLanguage=En [06.01.2019].

Pinnow, C. J., Pinnow, D. C., 2019. Industry 4.0 in Germany – Thoughts and Recommendations on the Discrepancy between Theory and Practice. In: Banse, G., Thelen, J., Lingner, St. (Eds.). Industrie 4.0 between Idea and Reality. A Country Comparison. trafo Wissenschaftsverlag, Berlin, pp. 333–350 (in German).

Schlund, S., Pokorni, B., 2016. Industry 4.0 – What is the Status of the Work Design Revolution? Results of a Survey of Production Managers in German Companies. Ulm/Stuttgart (Ingenics AG; Fraunhofer-IAO). – URL: https://www.ingenics.de/assets /downloads/de/Industrie40_Studie_Ingenics_IAO_VM.pdf [26.07.2018] (in German).

Schlund, S., Pokorni, B., 2017. Industry 4.0 – What is the Status of the Work Design Revolution? In: Banse, G., Busch, U., Thomas, M. (Eds.). Digitization and Transformation. Industry 4.0 and Digitized Society. trafo Wissenschaftsverlag, Berlin, pp. 139–164 (in German).

Schwab, K., 2017. The Fourth Industrial Revolution. Random House, New York a.o.

Schwab, K., 2018. Shaping the Future of the Fourth Industrial Revolution: A Guide to Building a Better World. Penguin Random House, New York a.o.

Staufen AG, 2018a. German Industry 4.0-Index 2018. A Study of Staufen AG and Staufen Digital Neonex GmbH. – URL: https://www.staufen.ag/fileadmin/HQ/02-Company/05-Media/2-Studies/STAUFEN.-Studie-Industrie-4.0-Index-2018-Web-DE-de.pdf [31.12.2018] (in German).

Staufen AG, 2018b. German Industry 4.0-Index 2018: Digital Transformation Passes the 50 Percent Mark. – URL: https://www.staufen.ag/de/unternehmen/news-events/news/newsdetail/2018/08/deutscher-industrie-40-index-2018-digitale-transformation-ueberspringt-50-prozent-marke-1/ [29.08.2018] (in German).

Wagner-Döbler, R., 1989. The Dilemma of Technology Control. Effects of Technological Development and Problems of Technological Policy. Edition Sigma, Berlin (in German).

Lean Thinking, Society 5.0 and Industry 5.0 Synergies

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Abstract

This paper objective is to discuss the importance of a fundamental mind-set as Lean Thinking in helping transformational changes provided by the Industry 4.0 technologies. It also discusses synergies of less known concepts such as Society 5.0 and Industry 5.0 with Lean. These concepts allow immensurable economic, social and of sustainability benefits. At the same time, promote societal transformations that are already happening. Allied with society growth on the digital path, physical and safety conditions must be consistent to maintain people creativity, responsibility, resilience and critical thinking. In this way, people will be prepared when digital does not work or disruptive events happen (e.g. pandemic, catastrophic and war situations).

Keywords: Lean Thinking, Society 5.0, Industry 4.0, Industry 5.0

Introduction

Lean Production System was the name given to Toyota Production System (TPS) by MIT International Motor Vehicle Program researcher John Krafcik in 1988 (Krafcik, 1988). Toyota was noticed in the car automobile industry and its success was attributed to the production system. This was kind different from their congeners, particularly, from Ford. Toyota had a more human approach to assembly line concept of Ford by considering the operator in the line more than just a machine extension. Toyota put the operator working in teams and think about the process, improving it. With this and many new concepts (e.g. JIT, Jidoka, kaizen), Toyota evolved from a techno centric production system to a more anthropocentric production system. Later on, Womack and colleagues popularized this production system by launching the book "The Machine that changed the world" (Womack et al., 1990). Then, they published the Lean Thinking five principles a fundamental mindset for companies to follow if they are interested in implementing a production system like TPS (Womack & Jones, 1996). Since 1977 some papers and books have been characterizing the TPS (Monden, 1983; Ohno, 1988; Shingo, 1989; Sugimori et al., 1977).
All of these reinforce the operators' role in this production system and putting the technology as needed to help them in their functions. As an example, quotations such as "In short, robots, like any other kind of technology must remain the tool of men and not the other way around!" (Monden, 1998, p. 236), "… a work environment that is safe physically, emotionally and professionally for every employee" (Spear & Bowen, 1999) or "Adopt and adapt technology that supports your people and processes" (Liker, 2020) are possible to find related to TPS. This is constantly referred because main driving principles of TPS are Respect for people and Continuous improvement since its origins. The "respect-for-human system" is part of the title of Sugimori (1977) paper.

In a technology world where, from the moment we get up until the moment we go to bed, technology is around us, in our houses, in our car, in our job, in our leisure time, this is important to remember.

Undoubtedly, the technology importance has been increasing in an exponential rhythmus in all human and industrial activities. The Fourth Industrial Revolution or Industry 4.0 (Kagermann et al., 2013) pointing out the need to integrate technologies in the industry and they had been integrated but they need to be in a pace with human capability of adaptation. Society 5.0 (Keidanren, 2018) and Industry 5.0 (Breque et al., 2021) concepts recently promoted are calling for a fundamental shift of society and economy towards a new paradigm that drive the transition to a sustainable, human-centric and resilient European industry. Thus, this paper discusses how Lean Thinking principles enabled by technologies of Industry 4.0 are addressing the Society 5.0 concept and Industry 5.0 pillars.

This paper is structured in four main sections. A background followed this introduction. Then, in the third section, some results about synergies and implications are discussed. Finally, the fourth section presents the main conclusions and future work.

Background

According to Womack and Jones (1996), Lean Thinking book was launched as a request from many companies interested in implementing Lean Production, after reading the best-seller book from the same authors. These authors defined five Lean Thinking principles: 1) Value; 2) Value Stream; 3) Flow; 4) Pull production and 5) Pursuit Perfection. These intended to drive the organizations in a journey that transform them in a Lean Enterprise (Womack & Jones, 2003) by adding value by constantly eliminating waste. Wastes were categorized by Ohno (1988) in seven types: 1) Transports; 2) Inventory; 3) Motion; 4) Waiting; 5) Defects; 6) Over-processing and 7) Overproduction.

This last waste type is considered the worst type because originates all the others, implies too many costs, not only for the clients but more important for the planet. In an overproduction situation, organizations produce more than clients need. This does not mean the organizations are satisfying them properly. Many times, this do not happen and all energy, water, natural resources employed to make the products are wasteful. Moreover, more toxic substances were released to the air, water and earth (Moreira et al., 2010; US-EPA, 2007). Pursing this reduction, global development, responsible consumption and production will be achieved (Alves et al. 2019).

Another type of waste, recognized by many authors, namely Liker (2004) is the untapped human potential. This is related with the need to capitalize on operator suggestions by their creative thinking or inventive ideas. This is considered one of key concepts of TPS (Monden, 1998). People could think that with technology that surround us, this creativity did not seems needed but, more than ever, we need people to be creative and Lean promotes this (Alves, Dinis-Carvalho, and Sousa 2012).

Nevertheless, it is important to remember that when technology is integrated in a system, this could inhibit this creativity and restrict people actions. This is why technology introduction needs to be well planned and justified. Nevertheless, when technologies are well integrated, it enables people creativity and unlock their potential. In literature, there are many examples describing this, mainly when this technology is pulled by Lean Thinking (Bittencourt et al., 2021). According to Pereira et al. (2019), Lean Thinking integrated with Industry 4.0 allow to:

- Develop smart products by Lean Product Development;
- Develop and improve processes to deal with smart machines;
- Transform conventional manufacturing systems into smart factories;

- Promote thinkers, decision-makers and problem-solvers aware of their potential and regarding risks;
- Establish good relations with suppliers and with customer (internal & external);
- Provide eco-efficient solutions that pursuit the SD goals by exploring Lean-Green synergy.

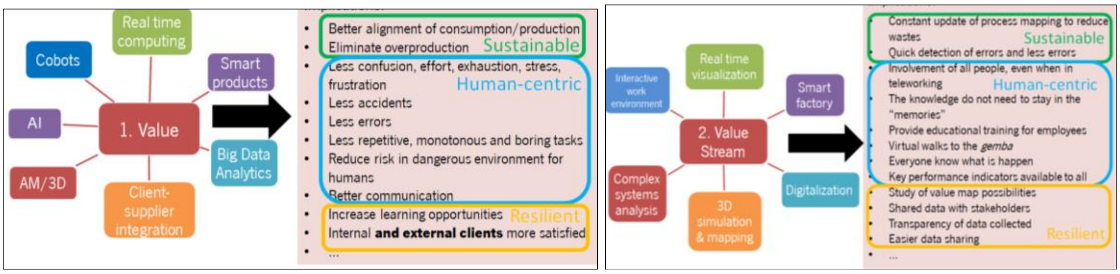
Technology is important and must be part of engineering curricula but more important are the competencies that will help students to use them wisely. It is not by chance that from the top ten competencies identified by World Manufacturing Forum in 2019 (World Manufacturing Forum, 2019) six of them were related with transversal competencies. Others give the same importance to such competencies (World Economic Forum, 2015, 2018). These competences must be part of Society 5.0 concept. Keidanren (Japan Business Federation) defined this concept in a World Economic Forum meeting as "*People will be expected to exercise rich imaginations to identify a variety of needs and challenges scattered across society and the scenarios to solve them, as well as creativity to realize such solutions by using digital technologies and data. Society 5.0 will be an Imagination Society, where digital transformation combines with the creativity of diverse people to bring about "problem solving" and "value creation" that lead us to sustainable development. It is a concept that can contribute to the achievement of the Sustainable Development Goals (SDGs) adopted by the United Nations*." (Nakanishi, 2019). This concept was introduced by Japan Prime-Minister in CEBIT2017 and it is seen a strategy to deal with the impact of an ageing population (Ferreira & Serpa, 2018; Keidanren, 2018; Komiyama & Yamada, 2018; A. G. Pereira et al., 2020).
In the same vein, European Commission launched a report discussing the concept of Industry 5.0 (Breque et al., 2021) as a vision that recognizes:

- Power of industry to achieve societal goals beyond jobs and growth;
- Need to become a resilient provider of prosperity, by making production respect the boundaries of our planet;
- Need to place the wellbeing of the industry operator at the centre of the production process.

According to the same report, Industry 5.0 complements the existing Industry 4.0 paradigm by having research and innovation drive the transition to a sustainable, human-centric and resilient European industry, being these three pillars for this new paradigm. Moreover, it referred that Society 5.0 and Industry 5.0 are related in the sense that both concepts refer to a fundamental shift of society and economy towards a new paradigm.

Industry 4.0 pulled by Lean Thinking principles in Industry 5.0 pillars

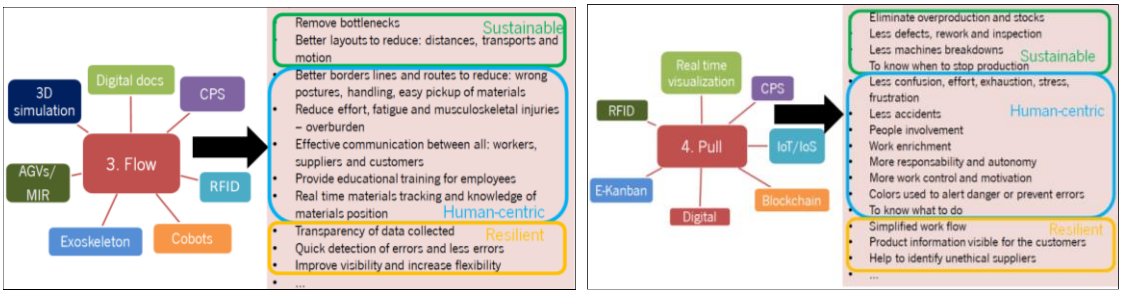
In this section, it is discussed how Industry 4.0 technologies pulled by Lean Thinking principles implementation implies human-centric, sustainable and resilience benefits. These three are the Industry 5.0 pillars, as referred in the previous section.
The first principle is Value, which is concerned with identifying (or creating) value from the client's perspective, i.e. any activities (waste) for which he or she is unwilling to pay. Figure 1a) depicts some of the technologies that enable the first principle, as well as some of the consequences of it in terms of human-centric (indicated by a blue colour line), sustainable (marked by a green colour line), and resilience (marked by yellow colour). The second principle, Value Stream, requires organizations to focus on removing recognized wastes from the value chain. Figure 1b) depicts some of the technologies that make the second principle possible, as well as some of its consequences, (same colours were used).



a) b)

Figure 1: Industry 4.0 technologies pulled by Lean Thinking principles: a) Value b) Value Stream; and synergies with Industry 5.0 pillars

The third principle is Flow. It is necessary to eliminate wastes after they have been identified in order to maintain flow. Figure 2a) depicts some of the technologies that enable the third principle, as well as some of its consequences. The fourth concept, pull production, entails allowing customers to pull what they want, when they need it, and in the amounts, they require (Just-in-time). Figure 2b) depicts this, along with the technology that enable it and some consequences.



a) b)

Figure 2: Industry 4.0 technologies pulled by Lean Thinking principles: a) Flow b) Pull production; and synergies with Industry 5.0 pillars

Finally, Figure 3 presents the fifth principle – Pursuit perfection – that means to continuously searching for wastes in order to eliminate them. These could be related with human effort, untapped human potential, environmental wastes, among others.

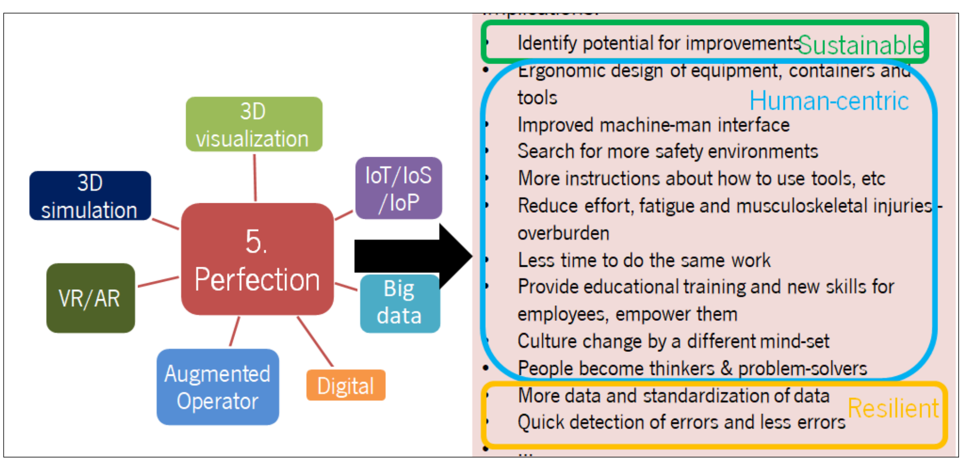


Figure 3: Industry 4.0 technologies pulled by Pursuit Perfection Lean Thinking principle and synergies with Industry 5.0 pillars

The technologies described were only used as examples; many more are likely to assist operators in decreasing their job effort. This paper's author worked on projects with industry to accomplish such improvements. Some of them are available elsewhere (Abreu et al., 2017; Afonso, Alves, et al., 2021; Afonso, Alves, et al., 2021; Alves et al., 2019; Freitas et al., 2017; Frontoni et al., 2020; Pereira et al., 2016; Witeck, Alves, Almeida, et al., 2021; Witeck, Alves, Santos, et al., 2021).

Conclusion

Lean Thinking principles implementation pulls Industry 4.0 technologies that conduct to the accomplishment of Industry 5.0 pillars. Although such relations were empirically presented in this paper, the perception of them resulted from the experience of this paper 'author involved in projects developed in industry. To uncover further evidence of such consequences, more in-depth research using more formal research methodologies is required. A systematic literature review and several cases could be used to support such research.

Acknowledgment

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References

Abreu, M. F., Pereira, A. C., Silva, A., Silva, F., Ferraz, F., Alves, A. C., Oliveira, J. A., Gomes, M., Analide, C., Cardoso, J., & Vicente, S. (2017). Collaborative process mapping to improve work instructions and standardized work. In Advances in Intelligent Systems and Computing (Vol. 569). https://doi.org/10.1007/978-3-319-56535-4_60

Afonso, T., Alves, A. C., & Carneiro, P. (2021). Lean Thinking, Logistic and Ergonomics: Synergetic Triad to Prepare Shop Floor Work Systems to Face Pandemic Situations. International Journal of Global Business and Competitiveness.

Afonso, T., C. Alves, A., Carneiro, P., & Vieira, A. (2021). Simulation pulled by the need to reduce wastes and human effort in an intralogistics project. International Journal of Industrial Engineering and Management, 12(4), 274–285.

Alves, A. C., Kahlen, F.-J., Flumerfelt, S., & Siriban-Manalang, A. B. (2019). Lean Engineering for Global Development. Springer International Publishing.

Alves, A. C., Dinis-Carvalho, J., & Sousa, R. M. (2012). Lean production as promoter of thinkers to achieve companies' agility. The Learning Organization, 19(3), 219–237.

Alves, A. C., Ferreira, A. C., Maia, L., P. Leão, C., & Carneiro, P. (2019). A symbiotic relationship between Lean Production and Ergonomics: insights from Industrial Engineering final year projects. International Journal of Industrial Engineering and Management, 10(4), 243–256. https://doi.org/10.24867/IJIEM-2019-4-244

Bittencourt, V. L., Alves, A. C., & Leão, C. P. (2021). Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review. International Journal of Production Research, 59(5), 1496–1510. https://doi.org/10.1080/00207543.2020.1832274

Breque, M., Nul, L. De, & Petridis, A. (2021). Industry 5.0: Towards a sustainable, human-centric and resilient European industry. https://doi.org/10.2777/308407

Ferreira, C. M., & Serpa, S. (2018). Society 5.0 and Social Development: Contributions to a Discussion. Management and Organizational Studies, 5(4), 26.

Freitas, A. C., Maio, A. F., Maia, P., Gomes, N., Nogueira, A., Fernandes, J. M., Carvalho, M. S., Alves, A. C., Costa, A., Afonso, P., Silva, P. V, Barbosa, D., & Machado, S. (2017). Savings in internal logistics using a RFID-based software system in a lean context. Proceedings of Int. Conference on Computers and Industrial Engineering, CIE.

Frontoni, E., Rosetti, R., Paolanti, M., & Alves, A. C. (2020). HATS project for lean and smart global logistic: A shipping company case study. Manufacturing Letters, 23, 71–74.

Kagermann, H., Wahister, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry.

Keidanren. (2018). Society 5.0: co-creating the future. www.keidanren.or.jp/en/policy/2018/095_outline.pdf

Komiyama, H., & Yamada, K. (2018). New Vision 2050. Springer Japan.

Krafcik, J. F. (1988). Triumph of the Lean Production System. Sloan Management Review, 30(1), 41–52.

Liker, J. (2020). When the Toyota Way Meets Industry 4.0. The Lean Post.

Liker, J. K. (2004). The Toyota way: 14 management principles from the world´s greatest manufacturer. In McGraw-Hill.

Monden, Y. (1983). Toyota production system: practical approach to production management. Engineering & Management Press.

Monden, Y. (1998). Toyota Production System: An Integrated Approach to Just-In-Time (Third). Engineering and Management Press.

Moreira, F., Alves, A. C., & Sousa, R. M. (2010). Towards Eco-Efficient Lean Production Systems. In IFIP Advances in Information and Communication Technology, Volume 322, Balanced Automation Systems for Future Manufacturing Networks (pp. 100–108).

Nakanishi, H. (2019). Modern society has reached its limits. Society 5.0 will liberate us. World Economic Forum Meeting. https://www.weforum.org/agenda/2019/01/modern-society-has-reached-its-limits-society-5-0-will-liberate-us

Ohno, T. (1988). Toyota Production System: beyond large-scale production. Productivity Press.

Pereira, A., Abreu, M. F. F., Silva, D., Alves, A. C., Oliveira, J. A., Lopes, I., & Figueiredo, M. (2016). Reconfigurable Standardized Work in a Lean Company – A Case Study. Procedia CIRP, 52, 239–244.

Pereira, A., Dinis-Carvalho, J., Alves, A., & Arezes, P. (2019). How Industry 4.0 can enhance Lean practices. FME Transactions, 47(4), 810–822. https://doi.org/10.5937/fmet1904810P

Pereira, A. G., Lima, T. M., & Charrua-Santos, F. (2020). Society 5.0 as a Result of the Technological Evolution: Historical Approach. In T. Ahram, R.Taiar, S. Colson, & A. Choplin (Eds.), Advances in Intelligent Systems and Computing. In Human Interaction and Emerging Technologies (pp. 700–705).

Shingo, S. (1989). A Study of the Toyota Production System from an Industrial Engineering Viewpoint (Revised Ed). Productivity Press.

Spear, S., & Bowen, H. K. (1999). Decoding the DNA of the Toyota Production System. Harvard Business Review, 77(5), 96–106.

Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977). Toyota production system and Kanban system Materialization of just-in- time and respect-for-human system. International Journal of Production Research, 15(6), 553–564.

US-EPA. (2007). The Lean and Environment Toolkit. www.epa.gov/lean

Witeck, G. R., Alves, A. C., Almeida, J. P., Santos, A. J., Lima, A. L., & Machado, R. J. (2021). Running Workshops to Identify Wastes in a Product Development Sample Shop. In R. C. A. M. Rocha Á., Adeli H., Dzemyda G., Moreira F. (Ed.), Trends and Applications in Information Systems and Technologies. WorldCIST 2021. Advances in Intelligent Systems and Computing, vol 1366 (29 March 2, pp. 234–243). Springer, Cham.

Witeck, G. R., Alves, A. C., Santos, A. J., Lima, A. L., Machado, R. J., de Almeida, J. P., Morais, J., & Fernandes, T. (2021). Leaning processes by mobile technologies in a Product Development Sample Shop. 2021 International Conference on Engineering and Emerging Technologies (ICEET), 1–6. https://doi.org/10.1109/ICEET53442.2021.9659798

Womack, J. P., & Jones, D. T. (1996). Lean Thinking: Banish Waste and Create Wealth in your Corporation (F. Press (ed.)). Free Press.

Womack, J. P., & Jones, D. T. (2003). Lean Thinking: Banish Waste and Create Wealth in Your Corporation (First Free). Free Press.

Womack, J. P., Jones, D. T., & Roos, D. (1990). The Machine That Changed the World: The Story of Lean Production. Rawson Associates.

World Economic Forum. (2015). The skills needed in the 21st century. New Vision for Education - Unlocking the Potential of Technology. https://widgets.weforum.org/nve-2015/chapter1.html

World Economic Forum. (2018). The future of jobs report 2018. http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf

World Manufacturing Forum. (2019). Skills for the future of manufacturing. https://worldmanufacturing.org/wp-content/uploads/WorldManufacturingFoundation2019-Report.pdf

Industry 4.0 Technologies as Organizational Capability for Environmental Sustainability in Supply Chains: An Empirical Study

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Abstract

Current competitive dynamics require companies to develop capabilities that allow them to implement environmental practices in their supply chains. This article aims to evaluate whether Industry 4.0 technologies facilitate the implementation of the environmental practices of GSCM approach, and the effect of the latter on organizational performance. The modeling of Partial Least Squares Structural Equations Model (PLS-SEM) was both applied and tested in a sample of 200 Colombian manufacturing companies. The results show that, on a general level, Industry 4.0 technologies have direct and positive impacts on green supply chain practices, and that these, in turn, have direct and positive impacts on economic and environmental performance. The main contribution of the present study was that it enabled the identification of Industry 4.0 technologies as relevant organizational capabilities for the implementation of environmental practices in supply chains, as well as the improvement of organizational performance.

Keywords: Industry 4.0 technologies, GSCM, Performance, Sustainability

Introduction

Progressive globalization, rapid market evolution, continuous innovation, and the need for rapid adaptation to new technologies, force the business environment to become dynamic (Lu et al. 2020), increasing supply chain vulnerability (Qin et al., 2021). As a result, manufacturing companies have been forced to redesign their supply chains in order to find a balance between economic growth and environmental sustainability (Lee, 2020). Green Supply Chain Management (GSCM) is a strategy with which to face sustainability challenges, because thereby, it is possible to redesign supply, production, and delivery operations, and to achieve better performance, in terms of consumption of natural resources, environmental protection, and economic value creation (Teixeira et al., 2020)

In this scenario, the development and adoption of Industry 4.0 technologies has become more of a necessity than an alternative (Bag et al. 2020). The benefits of Industry 4.0 technologies in the management of the green supply chain and in the design of strategies to achieve improved supply chain performance have been recognized in the literature (Singh & El-Kassar, 2019; Sarkis et al., 2020).

However, there are research opportunities in the study of this capability and its effect on the implementation of the GSCM approach and organizational performance. In the first place, Industry 4.0 technologies, are still a concept under development, thus additional empirical evidence is necessary to understand their influence and enabling role in the various dimensions of the GSCM approach (de Sousa Jabbour et al., 2018; Dubey et al., 2019; Sarkis et al., 2020). Second, there are empirical research opportunities in the context of developing countries, especially in Latin America (Teixeira et al., 2020). In this way, the present study aims to resolve the following research question:

RQ1: Do Industry 4.0 technologies influence the organizational performance through the implementation of GSCM?

To answer the research questions, the present study aims to develop a theoretical model by which to evaluate the effect of Industry 4.0 technologies on the implementation of environmental practices, as well as the effect of the latter on organizational economic and environmental performance.

Theory and hypotheses development

Industry 4.0 technologies and their effects on GSCM environmental practices

The Industry 4.0 or intelligent manufacturing/production concept was introduced in Germany in 2011 (Dhamija et al., 2020; Sunil Luthra & Mangla, 2018; Ying Li et al., 2020), and is characterized by the introduction of modern and advanced technologies for efficient production, production system digitization, Cyber-physical System (CPS) interconnectivity that permits the fusion of the real and virtual worlds, automation, and data networks, thus creating new production models (Bag et al.2020; Yadav et al., 2020; Zheng et al., 2020; Kumar et al., 2021). Likewise, different authors agree that the principles of Industry 4.0 are the horizontal and vertical integration of production systems driven by operation digitization, real-time data transactions, and flexible manufacturing (de Sousa Jabbour et al.,2018; Luthra & Mangla, 2018; Dubey et al.,2019; Sarkis et al., 2020), which allows for more personalized production and greater value generated by innovation (Effendi et al., 2021; Yu et al., 2021). Industry 4.0 (I4.0) consists of the use of enabling technologies, such as Cyber-physical Systems (CPS) and the Internet of Things (IoT) (Singh et al., 2019; Butt, 2020; Sarkis et al., 2020; Li et al., 2020; Zheng et al., 2020), Big Data Analytics (BDA) (Luthra & Mangla, 2018; Singh et al., 2019; Butt, 2020; Zheng et al., 2020; Raut et al.,2021), artificial intelligence (Singh et al., 2019; Bhatt et al., 2020; Ramirez-Peña et al.,2020), Blockchain technology (Bhatt et al.,2020; Sarkis et al., 2020), augmented reality (Butt, 2020; Zheng et al., 2020), additive manufacturing (de Sousa Jabbour et al., 2018; Butt, 2020; Zheng et al., 2020), autonomous robots (Singh et al., 2019; Butt, 2020; Zheng et al.,2020), information systems such as ERP (Bag, Gupta, et al., 2020; Mittal et al. 2019), autonomous guided vehicle (AGV) (Naseem & Yang, 2021), RFID technology (Ivascu, ,2020), cloud and computing/cloud manufacturing (Li et al. 2020; Zheng et al., 2020;Mittal et al. 2019), digital platforms (Li et al.,2020), among others.

The present study addressed so-called "Industry 4.0 digital technologies," which, according to Ying Li et al. (2020), are those that allow for operation connectivity and digitization, such as collection, exchange, analysis, and storage of data in real time. The most widely-recognized Industry 4.0 digital technologies are IoT, BDA, cloud computing, and digital platforms (Li et al., 2020; de Sousa Jabbour et al., 2018; Zheng et al., 2020).

Qin et al. (2021) state that Industry 4.0 technologies are recognized as a fundamental pillar of the GSCM approach, since their successful implementation depends upon their ability to capture data related to environmental efforts and the results of purchasing, manufacturing, logistics processes, and sales. The benefits of digital technologies in the management of the green supply chain and in the design of strategies to achieve improved supply chain performance have been recognized in the literature (Singh & El-Kassar, 2019; Sarkis et al., 2020). Certain benefits, such as greater flexibility and integration. increased resilience and visibility, connectivity and transparency, real-time information to facilitate decision-making, increased operational efficiency and productivity, less waste, and more sustainable production processes (Dubey et al., 2019; Bag et al. 2020; Zheng et al., 2020), among others, have been reported as results of the adequate adoption of digital technologies. Based on the above, the following hypotheses are offered:

H1: Industry 4.0 technologies have a positive and direct effect on GSCM practices ((a)green purchasing, (b)green manufacturing, (c)green logistics, (d)reverse logistics)

GSCM environmental practices and their effects on organizational performance

Green Supply Chain Management practices are designed to improve environmental performance (Green et al.,2019). These practices can reduce environmental impacts through the reduction of emissions to the air, consumption of toxic and non-toxic resources, solid and non-solid waste, and reduction of the frequency of environmental accidents (Mumtaz et al., 2018). Economic performance is typically the most important reason why a company would seek to implement GSCM practices, especially for enterprises in developing countries (Younis et al., 2016). Firm economic performance is affected by GSCM practices when its implementation results in higher profitability, cost reduction, higher sales, and market shares (Liu et al., 2020). Despite the above, Teixeira et al. (2020) carried out a literature review to identify the studies on GSCM in Latin America, finding that only six articles studied the environmental and economic impact of GSCM practices. Therefore, as the author states, it is necessary to explore, in depth, the empirical relationships between GSCM and environmental performance in developing countries in Latin America. The foregoing allows the proposal of the following hypotheses:

H2: GSCM practices (green purchasing (a), green manufacturing (b), green logistics (c), reverse logistics(d)), positively and significantly improves company environmental performance.

H3: GSCM practices (green purchasing (a), green manufacturing (b), green logistics (c), reverse logistics(d)), positively and significantly improves company economic performance.

Figure 1 shows the theoretical model and set of hypotheses to be tested in this study.

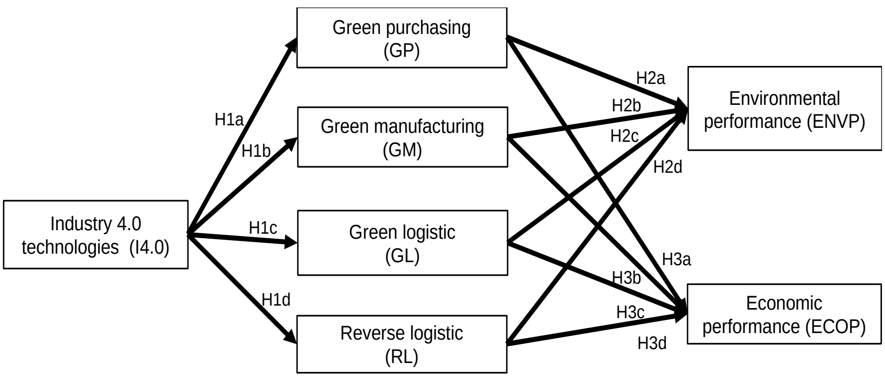

Figure 1. Proposed theoretical model

Methods

Survey design

To empirically explore the proposed hypotheses, a structured questionnaire was designed, and a digital survey was applied, in accordance with the procedure proposed by Dillman (2014). The digital technologies of Industry 4.0 (I4.0) were measured as a single reflective construct, with four indicators. A study by Ying Li et al. (2020) was used to measure the I4.0 that facilitate the implementation of GSCM practices, such as the internet of things, big data analytics, cloud computing, and digital platforms. The variables used by Chacón Vargas et al. (2018) to measure environmental practices from the GSCM approach (GP, GM, GL, RL) were adopted herein. The survey included several individual questions designed to assess the implementation levels of Industry 4.0 technologies and GSCM environmental practices, using a five-point Likert scale. Economic performance measures were adapted from Younis et al. (2016) and Qorri et al. (2020) (e.g. cost reduction for energy consumption, waste treatment and discharge, and purchased materials, market share growth, and profitability). Measures for environmental performance were adapted from Paulraj et al. (2017) and Yildiz et al.(2019) (e.g., reduction of solid/liquid waste, atmospheric emissions, dangerous/harmful/toxic material consumption, frequency of environmental accidents, and consumption of energy and water).

Population and sample

Considering the challenges of random sampling and given that the objective of the study was to test hypotheses, and not to generalize results for a population, convenience sampling was applied (Chacón Vargas et al., 2018). The literature suggests that a sample size of 200 or more is reasonable, when applying Structural Equation Modeling (SEM) analysis (Kline, 2005).

Data collection, non-response bias, and common method bias

This study used data collected from 1,523 manufacturing companies: large and medium-sized manufacturing companies in Colombia. In total, 200 complete questionnaires were collected (13% response rate). To analyze non-response bias, the Mann-Whitney U test was used. No significant differences were found for any of the comparisons (p-value> 0.05), indicating a probable absence of non-response bias (Armstrong and Overton 1977). Because data were collected from a single informant within each company, the Harman one-factor test was used to avoid Common Method Bias (CMB). The unrotated factor solution showed that the first factor explained only 35.982% of the total variance in the sample. Therefore, the non-significance of the common method bias problem was verified (Podsakoff et al., 2003).

Data analysis and results

For data exploration and measurement of the relationship between constructs, PLS-SEM technique was used, with the help of SmarPLS 3.0 software (Ringle et al, 2005).

Measurement model

Convergent validity was assessed using external loads, and the Average Variance Extracted (AVE) criterion. For convergent validity, the AVE for each of the constructs exceeds the recommended value of 0.5 (Bagozzi y Yi, 1988). To test the internal consistency of the survey instrument, a Cronbach's alpha value of greater than 0.7 was used (Hair et al., 2017). Since all α scores were considerably higher than the minimum acceptable level, internal reliability was confirmed. Likewise, the composite reliability factor was greater than 0.7 (Hair et al., 2017) (see Table 1).

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
I4.0	0.704	0.723	0.819	0.534
ECOP	0.858	0.859	0.898	0.639
ENVP	0.861	0.861	0.9	0.642
GL	0.816	0.819	0.868	0.524
GM	0.897	0.901	0.925	0.711
GP	0.894	0.895	0.922	0.702
RL	0.906	0.917	0.934	0.781

Table 1. Convergent validity and internal consistency

Structural model

Figure 2 and Table 2 provide the detailed values of the R2 (coefficient of determination), path coefficients, the significance of direct effects, and bootstrapping path analysis. In accordance with Figure 2 and Table 2, the R2 represent a suitable range, from 0.190 to 0.411. The results show that Industry 4.0 technologies contribute positively to GSCM practices, except for reverse logistics (b=1.132, p=0.076). Therefore, only H1a, H1b, and H1c were statistically accepted. Green purchasing, green manufacturing and green logistics were positively and significantly related to environmental performance (H2a, H2b, H2c), but no relationship was found between reverse logistic and environmental performance (b = 0.016, p = 0.818). Also, green purchasing, green logistics and reverse logistics manufacturing had a positive and direct impact on economic performance (H3a, H3c, H3d), but no relationship was found between green manufacturing and economic performance (b=1.152, p=0.057).

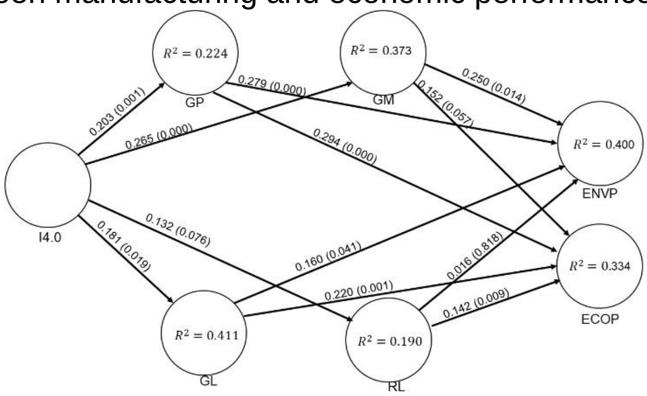

Figure 2. Structural model

Hypotheses	*Original Sample (O)*	*Sample Mean (M)*	*Standard Deviation*	*T Statistics*	*P Values*	*Remarks*
H1a=I4.0 -> GP	0.203	0.204	0.062	3.306	0.001	Supported
H1b=I4.0 -> GM	0.265	0.266	0.064	4.171	0.000	Supported
H1c=I4.0 -> GL	0.181	0.18	0.077	2.355	0.019	Supported
H1d=I4.0 -> RL	0.132	0.131	0.074	1.78	0.076	Not Supported
H2a=GP -> ENVP	0.279	0.279	0.077	3.637	0.000	Supported
H3a=GP -> ECOP	0.294	0.293	0.07	4.167	0.000	Supported
H2b=GM -> ENVP	0.250	0.246	0.101	2.471	0.014	Supported
H3b=GM -> ECOP	0.152	0.15	0.079	1.912	0.057	Not Supported
H2c=GL -> ENVP	0.160	0.169	0.078	2.045	0.041	Supported
H3c=GL -> ECOP	0.220	0.225	0.063	3.467	0.001	Supported
H2d=RL -> ENVP	0.016	0.017	0.068	0.230	0.818	Not Supported
H3d=RL -> ECOP	0.142	0.147	0.055	2.604	0.009	Supported

Table 2. SEM results with bootstrapping for hypotheses testing

Discussion

The unique contribution of this article lies in the empirical testing of the evidence of the theoretical linkage of Industry 4.0 technologies and green supply chain environmental practices, together with economic and environmental performance results. The results show that the set of Industry 4.0 technologies (IoT, BDA, digital platforms, and Cloud Computing) influence the development of green products, from green purchasing to green manufacturing and green logistics. Similarly, the importance of Industry 4.0 technologies in the implementation of GSCM environmental practices supports previous findings (Qin et al., 2021). Industry 4.0 technologies, such as Big Data Analytics, that analyze large amounts of data and linking digital and physical systems (Internet of Things) and facilitate the collection and monitoring of environmental data regarding the supply chain, are those that most influence environmental practices. Despite the above, no evidence was found of a relationship between digital technologies - reverse logistics and environmental performance, or between green manufacturing and environmental performance. These results are contrary to previous findings in the literature (Lopes de Sousa Jabbour et al., 2018).

Conclusions, limitations and future research

Based on the empirical analysis of 200 Colombian manufacturing companies, evidence of positive association between Industry 4.0 technologies and GSCM environmental practices, except for the relationship with reverse logistics, is provided. The results also suggest a positive effect of the implementation of GSCM environmental practices on economic and environmental performance, except for the relationship between green manufacturing and economic performance, and reverse logistics and environmental performance.

Due to the study design, there were several limitations: first, the results were derived from a relatively small sample, from a single country. Future research might survey more companies, both locally and internationally. Second, it is necessary to delve into the underlying causes of the hypotheses not supported herein, through specific case studies. Likewise, future research can improve the research scope by using the results obtained herein as a basis for the development more complex models.

References

Armstrong JS, Overton TS (1977) Estimating Nonresponse Bias in Mail Surveys. J Mark Res 14:396. https://doi.org/10.2307/3150783

Bag S, Gupta S, Kumar S, Sivarajah U (2020a) Role of technological dimensions of green supply chain management practices on firm performance. J Enterp Inf Manag 34:1–27. https://doi.org/10.1108/JEIM-10-2019-0324

Bag S, Telukdarie A, Pretorius JHC, Gupta S (2018) Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmarking 1463–5771. https://doi.org/10.1108/BIJ-03-2018-0056

Bag S, Wood LC, Xu L, et al (2020b) Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. Resour Conserv Recycl 153:104559. https://doi.org/10.1016/j.resconrec.2019.104559

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. Journal of the academy of marketing science, 16(1), 74-94.

Bhatt Y, Ghuman K, Dhir A (2020) Sustainable manufacturing. Bibliometrics and content analysis. J Clean Prod 260:120988. https://doi.org/10.1016/j.jclepro.2020.120988

Bressanelli G, Adrodegari F, Perona M, Saccani N (2018) Exploring how usage-focused business models enable circular economy through digital technologies. Sustain 10: https://doi.org/10.3390/su10030639

Chacón Vargas JR, Moreno Mantilla CE, de Sousa Jabbour ABL (2018) Enablers of sustainable supply chain management and its effect on competitive advantage in the Colombian context. Resour Conserv Recycl 139:237–250. https://doi.org/10.1016/j.resconrec.2018.08.018

Chin WW (2010) Handbook of Partial Least Squares

de Sousa Jabbour ABL, Jabbour CJC, Foropon C, Filho MG (2018) When titans meet – Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technol Forecast Soc Change 132:18–25. https://doi.org/10.1016/j.techfore.2018.01.017

Dhamija P, Bedi M, Gupta ML (2020) Industry 4.0 and supply chain management: A methodological review. Int J Bus Anal 7:1–23. https://doi.org/10.4018/IJBAN.2020010101

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). Internet, phone, mail, and mixed-mode surveys: the tailored design method. John Wiley & Sons

Effendi MI, Widjanarko H, Sugandini D (2021) Green Supply Chain Integration and Technology Innovation Performance in SMEs: A Case Study in Indonesia. J Asian Financ Econ Bus 8:909–916. https://doi.org/10.13106/jafeb.2021.vol8.no4.0909

Green KW, Inman RA, Sower VE, Zelbst PJ (2019) Comprehensive supply chain management model. Supply Chain Manag 5:590–603. https://doi.org/10.1108/SCM-12-2018-0441

Green KW, Zelbst PJ, Meacham J, Bhadauria VS (2012) Green supply chain management practices: impact on performance. Supply Chain Manag 17:290–305. https://doi.org/10.1108/13598541211227126

Hair Jr, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2017). A primer on partial least squares structural equation modeling (PLS-SEM). Sage publications.

Ivascu L (2020) Measuring the implications of sustainable manufacturing in the context of industry 4.0. Processes 8:1–20. https://doi.org/10.3390/PR8050585

Kline, R. B. (2015). Principles and practice of structural equation modeling. Guilford publications.

Kumar N, Kumar G, Singh RK (2021) Big data analytics application for sustainable manufacturing operations: analysis of strategic factors. Clean Technol Environ Policy 23:965–989. https://doi.org/10.1007/s10098-020-02008-5

Lee H (2020) The role of environmental uncertainty, green HRM and green SCM in influencing organization’s energy efficacy and environmental performance. Int J Energy Econ Policy 10:332–339. https://doi.org/10.32479/ijeep.9221

Li Y, Dai J, Cui L (2020) The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model. Int J Prod Econ 229:107777. https://doi.org/10.1016/j.ijpe.2020.107777

Liu J, Hu H, Tong X, Zhu Q (2020) Behavioural and technical perspectives of green supply chain management practices: Empirical evidence from an emerging market. Transp Res Part E Logist Transp Rev 140:102013. https://doi.org/10.1016/j.tre.2020.102013

Lu J, Ren L, Zhang C, et al (2020) Modified Carroll’s pyramid of corporate social responsibility to enhance organizational performance of SMEs industry. J Clean Prod 271:122456. https://doi.org/10.1016/j.jclepro.2020.122456

Luthra S, Mangla SK (2018) Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Saf Environ Prot 117:168–179. https://doi.org/10.1016/j.psep.2018.04.018

Mittal S, Khan MA, Romero D, Wuest T (2019) Smart manufacturing: Characteristics, technologies and enabling factors. Proc Inst Mech Eng Part B J Eng Manuf 233:1342–1361. https://doi.org/10.1177/0954405417736547

Paulraj A, Chen IJ, Blome C (2017) Motives and Performance Outcomes of Sustainable Supply Chain Management Practices: A Multi-Theoretical Perspective. J Bus Ethics 145:239–258. https://doi.org/10.1007/s10551-015-2857-0

Podsakoff PM, MacKenzie SB, Lee JY, Podsakoff NP (2003) Common Method Biases in Behavioral Research: A Critical Review of the Literature and Recommended Remedies. J Appl Psychol 88:879–903. https://doi.org/10.1037/0021-9010.88.5.879

Qin X, Godil DI, Sarwat S, et al (2021) Green practices in food supply chains: evidence from emerging economies. Oper Manag Res. https://doi.org/10.1007/s12063-021-00187-y

Qorri A, Gashi S, Kraslawski A (2020) Performance outcomes of supply chain practices for sustainable development: A meta-analysis of moderators. Sustain Dev 1–23. https://doi.org/10.1002/sd.2140

Rehman Khan SA, Yu Z, Sarwat S, et al (2021) The role of block chain technology in circular economy practices to improve organisational performance. Int J Logist Res Appl 0:1–18. https://doi.org/10.1080/13675567.2021.1872512

Ringle, C., Wende, S., & Will, A. (2005). SmartPLS 2.0 (Beta). Hamburg, (www.smartpls.de)

Sarkis J, Kouhizadeh M, Zhu QS (2020) Digitalization and the greening of supply chains. Ind Manag Data Syst 121:65–85. https://doi.org/10.1108/IMDS-08-2020-0450

Singh S, Mahanty B, Tiwari MK (2019) Framework and modelling of inclusive manufacturing system. Int J Comput Integr Manuf 32:105–123. https://doi.org/10.1080/0951192X.2018.1550678

Singh SK, El-Kassar AN (2019) Role of big data analytics in developing sustainable capabilities. J Clean Prod 213:1264–1273. https://doi.org/10.1016/j.jclepro.2018.12.199

Teixeira AA, Moraes TE da C, Stefanelli NO, et al (2020) Green supply chain management in Latin America: Systematic literature review and future directions. Environ Qual Manag. https://doi.org/10.1002/tqem.21712

Tiwari S (2021) Supply chain integration and Industry 4.0: a systematic literature review. Benchmarking 28:990–1030. https://doi.org/10.1108/BIJ-08-2020-0428

Wang C, Zhang Q, Zhang W (2020) Corporate social responsibility, Green supply chain management and firm performance: The moderating role of big-data analytics capability. Res Transp Bus Manag 37:100557. https://doi.org/10.1016/j.rtbm.2020.100557

Yadav G, Luthra S, Kumar S, et al (2020) A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case. J Clean Prod 254:120112. https://doi.org/10.1016/j.jclepro.2020.120112

Yildiz Çankaya S, Sezen B (2019) Effects of green supply chain management practices on sustainability performance. J Manuf Technol Manag 30:98–121. https://doi.org/10.1108/JMTM-03-2018-0099

Younis H, Sundarakani B, Vel P (2016) The impact of implementing green supply chain management practices on corporate performance. Compet Rev 26:216–245. https://doi.org/10.1108/CR-04-2015-0024

Yu Y, Zhang JZ, Cao Y, Kazancoglu Y (2021) Intelligent transformation of the manufacturing industry for Industry 4.0: Seizing financial benefits from supply chain relationship capital through enterprise green management. Technol Forecast Soc Change 172:120999. https://doi.org/10.1016/j.techfore.2021.120999

Zheng T, Ardolino M, Bacchetti A, Perona M (2020) The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. Int J Prod Res 0:1–33. https://doi.org/10.1080/00207543.2020.1824085

Being efficient or being innovative – does one hinder the other?

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Abstract

There is a considerable pursuit of process efficiencies in business. However, such initiatives are not always inimitable or tacit. Consequently, businesses seek additional or alternative sources of competitive advantage. An acknowledged source of competitive advantage is innovation. Yet, there is a natural tension between process efficiency and innovation. The defining metrics of process efficiency – flow time, flow rate, time to market, and yield improvement – militate against those of innovation, primarily, variation and tolerance for uncertainty. While research has explored this issue using ambidexterity and exploitative/explorative perspectives, the nature of, and contingencies underlying the efficiency-innovation narrative, remain unclear. This research examines the relationship between process efficiency and innovation, its effect along the supply chain, and its impact on firm performance.

Keywords: Innovation, Lean, Supply chain, Empirical

Introduction

The study seeks to examine the relationship between process efficiency and innovation in business organizations and in their supply chains.

Motivation and Significance

Theory building, based on insights on the positive and negative effects of process efficiency on innovation. Provide guidance to managers for recognizing potential incompatibilities between efficiency and innovation, and developing organizational strategies for improving innovation performance in process efficiency oriented environments.

Research Background and Research Questions

There is a considerable pursuit of process efficiencies in business. The language of process efficiency has entered general business lexicon with programs such as 6-sigma, JIT, TQM, ISO 9000, and awards such as the Baldridge Award and the Shingo Award. There are substantive reasons for this pursuit, including cost reduction objectives as well as time to market and customer satisfaction improvement goals.

Yet there are some disquieting realizations over time. One, that akin to many other organizational interventions, the process efficiency movement is experiencing the law of diminishing returns. Also, and perhaps, more importantly, process efficiency is not a perfectly inimitable initiative. Even tacit practices can eventually be, and in fact, are being identified, replicated and improved upon constantly by competitors. It is becoming increasingly difficult to use process efficiency as a sustainable source of competitive advantage (Lutz, 2011; Tian, Lo and Zhai, 2021). Consequently, businesses are seeking additional or alternative sources of competitive advantage.

An acknowledged source of competitive advantage is innovation. Companies, while not abandoning process efficiency, are turning their attention to innovation. They are not discarding 6-sigma, but realize that improving process efficiency may no longer be an adequate strategy to generate and sustain market differentiation and market position. Herein may lay a difficult contradiction, one that forms the core of this research study.

The organizing principles of the process efficiency movement center on:

- Variance reduction (increase yield)
- Flow time reduction (flow rate increases, inventory decreases)
- Waste reduction

These goals, in turn, require:

- A continuous cycle of incremental learning and improvement (kaizan, quality circles)
- Tight coupling between process steps, and a relentless focus on waste elimination
- Rationalization, consistency, and stability

From a process perspective, process efficiency programs usually traverse a three stage progression: process mapping, process improvement, and process standardization, with subsequent best practice replication at other sites. Efficiency programs often employ small testable experiments guided by flow time, waste and variance reduction goals (Spear and Bowen, 1999). These practices constitute the DNA of process efficiency initiatives. From a theory perspective, process efficiency involves ‘exploitation’ - systems and processes that develop reliability and consistency through “refinement, production and focused attention” (Holmquist, 2004).

In contrast, innovation requires variance, loose coupling, and a tolerance for ‘waste’. Availability of organizational slack promotes creativity and exploration. Innovation demands exploration, the creation of variety in experiences and thoughts, developed through experimentation, trials and “free associations” (Holmqvist, 2004; Marengo, 1993). It is by “its very nature a disorderly process” (3M CEO George Buckley quoted in Business Week, June 11th, 2007). In fine, innovation requires variance, experimentation, and a tolerance for inefficiency and waste. In terms of theory, such innovation represents exploration of new capabilities and technologies that are far removed from a company’s mainstream (March, 1991).

The capabilities that underlie innovation and efficiency may thus be mutually conflicting (Cao, Q., Gedajlovic, E. R., & H. Zhang, 2009). There is a natural tension between process efficiency and innovation. The defining metrics of process efficiency – flow time, flow rate, time to market, and yield improvement – militate against variation and tolerance for uncertainty. A process efficiency regime may thus constrict innovation in general or at a minimum, discourage truly creative types of innovation that depart radically from status-quo. This was seen in non-manufacturing scenarios too – to wit, Walmart or McDonalds, with their emphasis on efficiency, uniformity and scale. Yet innovation through freshness, personalized service variety and quick rotation of new designs and products may be driving customers away to competitors like Chipotle and Target and Costco.

So is the pursuit of process efficiency incompatible with the pursuit of innovation? Extant research suggests that it may depend on the type of innovation that a firm desire. Theory makes a distinction between exploitation and exploration, in initiatives to find or do new things (March, 1991). Exploitation denotes incrementalism in innovation, improving existing components and products by building on existing capabilities and knowledge using local search modes (March, 1991; Benner and Tushman, 2002). Exploration takes a very different trajectory, using distant search modes to seek and acquire entirely new capabilities that lie outside the boundaries of existing knowledge and routines. Exploration based innovation may even "destroy the value of the existing knowledge base" (Abernathy and Clark, 1985). For this reason, exploitative innovation usually is the preferred, and at times, almost organizationally subliminal route to new product or service development in established businesses (Christensen, 1998). More specifically, exploitative innovation itself has been dissected into 'repetitive' and 'incremental' forms with the former retarding and the latter reinforcing exploratory innovation, respectively (Piao and Zajac, 2016).

Benner and Tushman's (2002) seminal research investigating the paint and photography industries found that a greater focus on process efficiency led to increases in exploitative innovation, but "significantly reduced" more exploratory forms of innovation. Similar anxieties may extend to the supply base, with recent research suggesting more relational ties or stronger relational ties as conducive to innovation and efficiency objectives, respectively (Li, Zhang, and Zhang, 2021).

A natural question arises – are there circumstances that allow exploitation and exploration to co-exist? Perhaps even as complementary initiatives? One school of thought thinks so. Benner and Tushman (2003) recommend "ambidextrous organizations" that comprise of "tightly coupled sub-units" that yet remain "loosely coupled with each other". These sub-units are highly differentiated, with some designed for exploratory initiatives, and others for exploitative purposes. Process efficiency interventions are kept away from the former. However, the practical difficulties of doing so are significant and many managements fail to make such transitions since the "the skills required to explore are fundamentally opposed to those required to exploit" (Swift, 2016).
Similarly, Christensen's (1998) had recommended no coupling at all, with physical and financial separation of exploration units from the rest of the organization. Other research frames organizational innovation in iterations of exploitative and explorative structures, existing dissatisfaction with one form of structure prompting a migration to the other (Holmquist, 2004), though not without attendant frictions (Swift, 2016). The problem here is that the change group must be able to challenge the dominant and often still successful status-quo – for example, it was only after the departure of efficiency focused CEO, James McNerney, that 3M management could 'de-systematize' the R&D function (Business Week, June 11 2007). Additionally, long periods of exploitation may destroy or entropy exploration capital, making rapid switching difficult in a period of need.

To the extent that it can be done, the simultaneous pursuit of exploitation and exploration could lead to performance differentials, though such may not always be positive (Gualandris, Legenvre, and Kalchschmidt, 2018). Research suggests that standardization and replication may, in fact, facilitate the effects of creativity on customer satisfaction (Gilson, Mathieu, Shalley, and Ruddy, 2005). The performance superiority of mixed innovation environments though, is not a given. Booz Allen VP, Barry Jaruzelski, had a contrary view, observing that companies with breakthrough technological innovations are not inherently financially superior to companies that take an incremental follow-the-leader approach to innovation (Bernstein, 2008). He did not elaborate as to whether this would apply to companies that compete in the *same* industry. And as Christensen (1998) concluded, disruptive (exploration) innovations are usually low-end and low margin for extended periods until they catch up with the premium market needs and then rapidly proceed to destroy incumbents.

Consequent to the above discussion, three uninvestigated questions of interest arise:

- Is the relationship between process efficiency and innovation linear (negative or positive) or curvi-linear (arguments can be built for both)?
- Would process-efficiency driven lead customers / lead suppliers reduce upstream/downstream innovation as well?
- Is financial performance affected by the strength and nature of the relationship between process efficiency and innovation?

This study will investigate these issues through an empirical investigation of the impact of process efficiency practices on the innovation performance of companies and their supply chains.

Measures

Dependent variable: Innovation performance
Direct Measure: Constructed from published USPTO data on Patents # and type (classified as exploratory or exploitative following Benner and Tushman 2002). We will develop our dependent variable, measures of technological innovation, using data from the U.S. Patent and Trademark Office (USPTO). We will create measures of exploitation and exploration based on the extent to which a firm’s innovation efforts are anchored in its existing knowledge. Each patent abstract provides a list of citations to previous patents, that is, the “prior art” upon which the current patent builds. Using this information, we will assess the extent to which a firm’s patenting efforts build on the knowledge it has used in its previous patents. Following prior research that has measured exploitative and exploratory innovation from the knowledge cited in firms’ patenting efforts (Benner and Tushman, 2002), we will code the prior patents cited by a focal firm’s patent according to whether it is existing firm knowledge (either repeat citations or patents the firm has previously cited) or self-citations (the firm’s own previous patents). With these data, we will categorize patents according to the proportion of each one that was based on existing knowledge, and we will have developed count measures of these different types of patents for each firm.
At one extreme, the most exploratory patent category comprises patents that depart entirely from prior firm knowledge. In this case, our variable is the number of patents for a firm in each year having no repeat or self-citations. We will also construct measures of the number of less exploratory patents, for example at the 10 percent, 20 percent, and 40 percent levels, represented as the number of patents by year for each firm that are based 10 percent or less, 20 percent or less, and 40 percent or less, respectively, on the citations to prior knowledge of the focal firm. Thus, we will capture a firm’s innovation profile by assessing the number of patents in each of these categories, year by year.
At the other extreme, we will construct a similar measure of exploitation as the number of patents with 100 percent of their citations to familiar patents, that is, patents cited by the firm in an earlier innovation effort and/or self-citations. Similar to the measures constructed for exploration, we will construct additional measures of highly exploitative innovations, for example, the number of patents with 80 percent of their citations drawing on existing firm knowledge or familiar patents. We will develop similar measures at the 40 percent, 60 percent, 90 percent, and 100 percent level. Taken together, these measures will allow us to construct an in-depth picture of the extent to which a firm’s patenting efforts each year are

more or less anchored in prior knowledge from previous innovation efforts. Further, it allows us to carefully examine how a firm's intensity of exploitation and exploration changes as firms become more focused on process efficiency activities.
To link the patent measure to the time when innovation activity was undertaken in a firm, we will use recorded patents by their filing dates, rather than approval dates, as there may be arbitrarily long lags between filing and approval dates for patents.
Secondary measures of innovation performance will include R&D intensity (R&D expenses/sales) and since patents do not automatically translate into commercial products, how R&D spending is being monetized in terms of new-product sales. The latter would be a simple ratio of new-product sales (measured over a period of time depending on the industry) to R&D spending, both in $ terms. We would also look at the product-to-margin conversion metric, the ratio of gross margin to new-product sales.
Such an analysis can also be extended to key suppliers to the industry/firm since the supply chain can be an acknowledged source of innovation. It would be of interest to examine any correspondence between investments in key supplier development, the innovation performance of such key suppliers, and firm innovation performance.

Independent variable: Process Efficiency
Direct Measure: Constructed from published audited financials using Little's Law. We shall collect data on two variables from COMPUSTAT financials: Inventory and cost of goods sold (COGS). We will use *Little's Law* to develop an objective measure of company level process efficiency in terms of Flow Time (Note: i. Little's Law: Avg. Flow time = Avg. inventory/Flow rate – COGS; ii. Secondary measures: Efficiency related awards won – Shingo, Baldridge, ISO certifications).
We also plan to collect survey data on items measuring efficiency:

- Extent of use of lean practices
- Manufacturing cycle time (industry weighted).

Representative items are: Bottleneck removal (production smoothing), Cellular manufacturing, Competitive benchmarking, Continuous improvement programs, Cross-functional work force, Cycle time reductions, Focused factory production, JIT/continuous flow production, Lot size reductions, Maintenance optimization, New process equipment/technologies, Planning and scheduling strategies, Preventive maintenance, Process capability measurements, Pull system/Kanban, Quality management programs, Quick changeover techniques, Reengineered production process, Safety improvement programs, Self-directed work teams, Total quality management, Use of information technology

Control Variables:

- Company size, capital availability ("excess resources can actually impede effective innovation efforts" – Bernstein 2008; "innovation is no longer about the money, it's about the climate: are individuals allowed to flourish and take risks?" - William Weldon, CEO J&J - Economist.com, The age of mass innovation, Oct 11, 2007; contrary view - capital availability helps innovation – Katila and Shane, 2005);
- Competition (stimulates innovation – Katila and Shane, 2005);
- Total market size (small stimulates innovation – Katila and Shane, 2005);
- Manufacturing intensity (demands routine and planning skills – Katila and Shane 2005; and encourages process efficiency and incremental innovation, both contraindicated for exploration type innovation);
- Technology life cycle stage (growth: exploration; maturity: exploitative);
- Financial controls (A/Receivables changes, operating margin changes) that can be manipulated to inflate process efficiency metrics.

Moderating Supply Chain Design and Management Variables:

- Relational coupling: Measures from established scales in the literature (trust levels, cost info sharing, risk exposure, etc.).
- Structural coupling: Measures from established scales in the literature (personnel sharing; production schedule sharing; freq. and level of meetings, distance from focal firm in chain etc.)

Methods

- Survey data from the top 100 innovators list (Business Week) and other published sources of innovativeness ranking
- Compustat for financials
- US Patent Office database for innovation data
- Established statistical methodologies for data analysis

Note: Data collection is ongoing.

Conclusions

Worrying signs about innovation performance in the US are emerging. For example, in 2019, WIPO (World Intellectual Property Organization) reports, China filed more than twice the number of filings in the United States. The challenge lies, of course, in achieving both innovation and efficiency simultaneously. While we do not purport to offer a solution for the entire economy or the nation, our study shall probe the conflict between efficiency and innovation in companies and their supply chains and contribute to a clearer understanding of the dynamics of this relationship. Our study shall explain how such apparently incompatible priorities can be reconciled, such that companies and their supply chains can engage in a successful, simultaneous pursuit of both imperatives. Results from our study shall be submitted for publication in leading strategy, operations management, and management journals, with broad readership across academia and practice. The findings and recommendations shall be widely presented at conference and industry professional associations meetings.

References

Abernathy, W.J. and Clark, K., 1985. Mapping the winds of creative destruction. Research Policy 14, pp. 3-22.

Benner. M.J. and Tushman, M.L., 2003. Exploitation, exploration, and process management: The productivity dilemma revisited. Academy of Management Review 28(2), 238-256.

Benner. M.J. and Tushman, M.L., 2002. Process management and technological innovation: a longitudinal study of the photography and paint industries. Administrative Science Quarterly 47, 676-706.

Bernstein, A., “Making innovation strategy succeed”, Strategy + Business, Jan 8th 2008, www.strategy-business.com.

Cao, Q., Gedajlovic, E. R., & Zhang, H., 2009. Unpacking organizational ambidexterity: Dimensions, contingencies, and synergistic effects, Organ Science 20(4), 781–796.

Christensen, C.M., 1998. The Innovator’ dilemma: When new technologies cause great firms to fail. Boston: Harvard Business School Press.

Gilson, L.L., Mathieu, J.E., Shalley, C.E., and Ruddy, T.M., 2005. Creativity and standardization: complementary or conflicting drivers of team effectiveness? Academy of Management Journal 48(3), 521-531.

Gualandris, J., Legenvre, H., and Kalchschmidt, M., 2018. Exploration and exploitation within supply networks: Examining purchasing ambidexterity and its multiple performance implications. International Journal of Operations & Production Management 38 No. 3, 667-689, DOI 10.1108/IJOPM-03-2017-0162

Holmqvist, M., Experiential learning processes of exploitation and exploration within and between organizations: an empirical study of product development. Organization Science 15(1), Jan-Feb. 2004, 70-81.

Li, Z., Zhang, M. Y., and Zhang, H., 2021. Firm Growth Performance and Relative Innovation Orientation of Exploration vs Exploitation: Moderating Effects of Cluster Relationships. Management and Organization Review 17:1, 143–172, doi: 10.1017/mor.2020.35

Lutz, B., Life Lessons from the Car Guy, Wall Street Journal, June 11th 2011, retrieved at https://www.wsj.com/articles/SB10001424052702304259304576375790237203556 on Feb 19th 2021.

March, J., 1991. Exploration and exploitation in organizational learning, Organization Science 2(1), 71-87.

Marengo, L., 1993. Knowledge distribution and coordination in organizations: on some social aspects of the exploitation vs. exploration trade-off. Revue Internationale de Systemique 7, 553-571.

M. Piao and Zajac, E. J., 2016. How exploitation impedes and impels exploration: theory and evidence. Strategic Management Journal 37, 1431–1447, doi: 10.1002/smj.2402

Spear, S., and Bowen, H.K., 1999. Decoding the DNA of the Toyota Production System. Harvard Business Review 77(5), 96-106.

Swift, T., 2016. The perilous leap between exploration and exploitation. Strategic Management Journal 37, 1688–1698, DOI: 10.1002/smj.2423

Tian X, VI, L., and Zhai. X., 2021. Combining efficiency and innovation to enhance performance: evidence from firms in emerging economies, Journal of Management & Organization 27, 295–311, doi: 10.1017/jmo.2018.75

Digitalisation of a Bottling Process of a Hyperthermal Mineral Water Plant

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Abstract

This work involves the digitalisation of a bottling process of a hyperthermal mineral water plant in the Argentinian Guaraní aquifer. It was deployed to improve the value chain performance, ensuring the quality of the mineral water. The latter is essential for human consumption and of great interests for both company and consumers, hence the need to monitor and control some quality parameters through the chemical, physical and biological characteristics of the water. According to the regulations established by the Argentine Food Code, the maximum arsenic content allowed in mineral water for human consumption is 50 ppb, while the World Health Organization (WHO) proposes a limit of 10 ppb. Currently, most drinking water bottling plants in Argentina have semi-automatic processes in which manual intervention takes place in the stages of capping, labelling and storage of the final product. The aim of this project is the digitalisation and integration of the value chain of the hyperthermal mineral water bottling plant, in accordance with Industry 4.0 guidelines, so as to assure water quality and environment sustainability.

Keywords: Digitalisation, Industry 4.0, Innovation, Sustainability, Bottling Plant

Introduction

Industry 4.0 (I4.0) includes the complete digitisation of value chains, from suppliers to end customers, through the integration of data processing technologies, intelligent software and sensors. That digitalisation facilitates the plan, monitoring and control of the industrial processes, adding value to the entire value chain (Lin et al. 2017). I4.0 has three pillars: (1) production digitisation (2) automation and (3) automated data exchange (Antunes et al. 2018).

Small and medium enterprises (SMEs) frequently lack of a good communication between their different departments. It is the case of water bottling plants for human consumption, where manual intervention is carried out in the stages of capping, labelling, and storing of the finished products. This project was carried out in an hyperthermal water bottling plant in the Guaraní aquifer, in Concordia city, Argentina, close to a thermal tourist resort. The plant currently works in an "on demand production” strategy. For its part, production and the supply chain have no automated management, which on many occasions hinders adequate decision making producing significant economic losses for the company. Because of the characteristics of this industry, it is highly important to control the quality of its product, ensuring the natural properties and safety of the water, then, it is advisable to manage some chemical, physical and biological parameters continuously and in real time. To find dissolved mineral water contents, temperature, pH and electrical conductivity must be analysed in the packaging line. In addition, the arsenic is controlled aside. Though it is a natural element in water, it is known that its intake in high doses is harmful to health. The maximum arsenic content allowed in mineral waters for human consumption is 50 ppb, according to the Argentine Food Code, contrary to the WHO recommendations, which proposes a limit of only 10 ppb as the safest level.

In order to assure the quality of the process and the product, the digitisation of the entire value chain was needed, which brings together, among other advantages, real-time monitoring and control of all key variables. The research question is whether the use of I4.0 enabling technologies can improve the quality of the final product.

Research Methodology

A systematic literature review (SLR) was first performed. The work has been developed from June to December 2021. The theoretical framework has been a SLR, mapping method and bibliometric techniques. A screening of 68 documents was carried out, 34 of which were selected for a deeper analysis. It was performed as follows: (1) in academic databases with a search string through the combination of the operator "and" between keywords, the references that met the following criteria were collected; (2) were published in conference proceedings, articles, magazines, book series and books between 2014 and 2022; (3) contained, at least, one of the search terms in the abstract, title, and/or keywords; (4) duplicates were removed; (5) those that did not have full texts available were discarded; (6) documents that defined Digitalisation, Industry 4.0, Innovation, Sustainability or Bottling Plant outside the scope of this research work were excluded; (7) they were classified according to the research question; (8) the collected documents were analysed and the data of interest for the research question was collected. During Phase 2, the Mineral Water Bottling Plant solution was tested.

Digitalisation and Integration of the value chain

Digital transformation applied to I4.0 is characterised by both horizontal and vertical integration (Salimbeni 2021). Then, it is mandatory to achieve connectivity and interoperability between devices (Leitão, Colombo, and Karnouskos, 2016). The approach of I4.0 for manufacturing systems is based on the Smart Factory concept, which makes use of enabling technologies such as IoT and CPS (Alcácer and Cruz-Machado 2019). IoT refers to an internetworking world in which various objects are embedded with electronic sensors, actuators, or other digital devices so that they can be networked and connected for the purpose of collecting and exchanging data (Zhong et al. 2017). Besides that, CPSs require a two-way interaction between the digital and physical worlds typically achieved through digital modelling and the IoT via unique object identification, such as RFID in conjunction with materials, machines, products and people (Neal et al. 2021).

In this case study, the proposal to integrate the management of the production department with the commercial and services areas of the company seeks to improve the system quality, business management and product reliability. The digitisation of parts and products, throughout the entire life cycle, permits information to be shared, not only among all departments of the company, but also with suppliers and customers. This exchange of information is considered by most companies as one of the most important issues in knowledge management, which grants improving efficiency, quality and time to market in the development of new products (Gao and Bernard 2018).

Considering the economic limitations of SME, a system with low-cost sensors has been designed, which contributes with lower costs, not only for the installation, but also during ongoing operations.

It has been proposed in this project the adoption of an intelligent production using several of the I4.0 enabling technologies, such as IoT, Big Data (BD) and cloud computing (CC), which facilitates Data Driven Decision Making in real time allowing collaborative work between the different areas of the enterprise. For that purpose, the installation of sensors in the production line was mandatory to digitise measurements permitting share them with the other stakeholders.

Two stages of the water bottling process have been considered (Fig.1): (1) process improvement and (2) digitalisation.

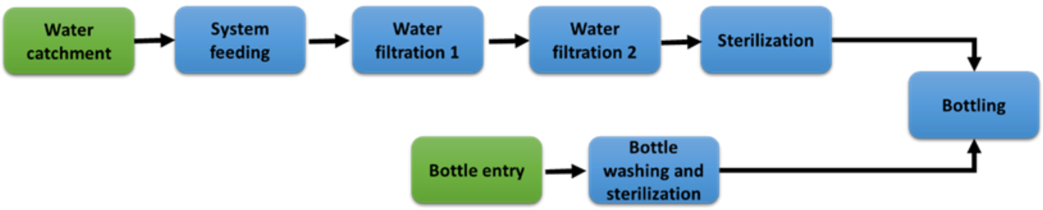


Fig 1. Bottling process. Source: author´s own

First stage: process improvements

A cooling tank is placed after the sterilisation station. At the tank outlet, a diversion valve for the treated water is placed so that a fraction goes through an arsenic filter and the other fraction goes directly to the feeding tank of the packaging machine. Taking into account the average values of the arsenic level samples in the last six months, a value close to 38 ppb and a desired final concentration of 8 ppb is considered so that not to saturate the 10 ppb arsenic sensor, which forms part of the second stage of the project. Based on these reference values, the calculation of the fraction of water to be diverted to the filter is carried out. Consequently, for every litre of unfiltered water, 4.75 litres need to be diverted to the filter.

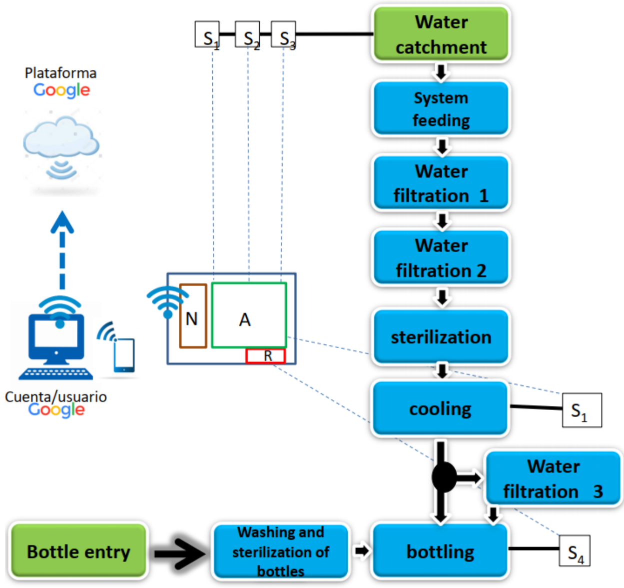
Second stage: digitisation

During this second stage, sensors are placed to control temperature, electrical conductivity, and pH at the entrance of raw water to the plant; then, a temperature sensor is installed at the outlet of the cooling tank and an arsenic sensor before the packaging machine.

Solution Description

The electronic system consists of two devices, one for data processing and the other one for communications, which will monitor the different variables by means of pH, Temperature and Conductivity sensors. The system has also a repeater and data storage control. The arsenic sensor is coupled to an Arduino™ device carefully enough to warn if the input signal exceeds 5 volts. Once the two stages of the improvement plan have been concluded, the process looks like as shown in Fig.2

A Temperature sensor measures the temperature of the water that circulates in the inlet pipe to the plant and at the outlet of the cooling tank. A pH sensor measures the acidity level of the water entering the bottling plant. It can be accurately quantified by a sensor that measures the potential difference between two electrodes. Conductivity sensor is suitable for measuring electrical conductivity since it varies depending on the soluble solids found in the water, including mineral salts. Arsenic sensor monitors trace levels of arsenic in the water contained in the filler tank, with a maximum detection level of 8 ppb for triggering an alert and stopping the process. Arduino™ device connects to the sensors previously considered in order to process the data that arrives. The processed data and the information obtained are uploaded to the cloud.



(S_1) temperature sensor;
(S_2) conductivity sensor;
(S_3) pH sensor;
(S_4) arsenic sensor;
(R) signal conditioner;
(A) Arduino™ device;
(N) Nodemcu™ device

Fig 2. Digitalised Process. Source: author´s own

The Nodemcu™ board installed in the system is a wifi device compatible with Arduino™ and widely used in IoT projects. It allows the transfer of data wirelessly. A Cloud account is used to publish the data on the internet so wifi communication can be established with the Nodemcu™ device. Finally, the connection between the Cloud account and the Cloud platform is established, which allows publishing all the data through IoT.

It is noteworthy that the implementation of this solution could be put into practice with an investment of less than €20,000.

Discussion

The aim of the project was to achieve a horizontal integration through the entire value chain in order to reduce costs, operational efficiency and improve the product´s quality. It has been designed based on regulatory requirements. Although the Argentine Food Code (Secretaria de Salud, 2021) allows a maximum content of arsenic in water up to 50 ppb, the goal was to reduce this element to 10 ppb according to the WHO ones. This improvement permits tackle new markets with more exigent consumers in terms of quality and food safety. One additional benefit is the availability of data for all stakeholders in the value chain, thus offering greater transparency and confidence to the consumer.

Although the company can visualize key indicators today, it has not an overview of the hole value chain, which is mandatory for a total quality management system (Cadenas Aneya, Baquero, and Zamudio 2021).

The use of CC allows the analysis and management of large amounts of data, achieving the optimization of the production and commercial processes, as well as the quality of the final product and post-sale services. Therefore, the use of these technologies contributes to a comprehensive and flexible management of the supply chain (Fig.3). Data eliciting and analysis in real time guarantees greater assertiveness in decision making, obtaining mineral water with international quality standards. On the other hand, remote monitoring of production processes is essential to avoid possible failures and thus make the production chain more efficient. ML also offer the possibility of evaluate different future scenarios (Nikolic et al. 2017).

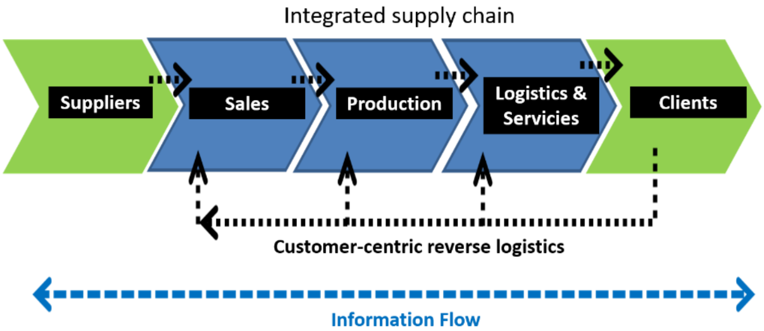


Fig.3. Integrated supply chain. Source: author´s own

Finally, a Blockchain implementation is being carried out. Blockchain provides powerful tools for traceability in multifarious scenarios, such as anti-counterfeiting, supply chain finance, and supply chain management (Zhang et al. 2020).

Conclusion and Future Research

This work consisted of the digitalisation of a bottling process in an hyperthermal mineral water SME in Argentine using I4.0 enabling technologies to assure process optimization, water quality and environment sustainability.

The implementation could be implemented with an investment below €20,000, which makes it attainable for an SME.

This project will be complemented with the digitalisation of other phases of the value chain, integrating suppliers and distribution channels.

Another topic for improvement is the count of bottles and measurement of their volume. Regarding the maintenance area, it is feasible to place sensors that measure the time of use of the filters and UV lamp of the steriliser, making a predictive maintenance.

After the horizontal integration of the value stream system, it could be carried out a Blockchain deployment to generate mechanisms that ensure the traceability of products, as well as guarantee the integrity of information, paving the way to advanced manufacturing.

References

Alcácer, V., and V. Cruz-Machado. 2019. “Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems.” Engineering Science and Technology, an International Journal 22(3):899–919. doi: 10.1016/j.jestch.2019.01.006.

Antunes, Joaquim, António Pinto, Pedro Reis, and Carla Henriques. 2018. “Industry 4.0: A Challenge of Competition.” Millenium - Journal of Education, Technologies, and Health (6):89–97. doi: 10.29352/mill0206.08.00159.

Cadenas Aneya, Carmelina, Giovanny Baquero, and Andres Zamudio. 2021. "Gestión En La Cadena de Suministro , Un Enfoque Desde La Perspectiva de La Calidad." Theorema, June, 19.

Gao, James, and Alain Bernard. 2018. "An Overview of Knowledge Sharing in New Product Development." International Journal of Advanced Manufacturing Technology 94(5–8):1545–50. doi: 10.1007/s00170-017-0140-5.

Leitão, Paulo, Armando Walter Colombo, and Stamatis Karnouskos. 2016. "Industrial Automation Based on Cyber-Physical Systems Technologies: Prototype Implementations and Challenges." Computers in Industry. doi: 10.1016/j.compind.2015.08.004.

Lin, Shi-Wan, Bradford Miller, Jacques Durand, Graham Bleakley, Chigani Amine, Martin Robert, Murphy Brett, and Mark Crawford. 2017. "The Industrial Internet of Things Volume G1 : Reference Architecture." Industrial Internet Consortium White Paper Version 1.:58 Seiten.

Neal, Aaron D., Richard G. Sharpe, Katherine van Lopik, James Tribe, Paul Goodall, Heinz Lugo, Diana Segura-Velandia, Paul Conway, Lisa M. Jackson, Thomas W. Jackson, and Andrew A. West. 2021. "The Potential of Industry 4.0 Cyber Physical System to Improve Quality Assurance: An Automotive Case Study for Wash Monitoring of Returnable Transit Items." CIRP Journal of Manufacturing Science and Technology 32:461–75. doi: 10.1016/j.cirpj.2020.07.002.

Nikolic, Bojana, Jelena Ignjatic, Nikola Suzic, Branislav Stevanov, and Aleksandar Rikalovic. 2017. "Predictive Manufacturing Systems in Industry 4.0: Trends, Benefits and Challenges." Annals of DAAAM and Proceedings of the International DAAAM Symposium (December):796–802. doi: 10.2507/28th.daaam.proceedings.112.

Salimbeni, Sergio (Universidad del Salvador). 2021. "Gestión Del Ciclo de Vida Del Producto En La Industria 4.0." ACCINI 1(3):24–41.

World Health Organization. https://www.who.int/es/news-room/fact-sheets/detail/arsenic

Zhang, Ziyao, Zhenmin Yuan, Guodong Ni, Han Lin, and Yujie Lu. 2020. "The Quality Traceability System for Prefabricated Buildings Using Blockchain: An Integrated Framework." Frontiers of Engineering Management 7(4):528–46. doi: 10.1007/s42524-020-0127-z.

Zhong, Ray Y., Xun Xu, Eberhard Klotz, and Stephen T. Newman. 2017. "Intelligent Manufacturing in the Context of Industry 4.0: A Review." Engineering 3(5):616–30. doi: 10.1016/J.ENG.2017.05.015.

Industry 4.0 for more competitive SMEs: Review of existing Industry 4.0 Maturity Models

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Abstract

The digitalization and Industy4.0 (I4.0) are more and more becoming a necessity for the companies. Since the implementation of I4.0 is very stochastic process, affected by many factors, researchers are trying to add determinism as much as possible through development of models for the road to I4.0, where understandably the determination of the maturity level for I4.0 is usually one of the first steps. This paper presents a comprehensive review of current maturity models for the assessment of I4.0 readiness of the enterprises. The paper aims to make a deeper analysis of selected models that are tackling the maturity and readiness for digitalization and I4.0, and to facilitate the process of selection of the appropriate model especially for the SMEs.

Keywords: Industry 4.0, digital transformation, maturity models, SME assessment.

Introduction

The Fourth Industrial Revolution was first thought of as the digital revolution occurring across the manufacturing industry. Yet Industry 4.0 nowadays is narrated as the digital transformation of industrial value chains in their totality (Culot, Orzes, Nassimbeni, & Sartor, 2020). The digital transformation under Industry 4.0 is characterized by implementing certain digital technologies, to enhance traditional manufacturing processes, products, and workforce (Mummolo, Digiesi, Facchini, Mossa, & Fertsch, 2019).

The first step towards implementing or enhancing the digital technologies in the organizations is the determination of their current maturity and readiness to accept these technologies offered by Industry 4.0. However, there are many factors that could be taken into consideration when assessing the readiness of the companies for digitalization such as type of industry, company size, region, personnel competitiveness etc., and these factors are usually different for each company. When it comes to SMEs and developing countries, the challenge is even bigger regarding their resources.

Having that in mind, the bilateral Austrian-Macedonian research project titled as "Lean Industry 4.0 for more competitive production and maintenance in the SMEs" was initiated in order to aid the digital transformation of SMEs and make the transition process easier and faster. The research will address the topic of readiness for the digital transformation of the Macedonian SMEs by systematic research and review of the current maturity models (MMs) for Industry 4.0 and digitalization readiness and selecting the most suitable model for evaluation of Industry 4.0 maturity. This paper aims to present the initial research considering the specifics of selected available models for determination of the maturity level regarding the digitalization and I4.0.

I4.0 concepts and technologies are tightly bonded with sustainability by providing circular economy, sustainable supply and value chains, and enabling monitoring the full product lifecycle (Ejsmont, Gladysz, & Kluczek, 2020). Additionally, some critical success factors for integrating I4.0 with sustainable development have been identified, such as transparency, resource efficiency, and creating knowledge through digitalization in the usage of Internet of Things (IoT) systems (Dikhanbayeva, Shaikholla, Suleiman, & Zhanybek , 2020). Implementation of these new technologies could be significantly easier if the management is aware of the current Industry 4.0 maturity level of their companies. The assessment of the enterprise's maturity through the maturity models could be marked as the very first step toward the digital transformation and therefore towards sustainable development.

Methodology

The phases of the aforementioned research project are shown in Figure 1.

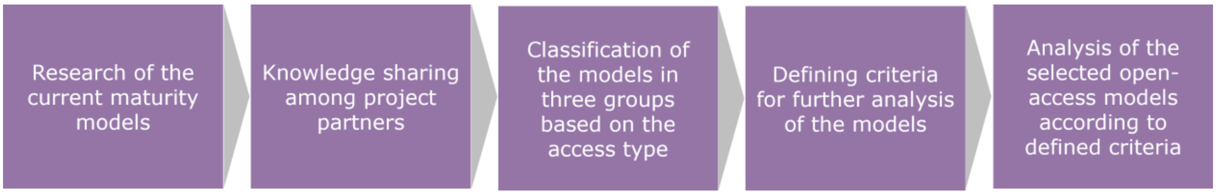

Figure 1. Proposed methodology

As it can be seen, the evaluation of the maturity models is in the initial stages and follows standard methodology for similar research: literature analysis, determination of the criteria for analysis and evaluation of the models regarding those criteria.

The future research will include selection of SMEs for the research, implementation the selected models in these SMEs along with analysis and comparison of the collected data in order to identify which of these models is the most suitable and which Industry 4.0 dimensions are the most relevant for the Macedonian SMEs.

Existing Maturity Models and Frameworks

To spread awareness and understand the readiness of a country or an organization to undertake an industrial revolution, surveys and analyses are required. Maturity models (MMs) can be used to observe the readiness for the I4.0 revolution. The MM is a tool that provides an assessment of the current effectiveness of the system. In other words, MMs are used to define the level of a system's effectiveness within the context of I4.0 technologies (Çınar, Zeeshan, & Korhan, A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case Study, 2021). Numerous maturity models were taken into consideration during the research, however only the ones that were accessible for the authors are taken for further analysis. The maturity models were classified into three groups according to the access type (Figure 2):

- MMs for which the authors have insufficient data to conduct proper analysis,
- MMs with implicit available data given in a form of survey reports or theoretical frameworks description
- MMs explicit data on their structure and questionnaires.

In the analysis only the second two groups were included in the research.

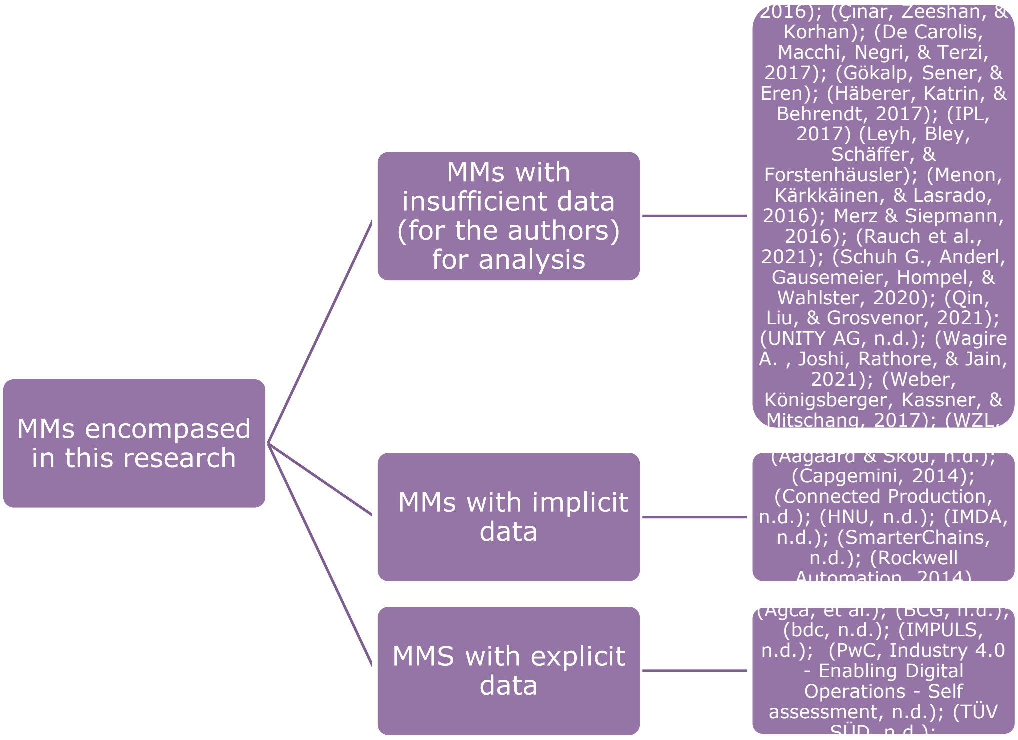

Figure 2. Classification of the selected maturity models according to access type

Table 1 is showing the list (in alphabetical order) of the selected open-access maturity models. Considering that these maturity models are accessible (accessible survey, scientific paper, and report) for researchers, they were analysed in more depth according to the following criteria: (i) description (with focus on dimensions and level of maturity), (ii) size of the enterprise, (iii) human aspect, (iv) quantification of the result, (v) pillars/dimensions of the model and (vi) orientation to products and/or processes.

No.	Source	Name of the maturity model	Description	Size of enterprise	Human aspect	Quantification of the maturity	Pillars/Dimensions of the model	Product/ process
1	(bdc, n.d.)	Digital maturity assessment	Enterprise assessment of the use of digital technologies and its abilities to manage changes. Includes **four maturity levels** of the companies – low, medium, high, and very high.	Small and medium	Not assessed explicitly	Maturity Level	No phases, only questions.	Process
2	(BCG, n.d.)	Digital maturity benchmark	**Six dimensions** are examined trough very detailed questions. **Four levels of maturity** (Nascent, Emerging, Connected and Multi-moment).	All	Not assessed explicitly	Maturity Level	Organisation, Access, Audience, Automation, Analytics and measurement, Assets & Ads.	Process
3	(PwC, Industry 4.0 - Enabling Digital Operations - Self assessment, n.d.)	I4.0 - Digital operations self-assessment	Focuses on digitization of the organization and oriented to large enterprises. **Seven dimensions and four maturity levels included.**	All	Not assessed explicitly	Maturity Level	Business Models, Product & Service Portfolio, Market & Customer Access, Value Chains & Processes, Organization and culture.	Process, products
4	(IMPULS, n.d.)	Industry 4.0 Readiness	Comprises **six dimensions and six maturity levels** with a description for each level.	All	Employees section	Maturity Level	General, Strategy and Organization, Smart Factory, Smart Operations, Smart products, Data-driven services, Employees, Comparison group.	Process, products
5	(TÜV SÜD, n.d.)	Industry 4.0 Transformation self-assessment	Based on the survey, this MM provides consultation on the areas which the company should focus on. **Four dimensions** are examined. The levels are not clearly defined - it provides MM index for each focus area (quality, speed, productivity, and flexibility) from 1 to 3.	Small and medium	Workforce learning and development section	Index in specific area	No phases, only questions.	Process
6	(Agca, et al.)	WMG Model	**Six maturity levels, six dimensions**, and **29 sub-dimensions** included. The difference of this model is in the assessment tool which is used in table format. Additionally, maturity level is calculated for each dimension.	Small and Medium	Not assessed explicitly	Index in specific area	Product and services, Manufacturing and operations, Strategy and organisation, Supply chain, Business model, Legal considerations.	Process, products

Table 1. Shortlisted maturity models for further analysis

Conclusion

Due to the space limitation, the discussion will be given in this conclusion part. Namely, initial analysis of the maturity models for I4.0 showed the importance of the process of determination of the readiness for I4.0, since a vast number of models are already designed. They understandably differ apropos certain aspects. The selected MMs were divided in three groups in order to identify which MMs have sufficient data (according to the authors) for further, more detailed analysis.

The brief overview of the analysed MMs showed that as it can be expected, there is a great variety among them. Certain conclusions that can be drawn are the following: (1) most of them define four levels of maturity with 4-7 dimensions/pillars that are analysed. (2) although bigger part of them is directed to all enterprises, there are MMs that are targeting SMEs, (3) many of the MMs provide original analysis framework according to pillars/dimensions and (4) most of MMs provide data on processes, products and people, although not always this data is explicit. Although certain insight in the MMs is obtained through this analysis it is clear that in order to make valid selection for future implementation, additional analyses have to be done. Further analysis of the MMs will be directed to analysis of the additional features. Some of the most important are those regarding the outputs of the analysis. Namely, the potential of the MM to show the directions for further development of the road to I4.0 should be one of its most important features.

Acknowledgement

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References

Aagaard, A., & Skou, A. K. (n.d.). Digital Maturity Assessment Tool (DMAT). Retrieved from DBD: https://dbd.au.dk/dmat/

Agca, O., Gibson, J., Godsell, J., Ignatius, J., Davies, C., & Xu, O. (n.d.). An Industry 4 readiness tool.

Andreas Schumacher, S. E. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP 52, 161-166. doi:10.1016/j.procir.2016.07.040

BCG. (n.d.). Digital Maturity Benchmark. Retrieved from https://digitalmaturitybenchmark.withgoogle.com/en/advertisers/

bdc. (n.d.). Digital maturity assessment. Retrieved from bdc.ca: https://www.bdc.ca/en/articles-tools/entrepreneur-toolkit/business-assessments/digital-maturity/digital-maturity-assessment

Capgemini. (2014). Industry 4.0 - The Capgemini Consulting View. Retrieved from https://www.capgemini.com/consulting/wp-content/uploads/sites/30/2017/07/capgemini-consulting-industrie-4.0_0_0.pdf

Çınar, Z. M., Zeeshan , Q., & Korhan , O. (n.d.). A Framework for Industry 4.0 Readiness and Maturity of Smart Manufacturing Enterprises: A Case Study.

Connected Production. (n.d.). INDUSTRIE 4.0 REIFEGRAD – TEST. Retrieved from Connected Production: https://www.connected-production.de/industrie-4-0-reifegrad-test/

Culot, G., Orzes, G., Nassimbeni, G., & Sartor, M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. International Journal of Production Economics. doi:10.1016/j.ijpe.2020.107617

De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2017). A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies. IFIP International Conference on Advances in Production Management Systems. doi:10.1007/978-3-319-66923-6_2

Dikhanbayeva, D., Shaikholla, S., Suleiman, Z., & Zhanybek, A. (2020). Assessment of Industry 4.0 Maturity Models by Design Principles. Sustainability.

Ejsmont, K., Gladysz, B., & Kluczek, A. (2020). Impact of Industry 4.0 on Sustainability—Bibliometric Literature Review. Sustainability. doi:https://doi.org/10.3390/su12145650

European Comission. (2019). 2019 SBA Fact Sheet - North Macedonia. Retrieved from https://ec.europa.eu/neighbourhood-enlargement/system/files/2019-11/sba-fs-2019_north-macedonia.pdf

Gökalp, E., ¸Sener, U., & Eren, P. (n.d.). Development of an Assessment Model for Industry 4.0: Industry.

Häberer, S., Katrin, L., & Behrendt, F. (2017). Development of an Industrie 4.0 Maturity Index for Small and Medium-Sized Enterprises. Conference: IESM 2017 - 7th International Conference on Industrial Engineering and Systems Management.

HNU. (n.d.). Retrieved from HNU: http://reifegradanalyse.hs-neu-ulm.de/

IMDA, I. M. (n.d.). IMDA Digital Acceleration Index. Retrieved from IMDA: https://www.imda.gov.sg/news-and-events/our-signature-events/IMDA-Digital-Acceleration-Index

IMPULS, F. o. (n.d.). Industry 4.0 Readiness - Online Self-Check for Businesses. Retrieved from Industrie 4.0 Readiness: https://www.industrie40-readiness.de/?lang=en

IPL, I. f.-u. (2017). How to Start with Industry 4.0 in SMEs. Retrieved from https://digital4industry.lu/wp-content/uploads/2017/11/IPL_FEDIL_Presentation_20171124.pdf

Leyh, C., Bley, K., Schäffer, T., & Forstenhäusler, S. (n.d.). SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0. Proceedings of the Federated Conference on Computer Science, (pp. 1297–1302). doi:10.15439/2016F478

Menon, K., Kärkkäinen, H., & Lasrado, L. (2016). Towards a maturity modeling approach for the implementation of. Pacific Asia Conference on Information Systems (PACIS 2016).

Merz, S. L., & Siepmann, D. (2016). Industrie 4.0 – Vorgehensmodell für die Einführung. Springer. doi:DOI 10.1007/978-3-662-48505-7_3

Ministry of Economy of North Macedonia. (2018). Industrial Strategy with a focus on the Manufacturing Sector. Retrieved from http://www.pintoconsulting.de/Images/pdf/ENG%20Macedonian%20Industrial%20Strategy%202018%20full.pdf

Mummolo, G., Digiesi, S., Facchini, F., Mossa, G., & Fertsch, M. (2019). Industrial Engineering and Management: an Analysis of the European Educatuonal offer in the Academia and Companies in the Framework of Industry 4.0.

PwC. (2015). Industry 4.0: Building the digital enterprise.

PwC. (n.d.). Industry 4.0 - Enabling Digital Operations - Self assessment. Retrieved from I4.0 Selft Assessment: https://i40-self-assessment.pwc.de/i40/landing/

Qin, J., Liu, Y., & Grosvenor, R. (n.d.). A Categorical Framework of Manufacturing for Industry 4.0 and Beyond. Procedia CIRP. doi:10.1016/j.procir.2016.08.005

Rauch, E., & et al., (n.d.). A Maturity Level-Based Assessment Tool to Enhance the Implementation of Industry 4.0 in Small and Medium-Sized Enterprises.

Rockwell Automation. (2014). The Connected Enterprise - Maturity Model. Retrieved from https://literature.rockwellautomation.com/idc/groups/literature/documents/wp/cie-wp002_-en-p.pdf

Schuh, G., Anderl, R., Gausemeier, J., Hompel, M., & Wahlster, W. (2020). Industry 4.0 Maturity Index: Managing the digital Tranformation of companies.

Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (n.d.).

SmarterChains. (n.d.). Industry 4.0 Maturity Assessment. Retrieved from SmarterChains: https://www.smarterchains.com/industry-40-assessment

TÜV SÜD. (n.d.). Start Your Industry 4.0 Journey Now: Quick Self-Assessment. Retrieved from https://www.tuvsud.com/en/i40-readiness-self-assessment

UNITY AG. (n.d.). Digital readiness check. Retrieved from https://www.unity.de/de/leistungen/digitale-transformation-industrie-4-0/digital-readiness-check/

Wagire, A., Joshi, R., Rathore, A., & Jain, R. (2020). Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice. Production Planning & Control - The Management of Operations, 603-622.

Wagire, A., Joshi, R., Rathore, A., & Jain, R. (2021). Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice. Production Planning & Control - The Management of Operations, Volume 32, 603-622. doi:10.1080/09537287.2020.1744763

Weber, C., Königsberger, J., Kassner, L., & Mitschang, B. (2017). M2DDM – A Maturity Model for Data-Driven Manufacturing. Procedia CIRP 63, 173-178. doi:https://doi.org/10.1016/j.procir.2017.03.309

WZL. (n.d.). Industrie-4.0-Audit für produzierende Unternehmen. Retrieved from Ingenieur: https://www.ingenieur.de/fachmedien/vdi-z/industrie-4-0/industrie-4-0-audit-fuer-produzierende-unternehmen/

A Review of Dimensions of Industry 4.0 Readiness and Maturity Models

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Abstract

Industry 4.0 marks a new paradigm in manufacturing and introduces many new technologies for manufacturing enterprises which make the adopter more competitive on the global market. Since there is a lack of common definition and standardized guide, many researchers have created Industry 4.0 readiness or maturity models. These models help companies to better understand their current state and how they can improve their capabilities. In this article we have compiled a brief list of highly cited papers that present Industry 4.0 readiness or maturity models. We have also presented dimensions which these models use.

Keywords: Industry 4.0, Readiness model, Maturity model, Dimension

Introduction

In the last 10 years there have been major technological advancements which are pushing the entire industrial sector towards a new manufacturing paradigm. Main driving forces are advanced digital technologies used in factories which combine ICT technologies with improved “smart” capabilities of machines and products. This has led to the creation of modular manufacturing systems where products control their own manufacturing process. These kinds of manufacturing systems would be able to produce highly individualised products in small batch sizes while retaining the economic benefits mass production.(Lasi et al., 2014)

Realizing the importance of this new paradigm, governments have created strategies and initiatives to improve the entire manufacturing sectors in their respective countries. One such example is German strategic initiative called “Industrie 4.0” which was created to increase the competitiveness of the German manufacturing sector through digitisation and interconnection. (Kagermann et al., 2013)

The (German) term “Industrie 4.0” or more known as Industry 4.0 has become synonymous with the fourth industrial revolution which will completely redefine the way companies manufacture products. However, since there are many new concepts and technologies being developed and introduced, it is difficult to clearly define what benefits does Industry 4.0 bring and how it benefits a company.(Bibby and Dehe, 2018).

With these issues in mind, researchers have developed many different tools in the form of readiness and maturity models which help enterprises to assess their current state and define a roadmap for implementation of advanced technologies.

Theoretical background

First, we will start with a definition of what is a readiness model and what is a maturity model. Since there is no general definition, we will start with dictionary definitions of each word.

Readiness is defined as “willingness or a state of being prepared for something” (Readiness, Cambridge Dictionary) while maturity is defined as “a very advanced or developed form or state” (Maturity, Cambridge Dictionary). And finally, a model can be defined as “a representation of something in words or numbers that can be used to tell what is likely to happen if particular facts are considered as true” (Model, Cambridge Dictionary).

With these definitions in mind, we can clearly establish that an Industry 4.0 readiness model tries to represent how ready an enterprise is to implement advanced technologies and concepts, while Industry 4.0 maturity model tries to represent how advanced an enterprise is in adopting Industry 4.0. Some authors define readiness model as “the degree to which organizations are able to take advantage of Industry 4.0 technologies” (Hizam-Hanafiah et al., 2020) while others define it as “an instrument to conceptualize and measure the starting point and allow for initializing the development process” (Schumacher et al., 2016).

These two models should be used separately, and readiness assessment should be done before the maturity assessment which captures the current state in the enterprise. (Schumacher et al., 2016).

Since many different Industry 4.0 readiness and maturity models exist, we wanted to explore how many articles have been published on this topic to this day and what dimensions, factors, or criteria they use to build the models.

Methodology

For the purposes of our research, we have conducted a systematic literature review using the following databases which are available online: Scopus, Web of science and IEEE. First, we defined keywords which we used for narrowing down the existing models in each database. Since we were searching for two distinct types of models, we had to conduct our search twice but with different sets of keywords. For Web of Science database, we searched by topic, for Scopus we used Article title, Abstract, Keywords and for IEEE Xplore we searched in All Metadata. The first keyword which stayed the same for every search iteration was Industry 4.0, followed by manufacturing to narrow down models which deal only with Industry 4.0 maturity or readiness models in manufacturing companies. Then we added a few terms which are frequently associated with explanation of the state of being (e.g. model, assessment, level and index) in a combination with the term readiness or maturity. Even though the Industry 4.0 was first mentioned in 2011 (Kagerman et al., 2013), we searched for articles that were published from 2010 onward. Other criteria that we used were only scientific and conference articles in English language excluding the review articles. The table 1 summarizes our search criteria.

Database	Web of Science, Scopus, IEEE
Keywords set 1 (readiness model)	“Industry 4.0” AND manufacturing AND (“readiness model” OR "readiness assessment" OR "readiness level" OR "readiness index") NOT review
Keywords set 2 (maturity model)	“Industry 4.0” AND manufacturing AND (“maturity model” OR "maturity assessment" OR "maturity level" OR "maturity index«) NOT review
Date range	2010 – 2022
Other criteria	Scientific article, conference article, English language

Table 1: Search criteria

Results

Based on the already implemented solutions for enabling p2p contactless work, the research team developed also ideas for future research. To increase the efficiency but also resilience in production the before mentioned worker assistance systems need to be integrated in a digital twin of the assembly station. The concept for such a future oriented workstation is shown in Figure 4. In the proposed model the assembly station captures data (related to quantity and quality of the work) through a Manufacturing Execution System (MES) and sends such data to a digital twin of the production system. While the connection of the work station to the ERP/MES allows real-time monitoring, the use of collected data for simulations in the digital twin model allows to find operational bottlenecks and to optimize the productivity.

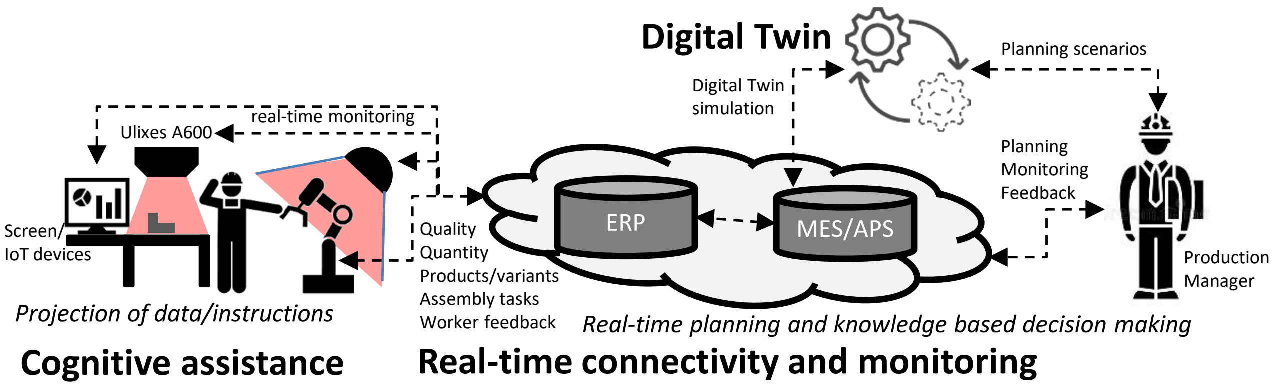

Figure 4: Real-time connected and digital twin based worker assistance system

Using such kind of an enhanced and digital twin based worker assistance system p2p interactions can again be reduced by minimizing the need to directly communicate with the production manager or supervisor. In the future the research team plans to start a project working together on the planning, design, realization and validation of such a real-time connected monitoring system and a digital twin based optimization of the workstation and work processes.

Our first finding was that the number of articles that specifically address readiness models for Industry 4.0 was a lot lower than the number of articles that address maturity of Industry 4.0. Upon further analysis we have also discovered that some researchers used maturity models as tools for assessing the Industry 4.0 readiness and some used maturity models to asses both readiness and maturity of Industry 4.0. Table 2 presents the number of results for each of the databases that were used.

	WoS	**Scopus**	**IEEE**
Readiness models	14	55	10
Maturity models	36	124	16

Table 2: Search results per database

Because of the limited scope of this review, we have compiled a short list of 9 models and their dimensions for the purpose of quickly understanding what factors, dimensions or other criteria the proposed models contain. For this reason, we have used the Scopus database since it had the most results, which we then sorted by the highest number of citations and excluded those articles where dimensions were not clearly explained. We have also included IMPULS model which is believed to be one of the most scientifically grounded models because it is based on a comprehensive dataset and can be explained in a transparent manner (Schumacher et al., 2016). The table 3 presents the brief list of Industry 4.0 readiness and maturity models, and their dimensions.

Article/model name	**Dimensions**
A maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises (Schumacher et al., 2016)	Products, Customers, Operations, Technology, Strategy, Leadership, Governance, Culture and People
Smart Factory Implementation and Process Inovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing (Sjödin et al., 2018)	People, Process, Technology
A maturity model for assessing the digital readiness of manufacturing companies (De Carolis et al., 2017)	Design and Engineering, Production management, Quality management, Maintenance management and Logistics management
Development of an assessment model for industry 4.0: Industry 4.0-MM (Gökalp et al., 2017)	Process transformation, application management, data governance, asset management and organizational alignment
SIMMI 4.0 (Leyh et al., 2016)	Vertical Integration of enterprise components, Horizontal integration across different value networks, Digital product development, Cross-sectional technology criteria
Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises (Schumacher et al., 2019)	Technology, Products, Customers and Partners, Value Creation Processes, Data & Information, Corporate Standards, Employees, Strategy and Leadership
360 Digital Maturity Assessment (360DMA) (Colli et al., 2018)	Governance, Technology, Connectivity, Value creation, Competence
Digitalization Maturity Model (Canetta et al., 2018)	Strategy, Processes, Technologies, Products, Services and People
IMPULS - Industrie 4.0 readiness (Lichtblau et al.)	Strategy & Organization, Smart Factory, Smart Operations, Smart Products, Data-driven Services, and Employees

Table 3: A list of highly cited models and their dimensions

As can be seen in the table, the existing models vary in the number of dimensions and in type of dimensions that they use. While some focus primarily on technological aspect of Industry 4.0, others include so-called supporting aspects in the form of people, strategy and organizational culture of enterprises.

Discussion

We are aware that there exist other maturity and readiness models with unique approaches and criteria for evaluating the implementation of Industry 4.0, but the scope of this research is limited so we can include only a few of them in this paper. Based on our short review of model dimensions it is obvious that the number of dimensions differs from model to model and that the technology is the most important dimension. One other finding is that only five out of nine models include people (or employees) as part of Industry 4.0 dimension. We believe that this is inadequate since it is our opinion that without people it is not possible to implement or maintain any high level of digitalization within a manufacturing enterprise.

One additional issue lies in the lack of common definition of what Industry 4.0 consists of. There have been several propositions from academia where authors proposed 12 design principles and 14 technology trends. Other authors have identified 64 technologies which are connected to Industry 4.0. Such confusion seemingly negatively impacts enterprises (mainly SMEs which have which have limited economic power compared to large enterprises) are struggling to adopt new technologies and concepts. (Stentoft et al., 2020)

Building a readiness or maturity model is not an easy task. Majority of the proposed models are created based on questionnaires and interviews with industry experts and case studies. It should be noted that these models could be considered country specific because the data is collected only in one country with its own specific industrial features or culture. One other limitation of these models is their applicability. Since they are made specifically for manufacturing, they cannot be generalised and used in other sectors (e.g. service or logistics). Besides general applicability we should also consider actual application in real world enterprises. Some authors have stated that their models were used in test companies but there is hardly any proof if the model was successfully implemented and if it was implemented in other enterprises as well. There is also a lack of comparison between different models and how well they capture the readiness or maturity.

Conclusions

In this article we have explored several Industry 4.0 readiness and maturity models and their dimensions. According to our expectations, technology is the leading dimension in all of the presented models, and we assume that it is also the same in many other models that we have not covered therefore an extensive review should be conducted periodically. While some authors focus more on the technological side of Industry 4.0, others also include people, culture, organization, and strategy as important dimensions of successful Industry 4.0 implementation. We believe that this is because different researchers have different understanding and perception of Industry 4.0 and that there is a lack of standardized definition of Industry 4.0 building blocks. We also believe that many of the proposed models are specific to the country of origin since they are built only on data from that country. Therefore, we propose a joint effort of different countries to create a model that would be more widely applicable. Up to this date (to the best of our knowledge), no article has been published which compares the reliability and usability of different models.

References

Bibby, L., Dehe, B., 2018. Defining and assessing industry 4.0 maturity levels – case of the defence sector. Production Planning & Control, 29, 1030-1043.

Cambridge Dictionary. (n.d.). Readiness. In dictionary.cambridge.org dictionary. Retrieved April 12, 2022, from https://dictionary.cambridge.org/dictionary/english/readiness

Cambridge Dictionary. (n.d.). Maturity. In dictionary.cambridge.org dictionary. Retrieved April 12, 2022, from https://dictionary.cambridge.org/dictionary/english/maturity

Cambridge Dictionary. (n.d.). Model. In dictionary.cambridge.org dictionary. Retrieved April 12, 2022, from https://dictionary.cambridge.org/dictionary/english/model

Canetta, L., Barni, A., Montini, E., 2018. Development of a Digitalization Maturity Model for the Manufacturing Sector. 2018 IEEE International Conference on Engineering, Technology & Innovation, ICE/ITMC 2018 Proceedings,17-20 June 2018, Stuttgart, Germany.

Colli, M., Madsen, O., Berger, U., Møller, C., Wæhrens, B. V., Bockholt, M., 2018, Contextualizing the outcome of a maturity assessment for Industry 4.0. IFAC-PapersOnLine. 51 (11) 1347-1352.

De Carolis, A., Macchi, M., Negri, E., Terzi, S., 2017. A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies, in: Lödding, H., Riedel, R., Thoben, KD., von Cieminski, G., Kiritsis, D. (eds) Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing. Springer, 13-20.

Gökalp, E., Şener, U., Eren, P. E., 2017. Development of an Assessment Model for Industry 4.0: Industry 4.0-MM, International Conference on Software Process Improvement and Capability Determination, 4 - 5 October 2018, Palma de Mallorca, Spain.

Hizam-Hanafiah, M., Soomro, M. A., Abdullah, N. L., 2020. Industry 4.0 Readiness Models: A Systematic Literature Review of Model Dimensions. Information, 11 (7).

Kagermann, H., Wahlster, W. & Helbig, J., 2013. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0 - Securing the Future of German Manufacturing Industry. National Academy of Science and Engineering, München, Germany.

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., Hoffmann, M., 2014. Industry 4.0. Business & Information Systems Engineering, 6 (4), 239-242.

Leyh, C., Schäffer, T., Bley, K., Forstenhäusler, S., 2016. SIMMI 4.0 – A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0, Proceedings of the 2016 Federated Conference on Computer Science and Information Systems, 11 - 14 September 2016, Gdansk, Poland.

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A.,Schmitt, K., Schmitz, E., Schröter, M., 2015. IMPULS - Industrie 4.0-Readiness. Impuls-Stiftung des VDMA, Aachen-Köln.

Schumacher, A., Erol, S., Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP, 52, 161-166.

Schumacher, A., Nemeth, T., Sihn, W., 2019. Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. Procedia CIRP, 79, 409-414.

Sjödin, D. R., Parida, V., Leksell, M., Petrovic, A., 2018. Smart Factory Implementation and Process Innovation. Research-Technology Management, 61 (5), 22-31.

Stentoft, J., Wickstrøm, K. A., Haug, A., Philipsen, K., 2020. Cost-driven motives to relocate manufacturing abroad among small- and medium-sized manufacturers. Journal of Manufacturing Technology Management, 32 (3), 646-666.

Data Fitting as the Next Level in the Management of Chances and Risks

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Abstract

In construction projects, data, information, and knowledge create the basic framework for fully achieving the targets defined by the client and the contractor. Furthermore, the knowledge generated from data and information forms the basis for subjecting the individual elements and relationships within the entire production system to a continuous improvement process. When managing chances and risks, it is crucial to know the chance/risk ratio associated with specific decisions made. This applies to strategic as well as operational decisions, which are made at all levels and in a wide range of different specialist areas. Regardless of whether it is made on the basis of heuristics (gut feeling or experience) or supported by complex simulation models, any decision will have to rely on corresponding basic data and information as well as contextual knowledge. Thanks to the increasing integration of new technologies, the collection and processing of such data will also continue to advance in construction management and economics, and thus find its way out of the factory floors and onto construction sites. This systematic data collection and handling aims to acquire, develop, share, distribute, and preserve knowledge, with the ultimate objective to reuse it in a beneficial and profitable manner. This paper deals with the quantitative management of chances and risks and the influence of digitalisation and data collection/documentation. On the conceptual level, it shows how data fitting can be applied to gain insights from data structures and to incorporate them into the process of managing chances and risks using appropriate models.

Keywords: Monte Carlo simulation, Chance/risk ratio, Distribution function, Calculation model, Data fitting

Introduction

As in many other areas, a shift from implementations and mindsets towards networked, interacting structures, systems and processes is also emerging in the construction industry, which is associated with both chances and risks. Digitalisation and the networking of processes also open up new opportunities for decision-making, the representation of possible event spaces and the systematic consideration of uncertainties.

The systematic quantitative management of chances and risks benefits from the digital transformation and the increasing amount of data that will be available in the future. At the same time, however, it raises issues with regard to delimitation, classification and filtering, which, if not solved appropriately, can distort results so that they ultimately prove to be less beneficial than originally expected.

The interplay and interaction between the production factors is fraught with many uncertainties particularly in the early project phases because, at this stage, not much progress will have been made towards detailed planning and project management. Purely deterministic considerations convey a false accuracy of forecast values. Calculated ranges are usually (more) consistent with the real situation, although they do not deliver precise results.

Probabilistic calculations (i.e. calculations based on probability theory) deliberately integrate the existing uncertainties and visualise them when analysing results, for instance as histograms.

Using a corresponding database reduces the epistemic uncertainties of a model whilst enhancing knowledge of the production processes and systems under consideration. Conducting sensitivity analyses and including ranges in the considerations improves the understanding of the project, and thus the chance to avoid or reduce makeshift solutions and short-term rescheduling. This is how the management of chances and risks in construction management also contributes to utilising resources as efficiently as possible. Calculations can be carried out, for example, as part of conducting life-cycle analyses or determining greenhouse gas emissions whilst taking the uncertainties inherent in the systems into account in order to ultimately provide those in charge with the opportunity to make the “right” decisions.

Data collection

The pure collection of data can take place, for example, in the form of measurements (such as through the use of sensors or multi-sensor systems), surveys (including interviews and surveys of experts), or observations, as well as by analysing historical records (statistics). The great difficulty, however, lies in the appropriate delimitation of different underlying conditions, use cases and extreme events. The circumstances under which consumption rates and output values were determined, for instance, should be recorded as accurately as possible in order to document these values in a meaningful manner. Categorisation according to building types, degrees of difficulty etc. can help to extract ranges or distribution functions for probabilistic calculations from the gathered data. The fact that there are often integration gaps between different data collection systems also makes it difficult to combine or interlink different data sources in a targeted manner.

Further challenges arise from the degree of subjectivity in the course of documentation. The following questions arise, among others: Which data and information appears to be important at all, and is thus recorded? Can data be condensed or must it be collected in a differentiated manner? Does a certain circumstance constitute a contractually relevant obstruction, or should the disruption to the construction process be considered as common?

At any rate, acquiring and using machine data is probably easier to implement, at least in the short to medium term, whilst also providing the opportunity to use data in a real-time or at least near-real-time setting. Generally speaking, it also currently appears to be easier to collect technical data compared to economic or environmental data (Hofstadler and Kummer, 2017).

Structuring and data adjustment

Data capture or acquisition is not sufficient on its own; it must be complemented by appropriate classification and division into corresponding groups (classes) in order to define initial delimitations and to arrive at more accurate conclusions. In building construction, for example, it is helpful to classify data pertaining to construction management and economics according to building type, size, area division, use, number of storeys, etc. so as to access appropriate data in the respective categories.

Irrespective of its size or scope, almost any type of data acquisition (including measured values, recordings, observations, or survey results) will inevitably raise the question, at a certain point during the analysis, of how to treat (supposed) outliers or extreme values. More specifically, the question is: Do these data points remain in the sample and are thus fed into future observations, calculations, simulations and forecasts, or are they erroneous values (measurement or input errors, or misinterpretations) that must be removed from the data structure?

Appropriate management and control tools, rules of thumb and empirical evidence are needed in order to check, analyse and, if necessary, adjust and/or delimit data that has been collected manually, semi-automatically and/or automatically.

Data fitting in the management of chances and risks

In the future, using collected, processed and refined data for managing chances and risks and/or systematically considering uncertainties in computation models will provide an essential prerequisite for decision-making, and will subsequently determine the possible event space of defined output parameters.

Decisions can ultimately be made on the basis of a chance/risk ratio (over- and underrun probabilities). It takes relatively little effort to visualise and analyse different scenarios. Selecting appropriate distribution functions for input parameters is crucial for arriving at predictions and forecasts. This is where data fitting provides an essential tool that can be used not just “once” for defining distribution functions because it also provides the option of continuously integrating new data into the data fitting, thus also responding to changes in the data structure and feeding such changes into the forecasts.

The issue of which distribution functions to apply to individual calculation parameters essentially determines the quality of the output, such as a Monte Carlo simulation. There is no “one size fits all” answer to this question. In the literature, considerations regarding the “nature” and possible characteristics of specific parameters are discussed in conjunction with utilising historical data and outcomes of expert surveys (e.g. Chau, 1995; Hofstadler, 2014; Kummer, 2015; Čadež, Brokbals and Wapelhorst, 2019, Hofstadler and Kummer, 2017 and 2021).

The concept of transferring such data records (such as from *ex ante*, *ex post* or *inter actio* surveys or observations) into distribution functions that can be described on a theoretical level is referred to as data fitting. In this process, available data is first processed or adjusted and then analysed graphically in the form of histograms. Subsequently, mathematical/statistical methods are used to identify the theoretical distribution function that best represents the available data (showing the smallest deviation). In the course of this fitting procedure, individual data records are compared with theoretical (mathematically describable) distributions and checked for equivalence.

Fitting aims to determine the parameters of a distribution function (displacement and curve parameters) in a numerical process such that the distribution represents gathered raw data as accurately as possible (Hofstadler and Kummer, 2017).

Integration of data fitting into the management of chances and risks

To integrate current data into the calculations to be carried out for the quantitative management of chances and risks, it is necessary to embed the data fitting tool into a process flow (see Fig. 1).

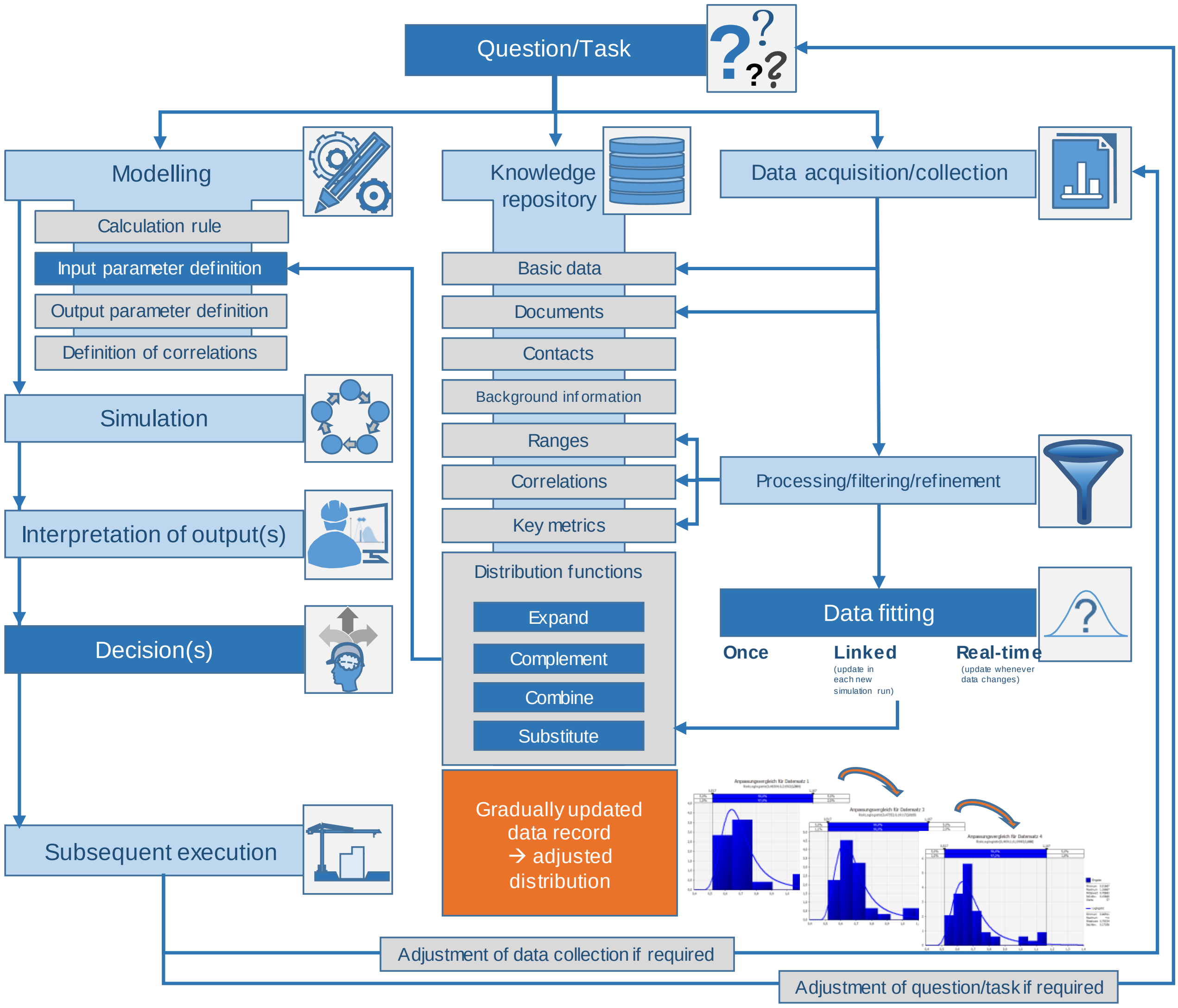

Figure 1: Flow chart – Integration of data fitting into the quantitative management of chances and risks (cf. Kummer and Hofstadler, 2021)

In the first step, the corresponding questions and tasks must be defined, and a model must be developed to answer them. In the modelling phase, a real or planned situation or system behaviour is abstracted to a mathematical computation model. In this process, the calculation rule (algorithm), the input parameters (grouped into deterministic and probabilistic parameters), the output parameters and possible correlations between the input parameters must be defined.

In an ideal setting, a knowledge repository will be available right from the outset of the project. Besides basic data and documents, this repository may also contain specific contacts and background information. Ranges, correlations or key metrics can be derived from this information, and input parameter distribution functions can be defined. Using this data and information makes it possible to carry out simulations, prepare forecasts and ultimately make decisions even before the project actually starts (such as in costing or process planning). In the course of the project, project-specific data is acquired/collected in order to extend or complement the distribution functions initially derived from the knowledge repository by adding specific data as the project progresses.

Alternatively, the distribution functions can be combined with this data or replaced altogether (substitution) if sufficient new data has been acquired. At this stage, it is important for this data to be subjected to processing/filtering or refinement, depending on the specific requirements.

Actual data fitting takes place in the next step. It results in one or several distributions that can then be used as input parameters in the model and the subsequent simulation in combination with the knowledge repository.

If distributions are adjusted or fitted from a static data record, the distributions may have to be adjusted to the respective project-specific circumstances. In contrast, with dynamic data records, which update (semi)automatically over time, the distribution functions are fed directly into the calculation model and thus into the simulation. Special attention must be paid to data quality and potential outliers/extreme values.

The simulation itself will require appropriate software with which probabilistic calculations or analyses, such as Monte Carlo simulations, can be carried out. Simulation outputs can be analysed with regard to certain statistical metrics after the calculation has been completed. Furthermore, it is advisable to conduct sensitivity analyses (including point, tornado or spider diagrams) that highlight the relationship between one or several input parameters and the output. Of particular interest are over- and underrun probabilities in relation to certain deterministic numerical values (chance/risk ratio).

Simulation results subsequently serve as a basis for decisions to be made by the acting stakeholders. After all, it is the people who can and must make decisions, drawing on their creativity and ability to conceptualise, with regard to adjusting the use of resources or certain behavioural patterns and processes. In this context, the question/task or the type and form of data collection may have to be adjusted.

Ultimately, the decision for further action on the operational level is made on the basis of a chance/risk ratio, which is determined not least by the chance/risk policy adopted by the company or organisation as well as by the personal (subjective) risk affinity or aversion of the stakeholders.

In the course of subsequent project execution, data is continuously generated and subjected to data fitting in order to be fed into new simulations and interpretations of results. The gradual update of the data record and the distributions adjusted to it make it possible to respond swiftly to changes within the project and to intervene in a controlled manner at a very early stage. This approach requires high data quality and up-to-dateness as well as consistently defined boundaries or limits in terms of time, space, and content.

The highest level of integration of data fittings into the management of chances and risks is achieved if new data is fed into the model or simulation in real time. This means that inputs and outputs are updated as soon as changes and/or additions are made to the data record.

Conclusion

The digital transformation increasingly influences the design of construction management and related processes whilst uncovering additional potential for optimisation. These trends make it increasingly necessary, yet also possible, to provide even more “accurate” data and information to be fed into calculations and simulations for future projects. Data from similar completed projects can be used even before the current project starts. In projects under construction, real-time data and information should contribute to establishing more efficient management, analysis and control of construction processes.

The quality of results depends on the quality of the calculation model, the collected data, the inputs (values, ranges, distribution functions) and the right feel for data and information (“garbage in, garbage out”).

This paper particularly dealt with how data fitting procedures can be systematically integrated into the quantitative management of chances and risks, but also generally into calculations and forecasts that take uncertainties into account.

This approach should shorten response times, increase agility and establish an early warning or control system. Near-real-time data acquisition and collection, which is far advanced in the stationary industry, will be increasingly gaining ground on construction sites thanks to the continuous improvement of digital tools, processes and methods.

References

Čadež I., Brokbals S., Wapelhorst V., 2019. Stochastische Berechnung bauleistungsspezifischer Risikokosten in der Angebotskalkulation. Bautechnik, Volume 96 (4), 319–328.

Chau, K. W., 1995. The validity of the triangular distribution assumption in Monte Carlo simulation of construction costs: empirical evidence from Hong Kong. Construction Management and Economics, Volume 13, Issue 1, 15–21.

Hofstadler, C., 2014. Monte-Carlo-Simulation im Baubetrieb – Verteilungsfunktion für Aufwandswerte bei Schalarbeiten – Herleitung der Verteilungsfunktion aus den Ergebnissen einer Expertenbefragung. Bauingenieur, 89, May 2014, 189–201.

Hofstadler C., Kummer M., 2017. Chancen- und Risikomanagement in der Bauwirtschaft. Springer Vieweg, Berlin, Heidelberg.

Hofstadler C., Kummer M., 2021. Chances and Risks in Construction Management and Economics. Springer Nature, Cham.

Kummer, M., 2015. Aggregierte Berücksichtigung von Produktivitätsverlusten bei der Ermittlung von Baukosten und Bauzeiten – Deterministische und probabilistische Betrachtungen. Doctoral thesis.

Kummer, M., Hofstadler, C., 2021. Datenfitting als nutzbringendes Werkzeug des Chancen- und Risikomanagements, In: Hofstadler C., Motzko C. (Eds.), Digitalisierung im Baubetrieb. Springer Vieweg, Berlin, Heidelberg, 167–196.

Inter-firm Cooperation: Basis of a Course in Industrial Engineering

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Abstract

Inter-firm cooperation, with its different goals and in its different forms as a source of productivity and competitiveness, has been a subject of active research during the last few decades. Based on a review of the literature, the authors analyse the goals that can be pursued through inter-firm cooperation and then, they examine industrial engineering curricula in five faculties of five different countries to verify if this source of competitiveness is sufficiently addressed in education. The results indicate that, in general, this topic is not directly addressed in studies in all its extents, and, in some cases, it is merely treated as a sub-product of internal productivity tools and concepts or a supply chain approach. The paper concludes that the inclusion of inter-firm synergies with a broad vision could improve industrial engineering curricula, and a basic course structure is proposed.

Keywords: Industrial engineering, Competitiveness, Inter-firm, Productivity, Synergies

Introduction

Retegi and Igartua (2021) suggest that broadening the optimisation scope from company to value chain and industrial ecosystems is one of the potential future paths for industrial engineering development for the future decades. In this sense, the European Commission (2020b) will support its new industrial strategy by a new focus on industrial ecosystems that encompass all players operating in a value chain. Moreover, considering the impact of digitisation, business process management will increasingly involve more integration across a complex network of partners (Caputo et al, 2018). Although it is still limited, research interest in coopetition increased from 1994 to 2014 (Dorn et al, 2016).

In this paper, the authors analyse some of the alternatives to obtain competitive advantage through cooperation between firms and verify if this source of competitiveness is sufficiently addressed in industrial engineering studies. To achieve this, the curricula of five different faculties in five different countries are analysed.

Methodology

For this research, a literature review was conducted. The articles were located using the Web of Science database. The research was carried out during February 2022 with the following search string: ((“competitive*” OR “productivit*”) AND (“inter-compan*” OR “intercompan*” OR “inter-firm*” OR “interfirm*” OR “industrial ecosystem*”)) in the title, abstract, and keyword fields with the publication year between 2016 and 2022. As a result, the authors identified 432 articles. The titles and abstracts of the selected articles were read, and those relevant to inter-firm cooperation for productivity and/or competitiveness were retained. During the examination of the articles, the main references linked to the topic of this article were analysed and classified. The purpose of the literature review was to identify the variety of inter-firm relationships leading to an increase in performance. The relevant articles were classified depending on the goal of the cooperation between firms and ranked depending on their citations. Due to length limitation of this paper, only one paper per inter-firm cooperation goal is indicated.

An analysis of industrial engineering curricula has been conducted for several European faculties in five different countries to identify subjects that can be related to the competences of identifying and/or developing inter-firm synergies. The cases were selected from among the schools or faculties offering industrial engineering degree studies for which details about the courses were publicly available.

Review of the literature

The phenomenon of inter-firm cooperation can be seen from different perspectives regarding the motivations, outcomes, form, or factors that affect its success. An extensive literature review and proposal for a framework of inter-firm collaborative business strategies is presented in Bhattacharyya (2020). Considering the outcomes of cooperation, Bengtsson and Raza-Ullah (2016) present an extensive literature review on the four main dimensions of the performance increase in coopetition: innovation performance, knowledge sharing, creation, acquisition, and economic, financial, market, and competitive performance. The network of the cooperation structure created to implement the inter-firm synergies can take different forms, as indicated in Nassimbeni (1998).

From the perspective of the goals, the inter-firm cooperation literature has addressed diverse perspectives linked with competitiveness and productivity (Franco and Haase, 2015), as is indicated in Table 1.

Type of synergies	Goals of synergies
Improvement of supplier’s quality	A driver company contributes to the quantitative and qualitative development of a supplier by a structured program of improvement (Mitrega et al, 2017).
Sharing of common services	Sharing common services as a way to reduce costs and improve quality: administration, information technologies, etc (Della Peruta et al, 2018).
Increase in procurement performance	Firms share a common procurement service to obtain better goods and/or services, quality, prices, and payment terms through a professionalised common structure and scale economies (Saha et al, 2011).
R&D and innovation efficiency	Firms in a region sharing the use of the same core technology promote the creation of an R&D alliance (Martínez-Noya et Narula, 2018; Huggins and Thompson, 2017).

Training and skills promotion	Firms in a region having similar skills needs promote the creation of a vocational education training unit (Della Peruta et al, 2018).
Industrial symbiotic relationship	Firms with geographic proximity are engaged in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products (Chertow, 2007; Bacon et al, 2020).
Financial services	Firms share financial resources through cash pooling or credit mechanisms (Everaert et al, 2008)
SMEs networking for internationalisation	Firms establish common services to facilitate internationalisation processes in selected countries (Montoro-Sánchez et al, 2018).
Knowledge management to support decision-making	Firms share resources to provide information for an effective decision making (Wulf and Butel, 2017).

Table 1: Goals for synergetic inter-firm relationships

In Institute of Industrial Engineers IIE (2006), the industrial engineer's roles in industry are presented. The references to inter-firm relationships to obtain productivity improvements are limited to supply chain management (audit suppliers and solve issues) and to the coordination of third-party quality audits. No references to the strategic relevance of inter-firm relationships are found.

In this research, as can be seen in Table 2, the curricula of five industrial engineering related degrees (bachelor's and/or master's degrees) offered in different European countries (France, Austria, Sweden, Switzerland, and Spain) have been analysed.

Country	**Bachelor's/Master's**	**Courses**
France	Bachelor's	3 ECTS. Oriented towards supply chain and purchase management and logistics.
Austria	Master's	2+2 ECTS. Manufacturing and supply chain network; implementing innovation strategy through M&A.
Switzerland	Master's	4+4 ECTS. Strategic partnership, supply chain network, and value chain management in practice in two different master's degrees.
Sweden	Master's	No specific courses found.
Spain	Bachelor's	Part of 6 ECTS. Linked to a mainly internally oriented logistics course.

Table 2. Analysis of some European curricula

It is found that, in general, this topic is not directly addressed in the studies, and in some cases, it is treated as a sub-product of supply chain management or logistics. Some specific courses addressing value chain management, implementation of innovation strategy through M&A, or strategic partnership are part of master's degree programs in the optional list of courses of programs analysed from Austria and Switzerland. It can be concluded that the scope of inter-firm productivity is mainly addressed from the supply chain/logistics optimisation perspective.

Considering the goals that can be achieved through inter-firm synergies exploitation and the residual presence of this topic in industrial engineering curricula, content is proposed that could include the contents in the Table 3.

Inter-firm sources of productivity and competitiveness	
Studies	Industrial engineering-related bachelor's or master's degrees (3 creds.)
Skills	To be aware of the importance of inter-firm cooperation to improve competitiveness and to face the future challenges of the firm. To be able to detect and conceptualise opportunities for improvement of productivity and/or competitiveness fostering inter-firm relationships
Contents	Procurement improvement through aggregation of purchasing capacity; supplier development processes; industrial symbiotic ecosystems; sharing of common services and resources (financial, knowledge exchange, etc.); collaborative research & development & innovation models; SMEs networking for internationalisation; regional promotion of training and research centres and activities; regional clusters/sectorial clusters; addressing the macro transitions through inter-firm cooperation
Methodology	Basic theory (motivations, forms of cooperation, expected synergies, strategic and inter-dependence issues) and case studies

Table 3: Basic information about a new subject on inter-firm productivity sources

This subject could be implemented in undergraduate or master's degree programs but should be compulsory.

Conclusions

The relevance of inter-firm cooperation for productivity and competitiveness with several approaches is well reflected in the literature. The skills needed to propose and implement efficient cooperation projects include strategic, competitive, and economic skills but also require integrating product, process, and technology aspects that can condition or foster the interest in such projects. That makes this field a natural area for industrial engineers' skills development and a challenge to contribute to firms' competitiveness.

After having analysed the research related to inter-firm cooperation as a source of competitiveness and the curricula of studies in industrial engineering and management, the following conclusions can be extracted:

- From the review of the literature, we can conclude that the topic of inter-firm cooperation as a source of productivity and competitiveness is much broader than the supply chain approach.
- In most of the programs, we did not identify specific subjects oriented towards identifying and exploiting the possibilities of inter-firm synergies in all its extents. In some cases, this can be addressed as a derivation of internal optimisation and/or an improvement of commercial relationships. Some institutions offer some courses from the optional list.
- Obtaining better productivity and competitiveness requires a new perspective of management that goes beyond internal sources of improvement and external competitive or vendor-buyer relationships.

- To be effective, the European trends (European Commission, 2019; European Commission, 2020a) that will affect industry (digitisation, energy transition, circular economy, climate neutrality, and strengthening of value chains) require coordinated action between firms belonging to the same value chain or firms constituting new value chains.
- The perspective of reaching inter-firm synergies requires a cooperative state of mind of managers that cannot be treated as a sub-product of the application of internal productivity increasing tools, nor as a transaction cost optimisation perspective.
- Industrial engineers should integrate the scope outside of the firm as a field to be managed to increase productivity and competitiveness through inter-firm synergies.
- The list of contents is too extensive for a 3-credit course. The basic content of a course and its items presented in this paper can constitute an initial approach that should be selected and developed depending on the priorities of the industrial sector of the region/country and the challenges to be addressed.

This paper has some limitations due to the small sample of industrial engineering studies that have been analysed and the availability of details of the teaching programs.

References

Bacon, E., Williams, M.D. and Davies, G. (2020), "Coopetition in innovation ecosystems: a comparative analysis of knowledge transfer configurations", Journal of Business Research, Vol. 115 No. 7, pp. 307-316.

Bhattacharyya, S.S., (2020) Development of an integrated framework regarding inter-firm collaborative business strategies. Journal of Science and Technology Policy Management. Vol. 12 No. 1, 2021. pp. 62-85. DOI 10.1108/JSTPM-02-2020-0019

Bengtsson M., Raza-Ullah T. 2016, A systematic review of research on coopetition: Toward a multilevel understanding, Industrial Marketing Management, Volume 57, 2016, Pages 23-39, ISSN 0019-8501.

Caputo, A., Fiorentino, R., & Garzella, S. (2019). From the boundaries of management to the management of boundaries: Business processes, capabilities and negotiations. Business Process Management Journal, 25(3), 391–413. doi:10.1108/BPMJ-11-2017-0334

Chertow, M. R. (2007). ''Uncovering'' industrial symbiosis. Journal of Industrial Ecology, 11(1), 11–30.

Della Peruta, M. R., Del Giudice, M., Lombardi, R., et al. (2018). Open innovation, product development, and inter-company relationships within regional knowledge clusters. Journal of the Knowledge Economy, 9, 680–693.

Dorn, S., Schweiger, B., & Albers, S. (2016). Levels, phases and themes of coopetition: A systematic literature review and research agenda. European Management Journal, 34 (5), 484–500. https://doi.org/10.1016/j.emj.2016.02.009

European Commission (2019) Communication from the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and the Committee of the Regions. The European Green Deal. Brussels, 11.12.2019. COM (2019) 640 final

European Commission (2020a) Communication from the Commission to the European Parliament, The European Council, The Council, The European Economic and Social Committee and the Committee of the Regions. Europe's moment: Repair and Prepare for the Next Generation. Brussels, 27.5.2020. COM (2020) 456 final

European Commission (2020b) Communication from the Commission to the European Parliament, the European Council, The European Economic and Social Committee of the Regions. A New Industrial Strategy for Europe. Brussels, 10.3.2020. COM (2020) 102 final

Everaert, P., Sarens, G. & Rommel, J. Using Transaction Cost Economics to explain outsourcing of accounting. Small Bus Econ 35, 93–112 (2010). https://doi.org/10.1007/s11187-008-9149-3

Franco, M., Haase, H. (2015) Interfirm alliances: A taxonomy for SMEs. Long range planning 48, 168-181.

Huggins, R., Thompson, P. (2017) Entrepreneurial networks and open innovation: the role of strategic and embedded ties, Industry and Innovation, 24:4, 403-435, DOI:

10.1080/13662716.2016.1255598

IIE Institute of Industrial Engineers (2006) Industrial Engineering Roles. Downloaded the 2021/02/20 from https://www.iise.org/uploadedFiles/IIE/About_IIE/What IEs Do IIE-IAB v2.pdf

Martinez-Noya, A., & Narula, R. 2018. What more can we learn from R&D alliances? A review and research agenda. BRQ Business Research Quarterly, 21(3): 195–212.

Mitrega, M., Forkmann, S., Zaefarian, G. and Henneberg, C.S. (2017), "Networking capability in supplier relationships and its impact on product innovation and firm performance", International Journal of Operations & Production Management, Vol. 37No. 5, pp. 577-606.

Montoro-Sanchez, A., Diez-Vial, I., & Belso-Martinez, J. A. (2018). The evolution of the domestic network configuration as a driver of international relationships in SMEs. International Business Review, 27(4), 727–736.

Nassimbeni, G. 1998. Network structures and co-ordination mechanisms. International Journal of Operations and Production Management 18(6): 538-554.

Retegi, J., Igartua, J.I. Trends and Proposals for European Industrial Engineering, Proceedings of the 14th EPIEM Conference 2021. DOI 10.3217/978-3-85125-827-1,

Saha, R.L., Seidmann, A., Tilson, V. (2011) Unexpected Motivations behind Joining Group Purchasing Organization (GPO). Proceedings of the 44th Hawaii International Conference on System Sciences.

Wulf, A., & Butel, L. (2017). Knowledge sharing and collaborative relationships in business ecosystems and networks. Industrial Management & Data Systems, 117(3), 1407–1425. https://doi.org/10.1108/IMDS-09-2016-0408

ERP and Digital Planning in Learning Factories for Increasing Digital Resilience

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Abstract

Enterprise Resource Planning (ERP) software systems have a crucial role in planning and management of manufacturing plants. The level of efficiency in ERP usage is strongly related with the architecture and hierarchy designed in its implementation. Additionally, manufacturing long term values as digital resilience should be taken as precondition in the designing process. Therefore, in this paper digital resilience supported ERP architecture design is proposed through a use case of an ERP implementation. Results present the digital resilience supported architecture of tangible machining and assembling resources, hierarchy of warehouse locations in an environment of limited resources and routing for sample product. Furthermore, the research covers preparation for further digital twin integration to the worker assistant systems as well as a didactic purpose.

Keywords: ERP, digital resilience, Learning factory, Manufacturing system, Business processes, Digitalization

Introduction

Enterprise resource planning (ERP) has become the core of manufacturing company software systems. Due to wide implementation of ERP systems, the standardization of management of manufacturing processes has reached a high level. However, each company needs to make multiple selections how to implicitly approach the processes that are covered by ERP. For instance, make-to-order and make-to-stock producers have different functionality requirements based on different decision-making processes (Aslan et al. 2015). In most modules and submodules of an ERP, there are different complexity levels provided. Additionally, the design of the architecture for resources, capacities, material movements, warehousing, reporting, etc. must be followed by company specific long-term values as digital resilience to decrease the influence of disturbances. Thus, ERP provides standardization of processes through large scale of modularization.

The paper is structured as follows: theoretical background consists of literature overview on advances of ERP focusing on advantages regarding to resilience. The method section explains the underlying ERP implementation use case for digital planning. Under results, the proposed resilient architecture and hierarchy together with sample product routings are presented and explained. Finally, the discussion section argues about redundancy cost and ERP impact for resilience overall. The research covers design of architecture and hierarchy of (1) physical manufacturing resources and (2) warehouse locations in implementation of ERP considering the preventive quality of resilience only, namely absorption.

Theoretical Background

ERP is an industrial information and decision support system (Bayar et al., 2016) that covers planning and management of several business processes in a company. While ERP stands for planning of resources in the level of a company, predecessors for ERP in manufacturing companies were Manufacturing Resource Planning and later Manufacturing Resource Planning II.

Implementation of ERP is an important task as it influences multiple qualities of manufacturing including productivity, resilience, and sustainability. According to the report (Panorama Consulting Group, 2021), the average ERP implementation time is 15 months. Restructuring of an already implemented architecture and logic of ERP management influences also other departments and integrated software systems. Despite that majority of ERP providers have added a Software as a Service (SaaS) solution in addition to on-premises solution (Ongowarsito et al., 2021) they still need support from manufacturing side for company specific implementation. Hankin et al. (2021) identified that one critical success factor for ERP implementation is top management support. Many challenges and impediments in implementing ERP have led to relatively high failure rates of ERP implementation projects (Mahendrawathi et al., 2017), whereas risk is especially implied to small companies without specific knowledge and experience in ERP implementation (Svensson et al., 2021). To decrease the risk, Alaskari et al. (2021) have developed a 9-phase implementation framework for small and medium enterprises.

Researchers have given different definitions to the term “resilience” (Gasser et al., 2021). In general, a common definition is that resilience includes three focal components: (1) an ability to absorb impact of disruptions (absorption), (2) adaptation to disruptions (adaptation), and (3) recovery to its normal regime (restoration). Traditional methods to manage disruptions are inclusion of redundancy in component level and preventive maintenance in system level (Uday and Marais, 2013). In manufacturing, redundancy basically means having backup machineries, tools, or workforce to absorb disturbances.

Method

The ERP system Microsoft Business Central was implemented in the Smart Mini Factory (SMF) laboratory of Free University of Bozen-Bolzano. This is base for the development of further digital twin integrated worker assistance and additionally it supports students in practical manufacturing related exercises. The work with the ERP allows students to understand the responsibility and further consequences when designing an architecture and hierarchy of ERP related processes and resources. Furthermore, ERP helps to simulate and play different situations that can come up in manufacturing.

The SMF laboratory is endowed with different type of assembly stations that are equipped with touch screens to get access to the ERP system on every workplace. SMF is in a close cooperation with another laboratory – Bitz Fablab (BITZ), that is equipped with machining equipment as milling machines, laser machine, polishing machine, cutoff saw, vacuum forming and 3D printers. This leads us to define two plants in our low variety make-to-stock production network - SMF and BITZ. Additionally, subcontractors are used for certain operations on the product components.

Our objectives in ERP implementation were: (I) increasing resilience in manufacturing, (II) while holding overall upkeep cost; (III) covering wide variety of possible manufacturing related scenarios; (IV) enable seamless manufacturing. Constraint in design of the architecture was the limited number of manufacturing resources as available space, machinery, and inventory. In this use case, ERP implementation covers hierarchy and architecture of production units, warehouse locations, number series planning and design of main/alternative routing for a sample mechanical engineering product – in our example a simple pneumatic cylinder. Each forenamed step additionally covers number series planning. Decision in ERP architecture planning were analyzed according to the resilience quality of absorption.

Results

Main production units as machinery and assembly stations are managed hierarchically in three horizontal levels (Figure 1).

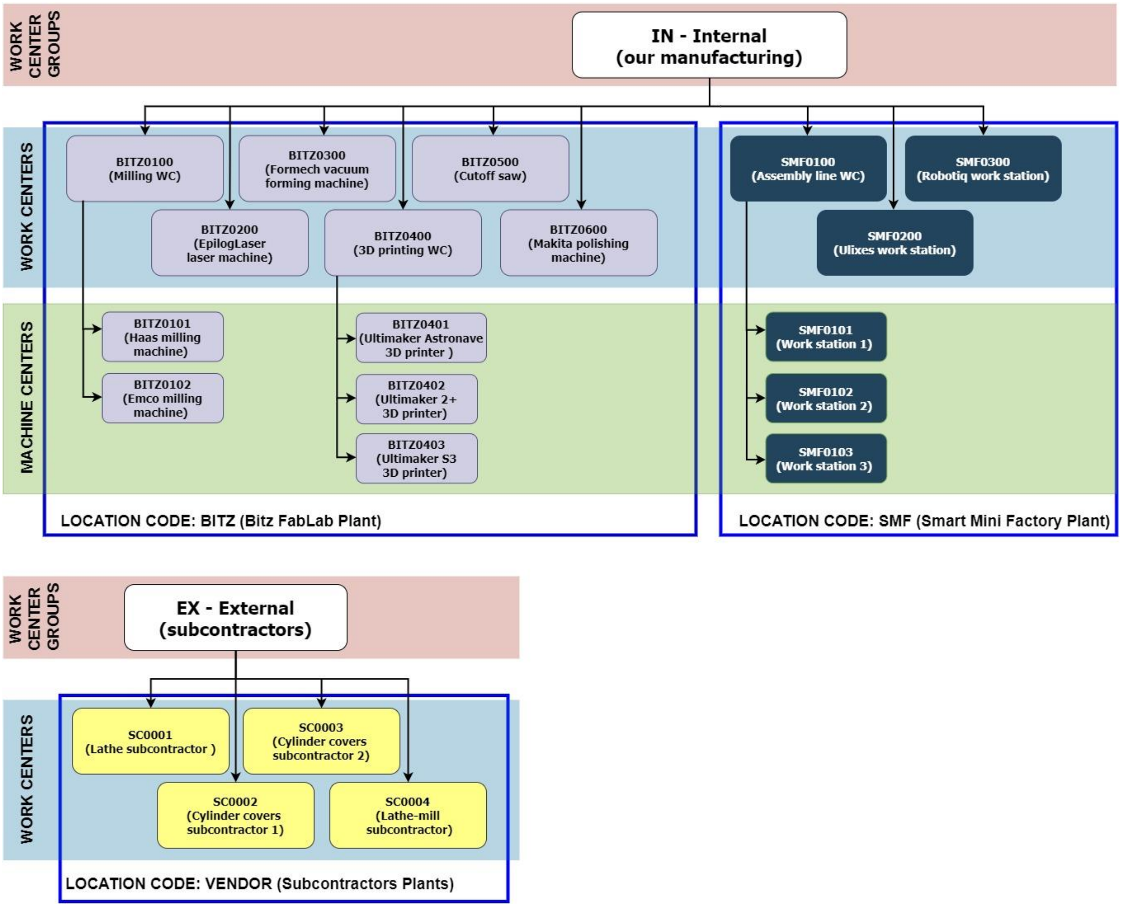

Figure 1: Architecture of WCG-s (divided into internal and external)

The highest level is work center group (WCG) that divides the management of them into internal and external. External WCG covers subcontractors that can be viewed and planned similarly with internal production. This gives a uniform approach for all manufacturing related planning. Internal production units are divided into work centers (WC-s) and machine centers (MC-s) based on their homogeneity in capabilities. If some units are equal in their capabilities, they are viewed as MC-s and work can be planned on WC level. Still, we allow slight differences in capabilities of MC-s that belong into one WC. The reason of differences can be machinery from different manufacturers or just natural wearing caused by rate of exploitation intensity. In this case, planning for certain items can be made in MC level.

Vertically, WC-s and MC-s are divided based on their location. Highest level location (location code) is given based on belonging to certain plant. In Figure 2, locations with their labelling structure in SMF are presented.

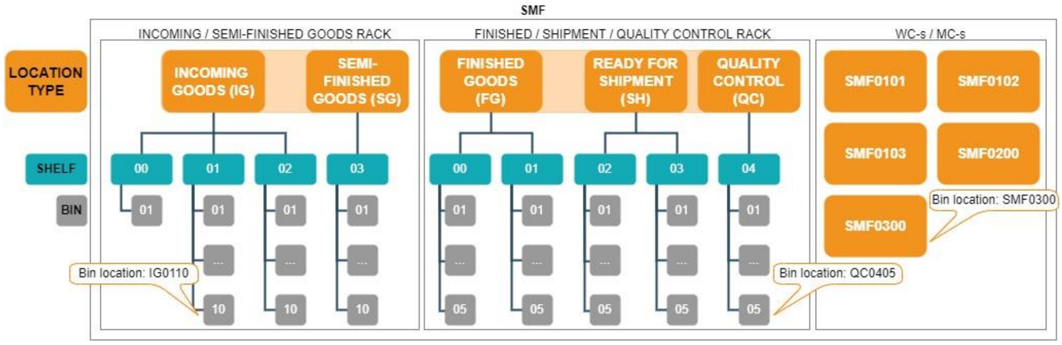

Figure 2: Labelling of bin locations in SMF plant

WC-s and MC-s remain the same code for location (type) as is their WC/MC code to avoid calling the same substance with different names in different departments. Despite of having multiple shelves in some production units, these are not divided into multiple locations as every movement of goods between locations requires to enable tracking of goods. In internal plants, locations architecture (except machining units) has three parameters, namely location type, shelf, and bin. Location type defines the type of goods that are stocked. Considering limited resources and sustainability, many type of items can be stocked in the same rack, but in different shelves. The smallest location unit location numbering consists of 6 digits (2 digits for location type, 2 digits for shelf and 2 digits for bin).

For pneumatic cylinders, main manufacturing routing follows an optimized manufacturing plan (Figure 3).

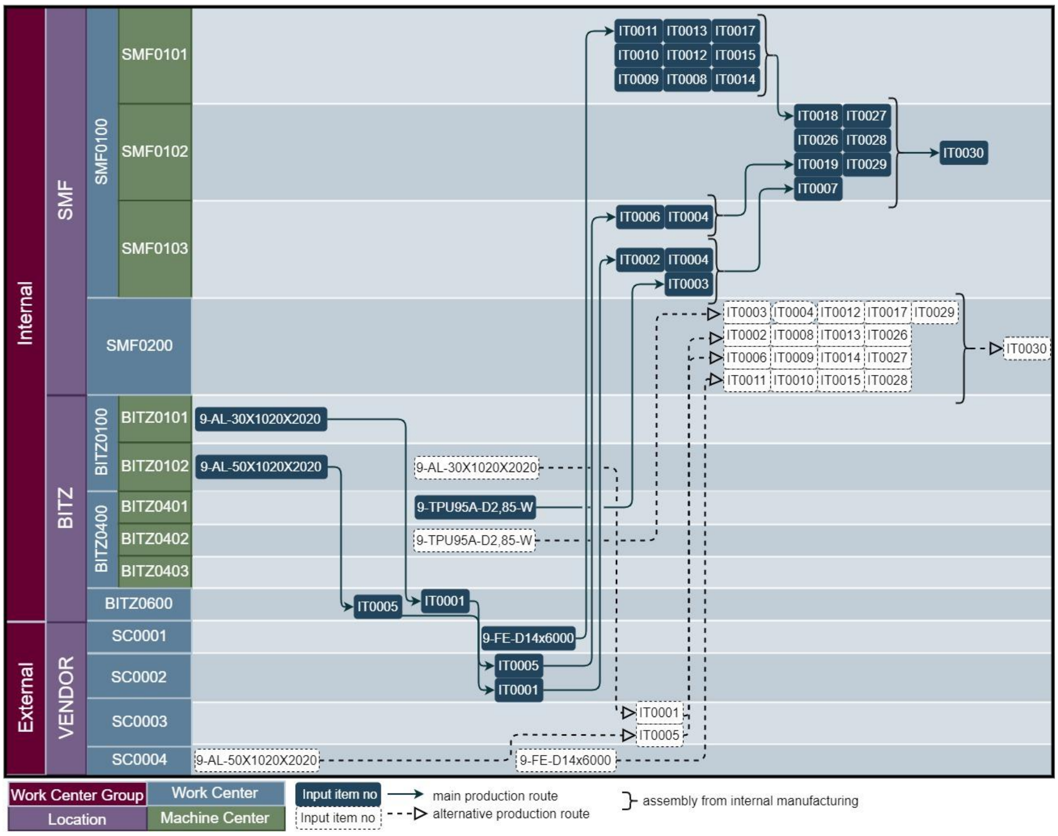

Figure 3: Pneumatic cylinder - main and alternative routings

Alternative routing is based on default available redundancy. For instance, based on optimized scenarios, assembling is planned in SMF0100 that includes assembly line (three assembly stations) to decrease work in progress time and to increase ergonomics. Alternatively, all these parts could be mounted in SMF0200 in single digitally assisted assembly station. Item numbers as inputs for every operation in specific WC/MC are presented. Therefore, input for first operations is raw material that can be easily distinguished from other items based on its labelling structure. Whereas raw material 9-FE-D14X6000 is sent directly from material provider stock to subcontractor as length of iron bars is 6 meters.

Discussion and Conclusion

ERP provides several complexity levels for different modules and architecture options based on manufacturing logic and objectives. In ERP implementation phase among other critical decisions, planning of number sequences, warehouse locations architecture and manufacturing resources hierarchy have crucial role in latter seamless usage of ERP. Resilient approach in implementation emphasizes redundancy. Although, additional redundancy increases the cost of a system (Youn et al., 2011) and decreases sustainability, usage of default available redundancy retains the cost level and even increases sustainability through more efficient usage of resources. ERP enables to increase resilience through more detailed and flexible planning. However, availability issues of the ERP system as crucial enabler for smooth manufacturing workflow becomes a threat. Therefore, reestablishment of main manufacturing structure in relation to planning must be ensured also without ERP. In this case, digital twin integration can provide additional resilience by backing up most important ERP information that is constantly used in relation with real time monitoring data to improve planning even further.

The bases for future digital twin realisation for worker assistance was realised through the implementation of an ERP architecture and hierarchy of resources, processes, and logic between them. The implemented solution supports a resilient approach through increasing of redundancy without additional system cost. Additionally, the designed solution also covers didactic purposes in SMF laboratory for teaching students how to design and to use ERP in manufacturing companies. The proposed solution contributes to increase resilience of manufacturing through increased absorption of impacts. Nevertheless, ERP integration with manufacturing execution system, data visualisation software and a central database is needed as well as deployment of real time monitoring, data analytics and bidirectional data exchange to realise a digital twin for resilient workstations (Rauch and Aruväli, 2021).

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References

Alaskari O., Pinedo-Cuenca R., Ahmad M.M., 2021. Framework for implementation of Enterprise Resource Planning (ERP) systems in Small and Medium Enterprises (SMEs): a case study. Proc Manuf. 55, 424-430.

Aslan B., Stevenson M., Hendry L.C., 2015, The applicability and impact of Enterprise Resource Planning (ERP) systems: Results from a mixed method study on Make-To-Order (MTO) companies. Comp. in Ind. 70, 127-143.

Bayar N., Darmoul S., Hajiri-Gabouj S., Pierreval H., 2016. Using immune designed ontologies to monitor disruptions in manufacturing systems. Comp. in Ind. 81, 67-81.

Gasser P., Lustenberger P., Cinelli M., Kim W., Spada M., 2021. A review on resilience assessment of energy systems. Sust. and Resil. Infrast. 6 (5), 273–299.

Hankin P., Almanei M., Salonitis K., 2021. An ISM analysis of the critical success factors in ERP implementation. Advances in Transdisciplinary Eng., 10 September 2021, Derby.

Mahendrawathi E.R., Zayin S.O., Pamungkas F.J., 2017. ERP post implementation review with process mining: a case of procurement process. Proc. Comp. Sci., 6-8 November 2017, Bali.

Ongowarsito H., Prabowo H., Meyliana, Gaol F.L., 2021. Priority factors for the adoption of cloud ERP based on the perspective of consultants and SMEs. Int. J. of Emerging Tech. and Advanced Eng. 11 (12), 126-133.

Panorama Consulting Group, 2021. The 2021 ERP report.

Rauch, E., Aruväli T., 2021. Resilience in manufacturing during COVID-19 through digital worker assistance systems. Proc. of the 14th EPIEM Conf. 2021, 28 May 2021, Graz.

Svensson A., Thoss A., 2021. Risk factors when implementing ERP systems in small companies. Information 12. (478).

Uday P., Marais K., 2013. Exploiting stand-in redundancy to improve resilience in a System-of-Systems (SoS). Proc Comp Sci 16, 532–541.

Youn, B.D., Chao, H., Pingfeng, W., 2011. Resilience-Driven System Design of Complex Engineered Systems. J of Mech. Des. 133 (10), 101011-1 – 101011-15.

Austrian Association of Industrial Engineering and Management (WING)

*„**Industrial engineers** are **engineers educated and trained in economic sciences** with an **academic degree** who **integrate their technical and economic expertise** in their professional activities.“*

► WING Facts

1964 Establishment of the **WING**

1984 WINGnet - the WING student group was founded

2022 WING has approx. 1.400 members

► WING Purpose

WING is a **non-political** association with the purpose of **perceiving** and **promoting** the **scientific**, **social** and **cultural** interests of its members.

► Implementation of WING Purpose and Activities

WING actively supports its members in **scientific** and **professional** matters e. g. by providing insights on **professional issues** as well as on **questions** about **educational matters**. **WING** promotes the **exchange of ideas** and the **social integration** of the members through **various activities**. There are **many activities** including, but not limited to

- maintaining network and/or contact among the members in e.g. **WING** regional districts,
- transfer of knowledge,
- supporting universities in design of the **WING** curriculum,
- targeted career development measures,
- representation of interests of the members and nourishing association´s image
- strengthening the link between economy and science.

► WING Cooperations

In 2010, the **Austrian Association of Industrial Engineering and Management**, the **German Association of Industrial Engineers** and the **Swiss Association of Business and Industrial Engineers** signed the following **“three-country declaration”**:

"We want to ensure high quality and the distinctive profile of the industrial engineers and managers in order to promote their high labor market value by creating a common and unique educational and training brand."

► WING International

WING and **WINGnet** are active members of the **international community** of European Professors of Industrial Engineering and Management (**EPIEM**) and European Students of Industrial Engineering and Management (**ESTIEM**).

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