A readiness level assessment framework for Zero Defect Manufacturing (ZDM)

Foivos Psarommatis [1*], Gokan May [2], Victor Azamfirei [3], Maria Chiara Magnanini [4], Daryl Powell [5]

[1] University of Oslo, SIRIUS Centre, Gaustadalleen 23B, 0373, Oslo, Norway
*foivosp@ifi.uio.no
[2] University of North Florida, Department of Mechanical Engineering, Jacksonville, USA
[3] Malardalen University, School of Innovation, Sweden
[4] Politecnico di Milano, Milan, Italy
[5] SINTEF Manufacturing AS, Raufoss, Norway

Abstract. In this study, a comprehensive framework for assessing the readiness of production systems for Zero Defect Manufacturing (ZDM) has been developed and presented. The framework includes four pillars of ZDM readiness, namely Personnel, Procedures, Infrastructure, and Company Culture, to help companies understand their level of readiness and plan for successful implementation of ZDM. We argue that a manufacturing company will be better equipped to embrace ZDM if it performs well in these four areas. We propose a tool that uses yes/no questionnaires to assess a manufacturing system's readiness for ZDM. The results of the questionnaire will objectively show the true level of cultural readiness for ZDM adoption, and the level of investment required for implementation will depend on the level of readiness. This tool can help companies gain a clear understanding of their readiness and create a plan for implementing ZDM. Overall, our framework and tool can help manufacturers improve the quality of their products and be ready for ZDM adoption.

Keywords: Zero Defect Manufacturing, ZDM, readiness, quality assurance.

1 Introduction

ZDM, or zero-defect manufacturing, is one of the most effective strategies available today for increasing product quality [1]. It is an Industry 4.0 paradigm that uses cutting-edge practices and digital technologies in production settings to go beyond conventional quality management approaches [2]. Most companies make the mistake of implementing quality management measures after the product has entered the manufacturing process instead of starting early in the design phase. To address this challenge, ZDM follows a cycle of continuous improvement synchronized with defined benchmarks and integrates into the manufacturing process from the start rather than addressing issues and faults later [3]. Using a combination of knowledge-based and data-driven approaches, as well as physics-based models, can help create tools and methodologies that prevent, correct, and predict defects in manufacturing processes. This leads to the implementation of Zero Defect Manufacturing (ZDM), which improves the customer experience and the sustainability of the manufacturing process [4]. When moving a product from concept to production, the idea of planning for zero defects is quite important yet complex. Zero defect is a goal; many controllable and uncontrollable factors may come into play when producing parts. It is important to develop a solid plan to manage and even get rid of any factors that lead to product defects. Design for manufacturability is crucial in this case, however many legacy items have problems that are unavoidable due to their inherent nature. Engineers can use the tools under the ZDM concept to better control these variables [5].

The current paper aims to create a framework and a tool for measuring the level of readiness of manufacturing systems for adopting ZDM. All the different levels of a manufacturing system will be analyzed from the top level, business – management until the bottom level of the production itself. The goal is to identify all the factors that are contributing to the implementation of ZDM.

2 State of the art

Many problems may occur in complex industrial environments, causing mistakes that would produce defective products [6]. Companies must adopt the techniques and mindset of producing high-quality products with minimal waste if they want to maintain a competitive edge in the present and future business landscape [7]. The efficiency and effectiveness of manufacturing organizations can be greatly impacted by poor product quality [8]. Poor quality can result in both direct and indirect costs, including those related to repairs, shipping, chargebacks, product returns, and lost sales [9]. Manufacturing defects can be brought on by, among other reasons, process variations driven by faulty equipment, worn out tooling, non-conforming materials, and human error [10]. Except for human error, these variances can be anticipated by applying Industry 4.0 technologies, methodologies, and tools to put corrective measures in place to get rid of the problems' underlying causes. ZDM is the strategy for obtaining Zero Defects by utilizing Industry 4.0 and its associated key enabling technologies [2, 11, 12].

To address the problem of ZDM implementation, many academics have offered general frameworks and architecture for applications in various industrial settings. These frameworks and architectures are generic in nature and frequently applicable to both new and current manufacturing systems. Wang (2013)[13] presented an earlier framework for ZDM that explains the application of DM approaches to produce zero-defect products. On that regard, May and Kiritsis (2019) [14] designed and developed a comprehensive framework and ad hoc approaches that could be used on both new and existing production lines for being able to manufacture products with zero defects by integrating cutting-edge industry 4.0 technologies while also improving the competitiveness and sustainability of manufacturing facilities. Psarommatis and Bravos (2022) [15] created a comprehensive framework that identifies all the essential elements of a manufacturing organization that must be connected for improving the sustainability of a manufacturing system with ZDM principles. Ringen (2022) [16] investigated the progression towards ZDM and the extent of Industry 4.0 readiness in relation to basic data integrity. The analysis revealed discrepancies between digitally defined values and physically measured values at a level demanding a high degree of autonomy and adaptability in decision procedures for the finished product to comply with ZDM. Konstadinidis et al. (2022) [17] provided a high-level overview of a generic manufacturing ecosystem that combines emerging technologies that are essential to the I4.0 vision to achieve optimal production conditions in industrial contexts.

Even though ZDM has attracted the attention of manufacturing researchers, it is still difficult to apply ZDM in real industrial systems. To speed such a deployment, it is essential to successfully follow the principles for creating ideal manufacturing system environments in a range of industrial verticals. Based on our review of the relevant literature, we found out a dearth of methods and instruments for evaluating the preparedness of manufacturing systems for ZDM deployment. Due to this gap, the current study's objectives include examining various production system levels and identifying the factors affecting the adoption of ZDM. The proposed tool is built on the transformation of qualitative data into quantitative, thus assessing the level of readiness using company's knowledge.

3 Readiness Framework

The current section is devoted on presenting the proposed framework for quantifying the level of readiness of a manufacturing system in the adoption of ZDM. The proposed framework has twofold purpose a) to develop a tool for the quantification of the level of readiness and b) identify the areas that are require improvement for the adoption of ZDM. The level of readiness is a function of multiple variables that are coming from all the different levels in a manufacturing system. A manufacturing system is encompassed by not only its operational and information technologies, but also the organization behavior, i.e., people, procedures, and information flow. [18].

In this scope four categories, that all those parameters belong to, have been defined. Those categories describe the four pillars of readiness "Personnel" (PE), "Procedures" (PR), "Infrastructure" (INF) and "Company culture" (CC) (**Fig. 1**). If a company performs well in these four pillars, then the level of readiness is high for the adoption of ZDM. Quantifying this level of readiness is a challenging and complex procedure, so a straightforward approach was chosen using a Yes/No questionnaire to eliminate subjectivity[19]. Such yes/no questionnaires have been employed successfully for many years in a variety of study fields, particularly in the biomedical and health sciences [20, 21] and in manufacturing [19, 22]. The developed questionnaire can be seen in **Error! Reference source not found.**, each question might belong to more than one of the readiness pillars. The questions are developed in order to cover all of the aspects that are affecting the adoption of ZDM. The survey is intended to be used by those involved in the design process of facilities for zero defect manufacturing and should be addressed to the relevant stakeholders in the organization. While results and conclusions of the survey are not presented in this paper, the proposed framework and tool will useful for future studies aimed at assessing the level of readiness of a manufacturing system in the adoption of ZDM.

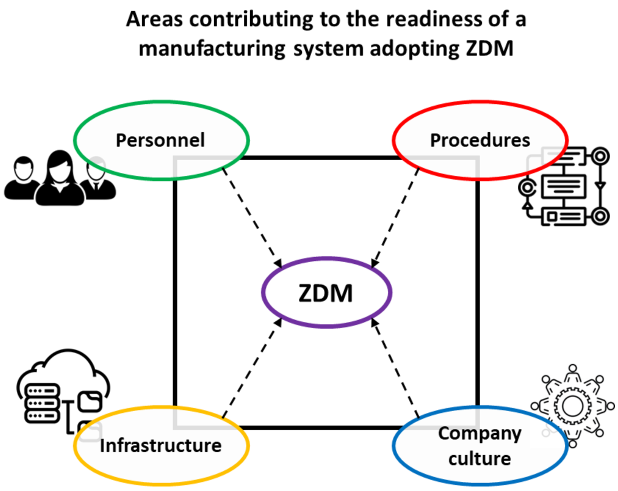

Fig. 1*: Key pillars for ZDM readiness*

When the primary data involve people's perception on something, questionnaires are a powerful tool, especially in a large number of people that some manufacturing systems may present. This data collection technique involves a number of personal to answer a number of questions via the Internet. For the design of such questionnaire and selection of the target group, the requirements encountered by Psarommatis and May (2022) were used [19]. When formulating the questionnaire questions, the purpose and scope of assessing ZDM readiness was kept in mind. Guidelines for formulating the questions were used as suggested by Säfsten and Gustavsson (2020) [23]. If the answer of a question is yes then the value of this question is 1 and if it no then it is -0.5. The calculation of the final readiness level is the sum of all questions values.

No.	Question	Description	Pillar
Q1	Are data collected from the production?	If there are data from the machines and other sources in digital form collected and stored.	INF
Q2	Are production data exploited in any way?	The data that are collected and stored are being utilized for improving any process that is happening in the production.	INF, CC
Q3	Is 100% inspection is taking place?	If there is in at least one manufacturing stage that all of the products are inspected	CC, PR
Q4	100% at last manufacturing stage?	If Q4 yes, is 100% inspection is performed only to the last manufacturing stage.	CC, PR
Q4.1	Physical detection is applied?	If the quality inspection is performed using physical measurements from the product, CMM, vision systems etc.	INF, PR
Q5	Virtual detection is applied?	If quality inspection is performed using virtual metrology approach. Utilizing collected data to estimate the product quality.	PR, CC

Q6	Quality prediction is applied?	Utilize any learning method, such as AI, machine learning for predicting when in the near future a defect will be produced	PR, CC
Q7	Are data analytics utilized?	Use data analytics for extracting valuable insights from the collected data.	PR
Q8	Are machine learning and AI etc utilized?	Use machine learning, AI and other learning methods for any optimization process.	PR
Q9	Is there a good communication between top management and production?	Whether any information between production an top management is easy to be communicated or not.	PR, CC
Q10	Is quality important?	If the product quality is important or not.	CC
Q11	Is there a quality assurance method implemented?	Whether there is a quality assurance method implemented to the production or not	CC
Q12	Quality inspection is performed only at the final stage?	Whether quality inspection is performed only at the last manufacturing stage when the product is ready?	PR, CC
Q13	A defected part is repaired or not?	If there is a defected part in the products the product is repaired or scraped/recycled	PR, CC
Q14	Is there a dynamic scheduling tool implemented?	If there is a dynamic scheduling tool that reschedules the production when a quality event or a set of events happen	INF, PR
Q15	Are workers familiarized with quality assurance?	Whether the workers are familiar with quality assurance and understand quality in depth.	PE
Q16	Are workers motivated to implement quality assurance	If the companies motivate workers to implement workers. If for example the only concern of a company is time or cost and pressure for lower then demotivate workers for implementing quality assurance.	PE, CC
Q17	Is there resistance to change from workers?	If workers are conservative and afraid the change on adopting new approaches.	PE
Q18	Is there resistance to change from management?	If top management is conservative and afraid to implement and adopt new approaches.	PE, CC
Q19	Do workers have all the required resources to conduct quality assurance?	If the workers have all the necessary tools for performing the quality assurance.	CC
Q20	Do workers understand data driven technologies?	If workers have the knowledge to use and understand data driven technologies.	PE
Q21	Is there a specific quality assurance method used?	Is there a specific quality method implemented, such as Six Sigma, Lean etc.	PR, CC
Q22	Is there a need of a specialist for the quality assurance implementation?	If quality assurance is relying on external experts or there is expertise inhouse.	PE
Q23	Installing sensors for collecting data is easy?	If the installation of new sensors for the collection of data is easy or not	INF

4 Discussion

The current study developed a tool to assess the readiness level of production systems for Zero Defect Manufacturing (ZDM). The four pillars of ZDM readiness were identified as Personnel, Procedures, Infrastructure, and Company culture. If a company excels in these areas, it has a high level of readiness for adopting ZDM. Affordable and easy to implement ZDM for SMEs will play an important role in the near future. Today we have skilled engineers, technologies, processes, and standards[12] that allow this philosophy to become a reality. Large manufacturing players like China and Germany are adopting a similar approach due to their sustainability goals. As quality and manufacturing support systems become more complex and require real-time control, their integration can be a challenge. According to [24], over 41% of EU companies have not adopted any new advanced digital technologies yet. Such survey does not consider the ZDM paradigm, and it is limited to only technologies. For ZDM to be successful in manufacturing companies, a certain level of readiness personnel, procedures, infrastructure, and company culture is necessary.

The infrastructure in companies and countries can vary. Scandinavian countries have a stronger infrastructure for Industry 4.0 compared to Eastern European countries, as reported by the EU. However, these differences should not be mistaken for the requirements for ZDM. To the best of our knowledge, this is the first survey that will help companies understand their actual level of readiness for ZDM.

Manufacturing companies face socio-technical challenges that vary in form and magnitude, depending on the starting points and goals for Industry 4.0 in different countries. Knowledge is becoming more transient, and the boundaries between disciplines are eroding. The ZDM readiness framework is based on yes/no questionnaires, offering companies a clear picture of their readiness while limiting in-depth information. This can still help companies create a plan for successful ZDM implementation.

Recently, many papers about ZDM procedures have been published in different fields, ranging from general papers [1, 11, 12] to papers focusing on quality inspection [24]. This survey can help companies determine which processes need to be developed for successful implementation of ZDM [1, 11, 12] [25]

The readiness level of a company's culture for adopting ZDM is reflected in the consciousness of its leaders. The use of yes/no questionnaires in the proposed tool objectively shows the true level of cultural readiness [18, 25], and the amount of investment needed for implementing ZDM varies based on the level of readiness. To avoid subjectivity an expert outside the company should conduct the questionnaire [19].

5 Conclusions

In this work, we have provided a designed questionnaire for the assessment of ZDM readiness in large and SMEs companies. Uniquely to ISO9000 family, which do not mention ZDM, we provide a framework that contains the four pillars of ZDM readiness, i.e., “Personnel” (PE), “Procedures” (PR), “Infrastructure” (INF) and “Company culture” (CC). Based on Psarommatis and May (2022) [19], 23 yes/no questions are formulated for the mentioned pillars. This study indicates that as knowledge becomes more transient and the level of company consciousness cannot exceed the one of its leaders, such survey will have a great impact on their assessment of readiness. Contrary to ISO9000 family, external third-party quality audit is recommended for the successful evaluation and deployment of ZDM. Finally, section 5 offers a starting point for new research ideas to be pursued.

6 Acknowledgments

The presented work was partially supported by the projects RE4DY, Eur3ka, TALON and PLOOTO, EU H2020 projects under grant agreements No 101058384, 101016175, 101070181 and 101092008 accordingly and by the Automation Region Research Academy (ARRAY) school founded by The Knowledge Foundation (KKS), Sweden.

References

1. Psarommatis F, May G, Dreyfus P-A, Kiritsis D (2020) Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research. Int J Prod Res 7543:1–17. https://doi.org/10.1080/00207543.2019.1605228
2. Psarommatis F, May G (2022) A literature review and design methodology for digital twins in the era of zero defect manufacturing. Int J Prod Res 1–21. https://doi.org/10.1080/00207543.2022.2101960
3. Soldatos J (2019) 1 Introduction to Industry 4 . 0 and the Digital Shopfloor Vision
4. Dreyfus P-A, Psarommatis F, Gokan M, Kiritsis D (2021) Virtual metrology as an approach for product quality estimation in Industry 4.0: a systematic review and integrative conceptual framework. Int J Prod Res. https://doi.org/https://doi.org/10.1080/00207543.2021.1976433
5. Psarommatis F (2021) A generic methodology and a digital twin for zero defect manufacturing (ZDM) performance mapping towards design for ZDM. J Manuf Syst 59:507–521. https://doi.org/10.1016/j.jmsy.2021.03.021
6. Eger F, Coupek D, Caputo D, et al (2018) Zero Defect Manufacturing Strategies for Reduction of Scrap and Inspection Effort in Multi-stage Production Systems. Procedia CIRP 67:368–373. https://doi.org/10.1016/J.PROCIR.2017.12.228
7. Cheng FT, Lee CY, Hung MH, et al (2022) Special Issue on Automation Analytics Beyond Industry 4.0: From Hybrid Strategy to Zero-Defect Manufacturing. IEEE Transactions on Automation Science and Engineering 19:1472–1476. https://doi.org/10.1109/TASE.2022.3180525
8. Psarommatis F, Kiritsis D (2021) A hybrid Decision Support System for automating decision making in the event of defects in the era of Zero Defect Manufacturing. J Ind Inf Integr 100263. https://doi.org/10.1016/j.jii.2021.100263
9. Olayeni A, Ogbo A, Okwo H, et al (2021) Green Strategy Effect on Financial and Environmental Performance: A Mediation Analysis of Product Quality. Sustainability 2021, Vol 13, Page 2115 13:2115. https://doi.org/10.3390/SU13042115

10. Nazarenko AA, Sarraipa J, Camarinha-Matos LM, et al (2021) Analysis of relevant standards for industrial systems to support zero defects manufacturing process. J Ind Inf Integr 23:100214
11. Powell D, Magnanini MC, Colledani M, Myklebust O (2022) Advancing zero defect manufacturing: A state-of-the-art perspective and future research directions. Comput Ind 136:103596. https://doi.org/10.1016/J.COMPIND.2021.103596
12. Psarommatis F, Sousa J, Mendonça P, et al (2021) Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper. Int J Prod Res. https://doi.org/10.1080/00207543.2021.1987551
13. Wang KS (2013) Towards zero-defect manufacturing (ZDM)-a data mining approach. Adv Manuf 1:62–74. https://doi.org/10.1007/S40436-013-0010-9/TABLES/3
14. May G, Kiritsis D (2019) Zero Defect Manufacturing Strategies and Platform for Smart Factories of Industry 4.0. In: Lecture Notes in Mechanical Engineering. Pleiades Publishing, pp 142–152
15. Psarommatis F, Bravos G (2022) A holistic approach for achieving Sustainable manufacturing using Zero Defect Manufacturing: a conceptual Framework. Procedia CIRP 107:107–112. https://doi.org/10.1016/J.PROCIR.2022.04.018
16. Ringen G (2022) Value chain data integrity and quality – a case study. INCOSE International Symposium 32:90–98. https://doi.org/10.1002/IIS2.12899
17. Konstantinidis FK, Myrillas N, Mouroutsos SG, et al (2022) Assessment of Industry 4.0 for Modern Manufacturing Ecosystem: A Systematic Survey of Surveys. Machines 2022, Vol 10, Page 746 10:746. https://doi.org/10.3390/MACHINES10090746
18. Groover MP Automation production systems and computer-integrated manufacturing. 809
19. Psarommatis F, May G (2022) A standardized approach for measuring the performance and flexibility of digital twins. Int J Prod Res 1–16. https://doi.org/10.1080/00207543.2022.2139005
20. Haasz M, Ostro D, Scolnik D (2018) Examining the Appropriateness and Motivations Behind Low-Acuity Pediatric Emergency Department Visits. Pediatr Emerg Care 34:647–649. https://doi.org/10.1097/PEC.0000000000001598
21. Ivanoff CS, Yaneva K, Luan D, et al (2017) A global probe into dental student perceptions about philanthropy, global dentistry and international student exchanges. Int Dent J 67:107–116. https://doi.org/10.1111/IDJ.12260
22. Tregerman I, Renne W, Kelly A, Wilson D (2019) Evaluation of removable partial denture frameworks fabricated using 3 different techniques. J Prosthet Dent 122:390–395. https://doi.org/10.1016/J.PROSDENT.2018.10.013
23. Säfsten K, Gustavsson M (2020) Research methodology : For engineers and other problem-solvers
24. (2017) Key lessons from national industry 4.0 policy initiatives in Europe
25. Azamfirei V, Granlund A, Lagrosen Y (2021) Multi-Layer Quality Inspection System Framework for Industry 4.0. International Journal of Automation Technology 15:641–650. https://doi.org/10.20965/IJAT.2021.P0641