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A holistic approach for achieving Sustainable manufacturing using Zero Defect Manufacturing: a conceptual Framework

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Abstract

Over the years, the manufacturing industry has seen constant growth and change. On one level, it has been affected by the fourth industrial revolution (Industry 4.0). On another, it has had to enhance its ability to meet higher customer expectations, such as more customized products at a faster rate. These factors have led many manufacturing companies to produce new products quicker than ever for two main reasons: to achieve higher profits and to meet the increasing demand from their customers. This phenomenon has imposed new rules on product manufacture, such as shorter production time and smaller batch output, making strategies, which had been successfully used in the past, obsolete or less efficient. Furthermore, to embrace agility and deliver a rich portfolio of services to the industrial sector, industrial automation based on digital connectedness will challenge the traditional digital boundaries among industrial systems. The flow of data created and collected by various actors in the manufacturing value chain will have to break these barriers in order to allow for the full-scale digital collaboration among production entities, ensuring at the same time multi-layer optimization. Additionally, sustainable manufacturing with zero defects and zero waste is one of the top priorities of manufacturers these days. A key approach for achieving sustainable manufacturing is called Zero Defect manufacturing (ZDM), therefore the current article proposes a holistic framework which is identifying all the critical components of a manufacturing company that needs to be integrated together in order to achieve sustainable manufacturing utilizing ZDM. The core of the proposed framework are data and data driven technologies that can increase the sustainability of a manufacturing system. The proposed framework would represent exactly what Industry 4.0 paradigm imposes.

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Keywords: Zero Defect Manufacturing; ZDM; holistic approach; data driven; Industry 4.0

1. Introduction

Over the years, the manufacturing industry has seen constant growth and change. On one level, it has been affected by the fourth industrial revolution Industry 4.0 and the newly imposed Industry 5.0 [1]. On another, it has had to enhance its ability to meet higher customer expectations, such as more customized products at a faster rate [2]. These factors have led many manufacturing companies to produce new products quicker than ever for two main reasons: to achieve higher profits and to meet the increasing demand from their customers [3]–[5]. On top of that, sustainability of manufacturing systems and processes is vital aspect of modern manufacturing industry. Sustainability is not only about the environment, it concerns also economic and social criteria [6] that manufacturers must balance to achieve true sustainability. Currently, manufacturing systems operate with high volume of wastes of any type, such as materials, manufacturing time, energy, and other natural resources, which is against the sustainability goals [7]. According to Deloite there are 7 types of wastes product defects, transportation time, waiting time, unnecessary movement of personnel or machinery, over processing, overproduction, and inventory [8]. European Environment Agency report revealed that 21% of total material waste is from

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manufacturing domain and immediate actions must be taken to reduce the wastes [9], [10].

Those phenomena have imposed new rules on product design and manufacturing process, such as more complex manufacturing strategies, shorter production time, smaller batch output and higher manufacturing sustainability. A concept that is highly related with sustainability is Quality, but not only product quality, but also process or service quality, in other words the quality of any aspect of a manufacturing system, something that traditional quality improvement methods do not consider. Such need of high manufacturing quality made traditional strategies, which had been successfully used in the past, obsolete, or less efficient. With these factors taken into consideration, newer and more sophisticated strategies and tools are needed. More specifically, better techniques of quality management are required to cope with the current needs [11].

Zero Defect Manufacturing is an emerging approach that constitutes a viable solution for achieving sustainable manufacturing [12], [13]. It aims to improve the quality of all manufacturing aspects (product, process, service etc.) by reducing any form of waste using data driven technologies. The core concept of ZDM is “Make it right at first attempt”. Doing so quality is improved and the sustainability increased leading in the end to higher customer satisfaction, which is a key factor for the success of a manufacturing company [14]. In contrast with contemporary optimization methods ZDM is an holistic approach dealing with all the manufacturing aspects at the same time considering the effects between each other rather that focusing on isolated process optimization [14]. ZDM is comprised by four strategies, detect, predict which are the triggering factors and the repair and prevent which are the action strategies [13]. Those strategies are implemented in pairs one strategy from the triggering and one from the action strategies. Below is the definition of ZDM as an outcome of standardization process from CEN/ CENELEC.

“*ZDM is a holistic approach for ensuring both process and product quality by reducing defects through corrective, preventive, and predictive techniques, using mainly data-driven technologies and guaranteeing that no defective products leave the production site and reach the customer, aiming at higher manufacturing sustainability*” [12]

The goal of the current research paper is to develop an holistic framework for achieving sustainable manufacturing utilizing the ZDM concept. The proposed framework will identify the key elements and functionalities that are required to be studied together for achieving for achieving true sustainable manufacturing.

2. State of the art

Studies have shown that companies are aware of the topic industry 4.0 and the benefits coming with its implementation, such as more flexible, resilient, and productive manufacturing sites [15]–[17]. While the outlook seems positive, the findings of several studies have also documented that most of the companies that are aware of industry 4.0 technologies and concepts still have not started to implement them [18], [19]. On the other hand, companies that have started implementing Industry 4.0 concept are facing numerous of challenges including scientific challenges, technological challenges, economic challenges, social problems, and political issues [20]. All these challenges make companies hesitate implementing Industry 4.0 concept. Although the vast amount of research in the era of Industry 4.0, the implementation of Industry 4.0 resembles a puzzle that has not been put together yet. As a result, the status of the implementation of Industry 4.0 is difficult to comprehend at best as the referring knowledge and expertise are widely dispersed throughout a number of different publications. Furthermore, the potential dynamic between implementation factors cannot be examined if elements are treated as isolated and individual phenomena [21].

In the context of this globalized ultra-connected world, benchmarking leads to a large number of competitive solutions to address a need. For a company, increasing and even keeping its market share is tougher than ever. One of the main factors that drives a product’s commercial success is its quality. The companies are paying particular attention to the product quality to assure that all of their customers are satisfied. Nevertheless, a need is not defined in a fixed manner. It evolves and so does the manufacturing to produce the items. This evolution places the organizations in a permanent state of questioning the quality of their products and processes, and binds them into a continuous improvement (CI) initiative to stay competitive and avoid direct and indirect losses [22][23], [24].

CI is done using Quality Management Systems (QMS) which traditionally rely on methodologies such as Lean Manufacturing (LM), Six Sigma (SS), Theory of Constraints (TOC), Total Quality Management (TQM), and Lean Six Sigma (L6S) (Hutchins, 2016), which are well established in the production systems with the goal to improve product quality [25]. These methods can be characterized as “corrective”, which means that they act after the creation of a problem and they do not take advantage of modern data-driven technologies that offers predictive capabilities [12], [26]. Furthermore, the traditional QMS methods do not learn from defects, they just remove them. These methodologies analyze the past to improve in the future. Therefore, there is a loss of potentially important information from the present. Not analyzing the present creates an inertia between the occurrence of an event and the identification of an improvement linked to this event [26]. Modern technological advancements provided capabilities that were not possible at the past. These technological advancements initiated the emergence of ZDM which constitutes a viable alternative solution for QMS [27][13]. One major change in ZDM is about the flow of information. Indeed, ZDM uses both historical and real-time data to prevent product from defect [12], [13], [28]. Doing this, ZDM combines several quality control applications concerning production lines, machinery, automation applications, and supply chain processes1. This is possible thanks to the development of IT systems and Industry 4.0.

Many research works have shown that single isolated solutions cannot perform as well as holistic approaches [29]. This is because all components of a manufacturing need to exchange information for taking the full potential of data driven approaches, as imposed by Industry 4.0 concept. In other words, data are the backbone of all the applications in a manufacturing system and therefore, careful attention should be given on the data gathering and exploitation [30]. Kozjek et al. developed a data driven holistic approach for fault prognostics in cyclic manufacturing [31]. In more details they developed a system for predicting unplanned machine stops in plastic injection molding. The case indicates an indispensability of high level of multidisciplinary that is required for the development of intelligent data-analytic systems. The use of typical concepts, techniques, and tools of the Big Data approach enables them to efficiently perform the analysis on real industrial data that is large in size and complex in nature. They stressed in their research that for successful prediction of events is critical the use of an holistic approach. Another study verified the abovementioned statement stating that the development of an isolated solution is not sufficient and there is the need for an holistic approach because there can be considerable amount of interactions between individual systems which is not treated as one there will be loss of information critical for the success of the system [32]. Furthermore, an holistic approach is critical also for the measurement of global KPIs of a system and not individual KPIs from isolated systems. If an holistic approach is used then the true KPIs of a system will be possible to be calculated and therefore manufacturers will be in a place that will be able to estimate the true performance of their system [33].

3. Proposed holistic ZDM Framework

The purpose of the proposed framework is to identify all the critical manufacturing aspect for proper, efficient, and successful implementation of ZDM and make sustainable manufacturing and achievable goal. To achieve this 8 layers were identified (Fig. 1), and it is imperative that no layer is skipped. The 7 out of 8 layers are collaborating at least 2 or 3 other layers to operate and produce the desired result, which is to improve manufacturing quality, by reducing defects, wastes and satisfying the three pillars of sustainability (economy, environment and social). The eighth layer is the data layer which is crossing all the other layers because all tools and applications in the different layers are consuming data to provide a result.

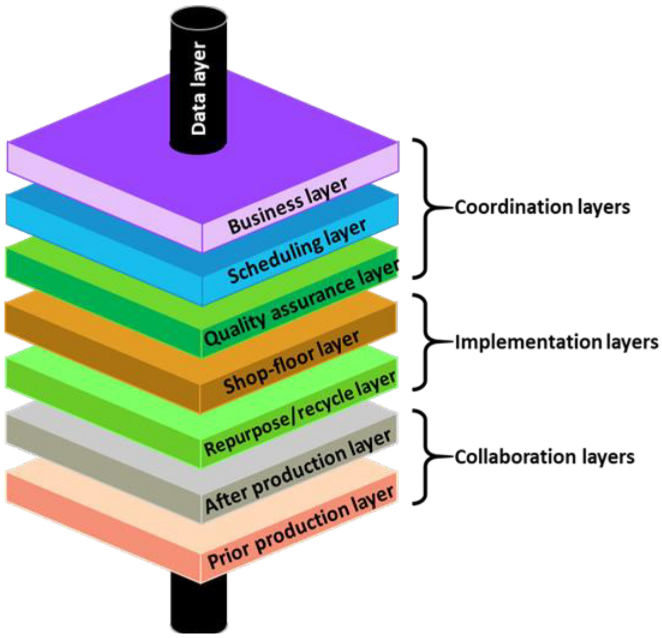

Fig. 1: ZDM holistic framework identified layers and groups

The defined layers can be classified into three categories the coordination, the implementation, and the collaboration layers. The coordination layers are composed out of the business, scheduling and quality assurance layers and they are responsible to perform all the design, organizational and decision-making tasks that are required for the other layers to operate. All these outcomes from the coordination layers are implemented to the implementation layers which includes the shop-floor and the repurpose/recycle layers. For achieving sustainable manufacturing, it is imperative that a distinct layer for creating and implementing protocols and procedures for repurposing of products and other resources exists to moderate these important tasks. The third class is the collaboration layer which includes the supply and distribution network and the customers.

From the defined layers (Fig. 1), the coordination layers are those that controls the sustainability levels, because they are those that coordinate and take all the key decision. The scheduling often is not given the attention that needs, which leads to poor solutions. Scheduling is critical because to achieve ZDM high flexibility and adaptability is required to compensate the different abnormalities of the production. Therefore, new scheduling tools are required for achieving ZDM and by extent zero waste and sustainable manufacturing [34] [35][36]. The new concepts that are introduced by Industry 4.0 concept such as defect prediction are not included in traditional scheduling tool and thus making them impossible to cope with the new challenges imposed by Industry 4.0 concept [35]. Furthermore, there is the need for a global scheduling tool that can coordinate the shop-floor alongside with the supply and distribution network. In that way better schedules will be created making possible the achievement of sustainable manufacturing.

The foundation of ZDM is quality inspection, because the data from the quality inspection are needed for both corrective actions and also for training predictive models. Traditionally, is performed by taking a statistical sample in certain time intervals. To achieve true sustainability and ZDM there is the need for inspecting all the parts being produced [37]. This can be very costly and time-consuming process, but Industry 4.0 technologies offers numerus of possibilities, such as quality estimation without the physical examination of the part, in other words the virtual inspection which is part of virtual metrology [28]. But it is not always possible to implement virtual metrology to all the cases and therefore physical inspection is required as well but utilizing the advance technologies offered by Industry 4.0.

As mentioned to section 2 the notion of prediction offers numerous of new capabilities for manufacturers if it is used properly. Manufacturers can utilize technologies such as artificial intelligence, machine learning, digital twins, knowledge-based tools etc. for predicting events not only at the production level such as product defects or process or machine failure, but also events at the management level. Having accurate events prediction can lead to high quality decision at the right time leading to high efficiency and sustainability.

Fig. 2 presents the proposed holistic framework for achieving sustainable manufacturing with zero defects and zero wastes based on the identified layers of Fig. 1. Quality assurance layer, where Zero Defect Manufacturing approach is implemented constitutes the core of the proposed holistic framework. It is impossible for a single methodology to achieve sustainable manufacturing and therefore a set of methodologies are embraced such as corrective, preventive, and predictive tools to minimize defects and wastes, which are coming from the ZDM approach [12]. An important note at this point is the fact that the ZDM approach can be implemented to both the product and process level according to Psarommatis et al. [12], [13]. Therefore, the proposed framework includes tools that are addressing both product and process level to eliminate all possibilities for defects, failures, or wastes. Once there is a quality issue either on the product or the process level a decision should be taken to mitigate the issue and avoid a potential defect or a failure. This decision is critical for achieving sustainable manufacturing and to be efficient it requires data from multiple levels. More specifically, it requires data from the scheduling and the business layers [35]. In that way the decision will be tailored to the exact characteristics required at the current moment from the production achieving sustainable manufacturing [38].

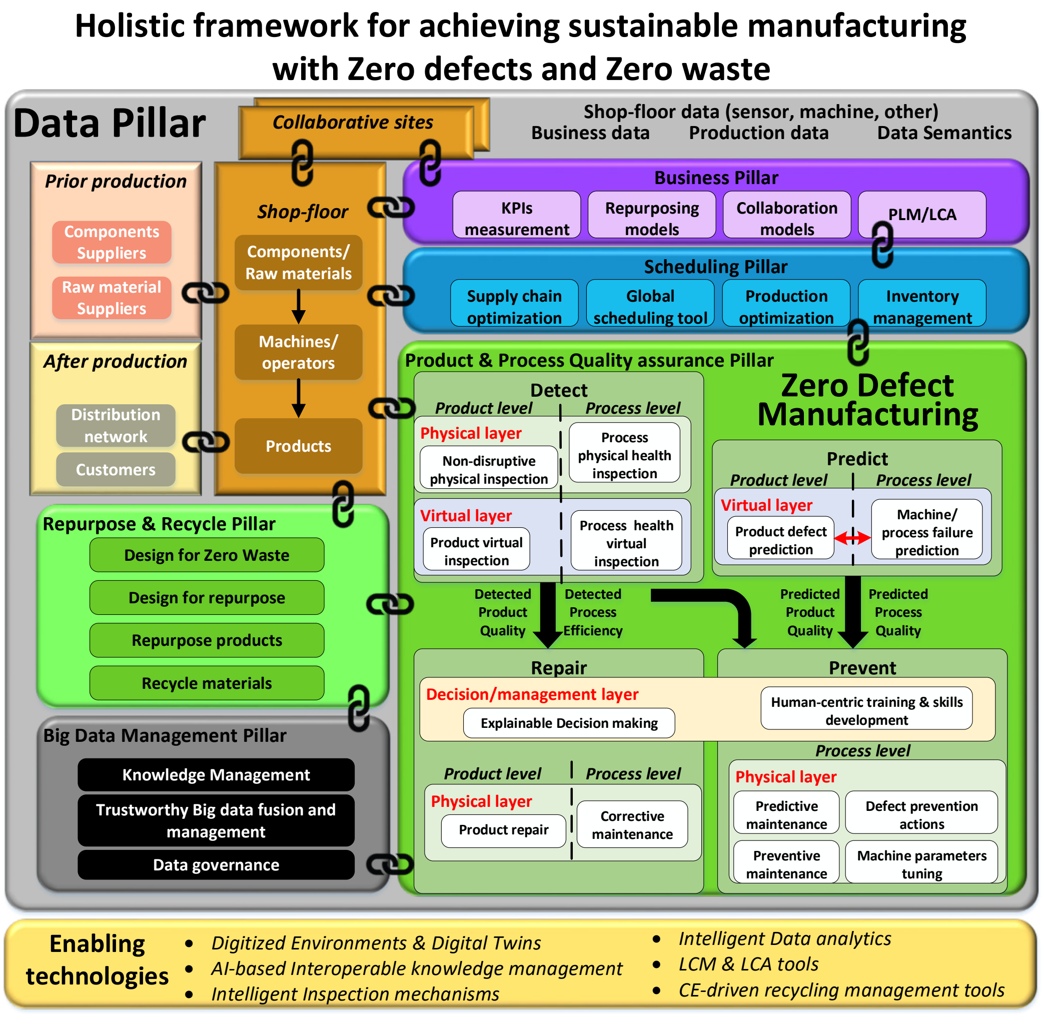

Fig. 2: Proposed holistic framework for sustainable manufacturing

Triggering ZDM strategies, detect or predict, are mostly consuming real time data coming from the shop-floor such as data from sensors, machines controllers, PLCs etc. in order to be able to detect or predict a defect. Virtual detection or prediction of defects constitutes a critical role in the proposed framework. On the other hand, the action strategies (prevent or repair) are consuming higher level data such as business, scheduling and past knowledge to make a correct decision on the future of the quality issue. Another important factor is the time that decisions are implemented to the actual production. That is the reason for the importance of advanced scheduling tools that can handle the high number of events to consider and be able to re-schedule the production, creating high quality schedules. The mitigation actions can be classified also into product and process levels. More specifically, for the repair strategy if there is a defect detected on a product then this product must be repaired, if possible, if the defect is for the process, then corrective maintenance is required. Furthermore, if there is a defect detected then some preventive actions can be also taken, such as preventive maintenance or machine tuning to avoid future defects. Moving forward, if a defect is predicted then the required actions are either predictive maintenance, machine parameters tuning and must be implemented to the schedule before the defect predicted time. It is important to note that all the preventive actions are referring to the process level, because it is the level that affects the product quality. Knowledge based or Artificial intelligence technologies will be primarily used for the decision-making process during a quality issue.

To achieve true sustainable manufacturing there is the need for tools and procedures for handling the product re-purposing, re-using and efficient recycling of natural resources and minimizing wastes. Wastes are inevitable, but products can be designed in a way that wastes are minimized and therefore such component is crucial for a manufacturing system. New product designing methods should be developed to take into consideration the re-using and re-purposing concepts.

The most important layer of the proposed framework is the data layer. Most, not all the Industry 4.0 technologies are data driven and therefore, data and their proper exploitation is a key for achieving sustainable manufacturing and at the same time a big challenge. Data are coming from a high variety of different sources, such as sensors, machines controllers, PLCs, business data etc. All those data must be exchanged in a secure, structured, and efficient way to be able for applications to consume them when it is required. More specifically knowledge management systems are required to extract and capture the knowledge from past decisions, further to that data will be structured using ontologies which is a key technology for knowledge capturing and systems interoperability [39]. Re-using of existing mid-level, domain specific and upper level ontologies, such as Basic Formal Ontology (BFO) and Industrial Ontology Foundry (IoF) core ontology are critical aspects as well.

4. Concluding remarks

Realizing Sustainable manufacturing requires specific mechanisms and addressing complementary challenges that urge for holistic approaches. The current paper proposes a structured realistic holistic approach for achieving sustainable manufacturing using ZDM as the core of this framework. This is due to the fact that assuring product and process quality will increase the sustainability of a manufacturing system. The proposed holistic approach suggests many individual components that need to work all together and exchange data between each other to achieve the desired outcome. Single components cannot at any circumstances outperform the holist approach. All components are linked together and each one is depending on the others. The main idea behind the proposed framework is that there is a backbone layer which is the data layer which stores, manages, retrieves, and distributes data from all the available tools that are within an industrial company. It is crucial that each tool have access to all the data, to perform as efficiently as possible for achieving sustainable manufacturing. Finally, companies for achieving sustainable manufacturing must rethink their business models and relationships along the value chain, with more collaboration with suppliers and providers.

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References

[1] "Industry 5.0 | European Commission," 2021. https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (accessed Nov. 16, 2021).

[2] R. Goel and P. Gupta, "Robotics and Industry 4.0," *Advances in Science, Technology and Innovation*, pp. 157–169, 2020, doi: 10.1007/978-3-030-14544-6_9.

[3] D. Mourtzis, M. Doukas, G. Michalos, and F. Psarommatis, "A WEB-BASED PLATFORM FOR DISTRIBUTED MASS PRODUCT CUSTOMIZATION: CONCEPTUAL DESIGN," 2012, pp. 1–611.

[4] D. Mourtzis, M. Doukas, and F. Psarommatis, "A multi-criteria evaluation of centralized and decentralized production networks in a highly customer-driven environment," *CIRP Annals - Manufacturing Technology*, vol. 61, no. 1, pp. 427–430, 2012, doi: 10.1016/j.cirp.2012.03.035.

[5] D. Mourtzis, M. Doukas, and F. Psarommatis, "Design and operation of manufacturing networks for mass customisation," *CIRP Annals - Manufacturing Technology*, vol. 62, pp. 467–470, 2013, doi: 10.1016/j.jmsy.2014.06.004.

[6] M. Chand, "Strategic assessment and mitigation of risks in sustainable manufacturing systems," *Sustainable Operations and Computers*, vol. 2, pp. 206–213, Jan. 2021, doi: 10.1016/J.SUSOC.2021.07.004.

[7] J. Malek and T. N. Desai, "A framework for prioritizing the solutions to overcome sustainable manufacturing barriers," *Cleaner Logistics and Supply Chain*, vol. 1, p. 100004, Oct. 2021, doi: 10.1016/J.CLSCN.2021.100004.

[8] M. Schmidt, H. Spieth, C. Haubach, and C. Kühne, "Lean production and resource efficiency," *100 Pioneers in Efficient Resource Management*, pp. 58–64, 2019, doi: 10.1007/978-3-662-56745-6_5.

[9] European Commission, "Waste generation in Europe — European Environment Agency." https://www.eea.europa.eu/data-and-maps/indicators/waste-generation-4/assessment (accessed Nov. 08, 2021).

[10] "Waste generation and decoupling in Europe — European Environment Agency." https://www.eea.europa.eu/data-and-maps/indicators/waste-generation-5/assessment (accessed Nov. 08, 2021).

[11] M. Colledani, D. Coupek, A. Verl, J. Aichele, and A. Yemane, "Design and evaluation of in-line product repair strategies for defect reduction in the production of electric drives," *Procedia CIRP*, vol. 21, pp. 159–164, 2014, doi: 10.1016/j.procir.2014.03.186.

[12] F. Psarommatis, J. Sousa, P. Mendonça, D. Kiritsis, and J. P. Mendonça, "Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper," *International Journal of Production Research*, 2021, doi: 10.1080/00207543.2021.1987551.

[13] F. Psarommatis, G. May, P.-A. Dreyfus, and D. Kiritsis, "Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research," *International Journal of Production Research*, vol. 7543, pp. 1–17, 2020, doi: 10.1080/00207543.2019.1605228.

[14] F. Eger, C. Reiff, B. Brantl, M. Colledani, and A. Verl, "Correlation analysis methods in multi-stage production systems for reaching zero-defect manufacturing," *Procedia CIRP*, vol. 72, pp. 635–640, 2018, doi: 10.1016/j.procir.2018.03.163.

[15] Z. Rajnai and I. Kocsis, "Assessing industry 4.0 readiness of enterprises," *SAMI 2018 - IEEE 16th World Symposium on Applied Machine Intelligence and Informatics Dedicated to the Memory of Pioneer of Robotics Antal (Tony) K. Bejczy, Proceedings*, vol. 2018-February, pp. 225–230, Mar. 2018, doi: 10.1109/SAMI.2018.8324844.

[16] K. Fettig, T. Gacic, A. Koskal, A. Kuhn, and F. Stuber, "Impact of Industry 4.0 on Organizational Structures," *2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings*, Aug. 2018, doi: 10.1109/ICE.2018.8436284.

[17] R. Brozzi, D. Forti, E. Rauch, and D. T. Matt, "The Advantages of Industry 4.0 Applications for Sustainability: Results from a Sample of Manufacturing Companies," *Sustainability 2020, Vol. 12, Page 3647*, vol. 12, no. 9, p. 3647, May 2020, doi: 10.3390/SU12093647.

[18] H. S. Birkel, J. W. Veile, J. M. Müller, E. Hartmann, and K. I. Voigt, "Development of a Risk Framework for Industry 4.0 in the Context of Sustainability for Established Manufacturers," *Sustainability 2019, Vol. 11, Page 384*, vol. 11, no. 2, p. 384, Jan. 2019, doi: 10.3390/SU11020384.

[19] L. S. Dalenogare, G. B. Benitez, N. F. Ayala, and A. G. Frank, "The expected contribution of Industry 4.0 technologies for industrial performance," *International Journal of Production Economics*, vol. 204, pp. 383–394, Oct. 2018, doi: 10.1016/J.IJPE.2018.08.019.

[20] K. Zhou, T. Liu, and L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges," *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015*, pp. 2147–2152, Jan. 2016, doi: 10.1109/FSKD.2015.7382284.

[21] C. Hoyer, I. Gunawan, and C. H. Reaiche, "Implementing Industry 4.0—The Need for a Holistic Approach," *Studies in Computational Intelligence*, vol. 928, pp. 3–14, 2021, doi: 10.1007/978-3-030-61045-6_1.

[22] J. Jun, T.-W. Chang, and S. Jun, "Quality Prediction and Yield Improvement in Process Manufacturing Based on Data Analytics," *Processes*, vol. 8, no. 9, p. 1068, Sep. 2020, doi: 10.3390/pr8091068.

[23] F. Psarommatis, X. Zheng, and D. Kiritsis, "A two-layer criteria evaluation approach for re-scheduling efficiently semi-automated assembly lines with high number of rush orders," *Procedia CIRP*, vol. 97, pp. 172–177, Jan. 2021, doi: 10.1016/j.procir.2020.05.221.

[24] F. Psarommatis and D. Kiritsis, "Comparison Between Product and Process Oriented Zero-Defect Manufacturing (ZDM) Approaches," in *IFIP Advances in Information and Communication Technology*, Sep. 2021, pp. 105–112. doi: 10.1007/978-3-030-85874-2_11.

[25] A. M. Özcan, A. Akdoğan, and N. M. Durakbasa, "Improvements in Manufacturing Processes by Measurement and Evaluation Studies According to the Quality Management System Standard in Automotive Industry," in *Lecture Notes in Mechanical Engineering*, Sep. 2021, pp. 483–492. doi: 10.1007/978-3-030-62784-3_41.

[26] F. Psarommatis, S. Prouvost, G. May, and D. Kiritsis, "Product Quality Improvement Policies in Industry 4 . 0 : Characteristics , Enabling Factors , Barriers , and Evolution Toward Zero Defect Manufacturing," *Frontiers in Computer Science*, vol. 2, no. August, pp. 1–15, 2020, doi: 10.3389/fcomp.2020.00026.

[27] R. J. Eleftheriadis and O. Myklebust, "A guideline of quality steps towards zero defect manufacturing in industry," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2016, pp. 332–340.

[28] P.-A. Dreyfus, F. Psarommatis, M. Gokan, and D. Kiritsis, "Virtual metrology as an approach for product quality estimation in Industry 4.0: a systematic review and integrative conceptual framework," *International Journal of Production Research*, 2021, doi: https://doi.org/10.1080/00207543.2021.1976433.

[29] D. Chen, S. Thiede, T. Schudeleit, and C. Herrmann, "A holistic and rapid sustainability assessment tool for manufacturing SMEs," *CIRP Annals*, vol. 63, no. 1, pp. 437–440, Jan. 2014, doi: 10.1016/J.CIRP.2014.03.113.

[30] A. Majeed *et al.*, "A big data-driven framework for sustainable and smart additive manufacturing," *Robotics and Computer-Integrated Manufacturing*, vol. 67, p. 102026, Feb. 2021, doi: 10.1016/j.rcim.2020.102026.

[31] D. Kozjek, R. Vrabič, D. Kralj, and P. Butala, "A Data-Driven Holistic Approach to Fault Prognostics in a Cyclic Manufacturing Process," *undefined*, vol. 63, pp. 664–669, 2017, doi: 10.1016/J.PROCIR.2017.03.109.

[32] S. A. Blume, "Existing holistic approaches to increase resource efficiency in manufacturing," *Sustainable Production, Life Cycle Engineering and Management*, pp. 41–67, 2020, doi: 10.1007/978-3-030-51894-3_3.

[33] A. R. Khan Mohammed, B. Ahmad, and R. Harrison, "A Holistic Approach for Selecting Appropriate Manufacturing Shop Floor KPIs," *Proceedings - 2020 IEEE Conference on Industrial Cyberphysical Systems, ICPS 2020*, pp. 291–296, Jun. 2020, doi: 10.1109/ICPS48405.2020.9274690.

[34] F. Psarommatis, G. Martiriggiano, X. Zheng, and D. Kiritsis, "A Generic Methodology for Calculating Rescheduling Time for Multiple Unexpected Events in the Era of Zero Defect Manufacturing," *Frontiers in Mechanical Engineering*, vol. 7, p. 646507, Apr. 2021, doi: 10.3389/fmech.2021.646507.

[35] F. Psarommatis and D. Kiritsis, "A scheduling tool for achieving zero defect manufacturing (ZDM): A conceptual framework," in *IFIP Advances in Information and Communication Technology*, Aug. 2018, vol. 536, pp. 271–278. doi: 10.1007/978-3-319-99707-0_34.

[36] J. C. Serrano-Ruiz, J. Mula, and R. Poler, "Smart manufacturing scheduling: A literature review," *Journal of Manufacturing Systems*, vol. 61, pp. 265–287, Oct. 2021, doi: 10.1016/J.JMSY.2021.09.011.

[37] F. Psarommatis and D. Kiritsis, "Identification of the Inspection Specifications for Achieving Zero Defect Manufacturing," in *IFIP Advances in Information and Communication Technology*, 2019, vol. 566, pp. 267–273. doi: 10.1007/978-3-030-30000-5_34.

[38] F. Psarommatis and D. Kiritsis, "A hybrid Decision Support System for automating decision making in the event of defects in the era of Zero Defect Manufacturing," *Journal of Industrial Information Integration*, no. xxxx, p. 100263, 2021, doi: 10.1016/j.jii.2021.100263.

[39] F. Ameri, D. Sormaz, F. Psarommatis, and D. Kiritsis, "Industrial ontologies for interoperability in agile and resilient manufacturing," *https://doi.org/10.1080/00207543.2021.1987553*, 2021, doi: 10.1080/00207543.2021.1987553.