# Human factors in the design of advanced quality inspection systems in the era of Zero-Defect Manufacturing

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**Abstract.** Manufacturing companies around the world are under constant pressure to perform effectively and sustainably. Incidental processes, such as Quality Inspection (QI), are needed to achieve Zero-Defect Manufacturing (ZDM). This study aimed to identify the Human Factors and Ergonomics (HF/E) in the design of advanced automation, QI systems, and ZDM through selected papers and empitical observations. Our presented model is built around the six main dimensions, i.e., top management, manager (project owner), designers, engineers (internal and suppliers), and operators. The commitment of top management, the openness of the manager, the design-friendly nature of the technological system, and the constant updating of knowledge by engineers are important for the success of ZDM. Researchers need to be familiar with cognitive and organisational human factors to align theory with specific cases. Operators face physical and cognitive challenges, and their environment and health must be considered for their successful contribution to the design of advanced QI systems.

**Keywords:** Zero-Defect Manufacturing (ZDM), Quality Inspection (QI), Human Factors, Ergonomics

## 1 Introduction

Manufacturing companies around the world are under constant pressure to perform as effectively and as sustainable as possible. The current manufacturing landscape is a highly competitive and rapidly evolving business environment [1]. Manufacturing companies should update their strategy to account for the needs of many regional markets in the context of global competition to maintain the rates of existing market share rates and also to approach new markets [2]. Traditional mass producers of goods such as automobiles and CNC machines are moving closer to embracing the mass Mass Customisation (MC) paradigm in order to maintain their responsiveness and competitive advantages [3]. Serving consumer demands is MC's main priority [4]. But this customer-focused economy also includes traits such as unstable product demand, quick time to market, and short life cycles. However, providing customised solutions becomes a means for manufacturing companies to move away from hardware-centric and towards solution-centric [5].

Based on current market needs, manufacturers have encountered a critical challenge that they had never encountered before. The variety of items produced by the manufacturers leaves no time for production optimisation, which was taking place up to this point [6]. As a result, there are many defective parts that are scrapped, recycled or repaired if possible [7]. MC strategy could make the production process unprofitable because it increases the price of the finished products and uses more resources such as energy. In light of the contemporary market and environmental situations, many manufacturing enterprises focus on true sustainability—that is, social, economic and environmental sustainability—in order to survive [8, 9]. Today, the idea of a smart industry is gradually moving away from a technology-driven solution and toward a value-driven one. Human-centricity, sustainability, and resilience serve as the foundation for this value [10]. Modern manufacturing businesses must strike a balance between providing competitive jobs and new goods with innovative materials and customisable alternatives while minimising their environmental imprint. In order to fulfil these qualities, the implementation of the philosophy of Zero-Defect Manufacturing (ZDM) and of enhanced automation for a number of quality control procedures [9, 11]. The ZDM philosophy, also viewed as an emerging paradigm in the domain of quality assurance, attempts to completely eradicate defects in production using all the potential of Industry 4.0 technologies [12, 13]. However, the challenging objective of zero faults requires the fusion of digital technologies with human components, including Industry 4.0 enabling technologies and smart factories [13].

Given that human behaviour has a substantial impact on manufacturing quality [14], the human-centric ZDM method could produce new insights and improvements in quality [9, 11]. Unlike Lean manufacturing and Lean safety that aim to identify and reduce waste in processes [15] and have been criticised for increasing stress or removing human intervention, HF/E focuses on the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use [16]. Numerous studies show that incorporating humans into the production process can boost efficiency, despite the beliefs of recent years that humans should be removed from the production environment to minimise human errors [17]. Businesses must also invest in knowledge and skills if they want to remain competitive, although innovative technology is crucial [18, 19]. Along with correction and compensation, the nurturing of human resources has been added as a third crucial policy under ZDM [20]. However, implementing human-centric methods to ZDM in production systems could be argued is hampered by organisational, psychological, and technological hurdles. The route towards ZDM is made more bearable by acknowledging the varied challenges faced by the different roles, even though these barriers may take different forms for the those human jobs in the manufacturing sector [21]. Technology should be used to support people, not the other way around, according to Industry 5.0 [10]. Synergy effects between man and machine will move the industry closer to the ZDM vision by considering people's demands in the development and adoption of new technology.

To our knowledge, a model for estimating human factors in the design of advanced QI systems is missing. Thus, the purpose of this article is to (i) examine human design factors on advanced automation, QI systems, and ZDM, and (ii) propose a model which could be used to estimate such challenges. This paper is structured as follows. Section 2 explains the theoretical background for the creation of this work. Section 3 introduces the theoretical model for estimating the impact of the HF/E on advanced QI systems. Section 4 summarises the scientific and practitioner contribution of the article and presents future steps towards ZDM.

## 2 Theoretical Background

Historically, QI standards have been left to company interpretation. ISO 17020 and Juran [22] provide simple steps on how QI should be performed, these are (i) interpretation of specification, (ii) measurement of the quality of the characteristic, (iii) comparison between (i) 'interpretation of specification' and (ii) 'measurement', (iv) judgement on conformance, (v) process of conforming items, (vi) disposition of nonconforming items, and (vii) record of obtained data. Furthermore, the Automotive Industry Action Group (AIAG) [23] states that the collection of instruments or gauges, standards, operations, methods, fixtures, software, personnel, environment, and assumptions used to quantify a unit of measure or assess the characteristic of the feature being measured should be included in the consideration. Azamfirei et al [24] considered both the frameworks and current literature on digital transformation and proposed a multi-layer QI system framework for Industry 4.0. In it, 'resources', 'actions', and 'data' are described; Humans interplay in such framework as operators, engineers, and designers of the specifications, measurement equipment, and quality evaluation. In addition, the commitment of top management is vital for the success of ZDM and its techniques [13]. When dealing with HF/E, the following three factors need to be considered i.e., physical, cognitive and organisational [16]. Physical, cognitive, and organisational factors as well as challenges change depending on the level of automation the quality system may present [25, 26].

### 2.1 Physical Ergonomics

Physical ergonomics refers to the physical load and its potential effect on the human body when performing activities [16], in this case the QI actions mentioned above. The most debated subject in physical support in QI involve

(i) collaborative robotics (cobots) for joined work and QI, and (ii) in-line lightweight metrology equipment such as Articulated Arm Coordinate Measuring Machine (AACMM).

### 2.2 Cognitive Ergonomics

Cognitive ergonomics refers to the study, evaluation and design of tasks, tools, environment and system in conjunction with their interaction with humans and their abilities [16]. Today's challenging time with increasing speed of change, uncertainty, and complexity require new ways of thinking and acting. Good actions can be taken only if we can make good decisions [27]. Stallard et al [28] estimated visual inspection error for metal-castings given different training and judgement types, environmental and human factors. Their model included 'human capabilities' (fatigue, health, judgement error, training error), 'environmental impact' (work atmosphere, lightning, noise), and 'defect density'. Since humans are in constant contact with automation for QI, ironies of automation need to be considered as they drastically affect human cognition [29]. The most debated subjects in the field of QI involve (i) human stress [14, 30], (ii) tasks design and human stubbornness, (iii) human-machine interface of in-line inspection tools, (iv) environment consideration, (v) decision-support systems.

### 2.3 Organisational Ergonomics

Organisational ergonomics refers to the optimisation of social technical systems that include organisational structures, policies, and processes [16]. Relevant topics include quality management, resource management, communications, organisational culture, team work, and participative projects, among others. Organisational core values are the basis for the successful implementation of practices [31]. Access to core values is often hindered by stress which, if it is perceived to be too demanding, makes the frontal association areas of the brain shut down. At a manager level, studies shown that high levels of brain integration are related to higher moral reasoning as well as superior performance. At an operator level, in Azamfirei et al [26] the performance of the manufacturing system was drastically affected by undocumented human interference in the system as operators were stressed in maintaining a level of quality and productivity. Thus, brain integration can be seen as a basis for all kinds of quality management to be successful [14].

## 3 Proposed model

Our interpretation of the literature, together with empirical observations in the field of semi- and fully automated in-line QI, let us create six dimensions of HF/E in the design of advanced QI systems, i.e. (i) top management, (ii) manager (project owner), (iii) designers, (iv) engineers (internal and suppliers), (v) researchers, and (vi) operators, see Figure 1.

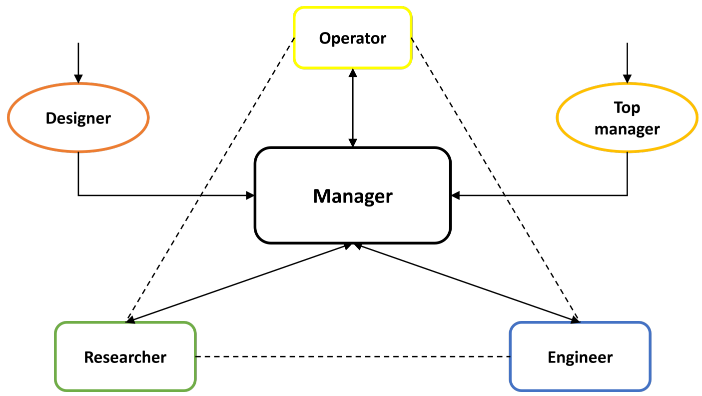


**Fig. 1.** Proposed integrated model for estimating human factors in the design of advanced QI systems

### 3.1 Top Manager

The commitment of top management is vital for the exit of ZDM and its tools, such as advanced QI systems [13]. Their commitment should be at all stages of implementation, from university-industry collaboration, education, system design, and deployment.

### 3.2 Manager

Managers are the main responsible for the design of advanced QI systems in collaboration with different entities, such as designers, operators, researchers and internal and external engineers. The openness of the manager is vital for the success of the project. As described in Azamfirei et al [26], when a preexisting paradigm is questioned, such as Industry 4.0 and ZDM, managers can experience challenges and paradoxes. It is argued that it is due to the managers being 'stuck' within previous production paradigm in terms of techniques, beliefs, and values. In the case of ZDM, the standardisation of the term in CEN/CENELC-CWA-17918 [32] is still taking place, and some local managers still mistake modern ZDM from 'zero-defect' movement inside Six-Sigma. In our model, we value the maturity of the paradigm and the familiarity of the manager with the requirements and values. Furthermore, management stress is considered. We believe university-industry collaboration and co-creation could ease with such challenges.

### 3.3 Designer

Designers are responsible for the study, research and develop of ideas for new products and the systems used to make them. Nevertheless, certain organisation might separate 'product design' from 'system design'. Their understanding of the needs and state-of-the-art technologies can be jeopardised by the reality that no system is perfect or free of uncertainties. Certain design parameters can place a level of stress that might hinder the physical and cognitive load. The increased level of customisation together with their corresponding adjustment of processes will require designers to be closer in the loop and have a deeper understanding on the physical, cognitive, and organisation factors.

### 3.4 Engineer

This category covers both internal engineers and suppliers. They are responsible for the creation of the technological system and its guidelines. Physical ergonomics apply when designing systems that will accommodate the needs of the operators. Cognitive and organisational HF/E apply to this category. The system design must be user-friendly and intuitive for its correct purpose. Additionally, engineers must constantly update their knowledge as technology and paradigms change. Such adaptation may lead to paradoxes, memory fatigue, and stress. Additionally, the correct communication channel is important for them to receive the right information. Though engineers do not actively participate in organisational ergonomics, their creation will be part of a socio-technological system, thus a holistic picture is needed in co-creating with managers, operators, and researchers.

### 3.5 Researchers

Researchers represent in this model the source of new knowledge in the changing fields. Researchers may lack a true perception of the state of the manufacturing companies and the use of technology. Their familiarity with cognitive and organisational HF/E is important for the adjustment of theory to specific cases.

### 3.6 Operators

Operators are challenged by all three HF/E in modern manufacturing systems. They are physically challenged by repetitive, dull and dangerous tasks in an unfriendly environment. The environmental impact and health need to be considered and "calibrated". Not all operators present the same training, judgement and health. Cognitively the stress can shut down their ability to learn and process companies values such as 'zero-defect'. Such shut down can also affect their capability to follow quality instructions. Such physical and cognitive challenges need to be overcome for operators to successfully contribute to the design of advanced QI systems where they will be part of.

## 4 Conclusions

The purpose of this article is to (i) examine human factors in the design of advanced automation, QI systems, and ZDM, and (ii) propose a model which could be used to estimate such challenges. Selected papers in the field of QI, ZDM, and HF/E were interpreted and used againts empirical observations in the design of semi- and fully automated in-line QI systems. To our knowledge, an integrated model of the cause and effect of HF/E in the design of advanced QI systems is missing. Our presented model is built around the six main dimensions that influence the design of advanced QI systems, i.e., top management, manager (project owner), designers, engineers (internal and suppliers), and operators. HF/E affect all the dimensions described and its effect must be measured at the same time to understand the efficiency of the designed QI system. ZDM will require full commitment of the top management to operators for its implementation. Future work will imply computerisation of the proposed model and simulation of different scenarios. Furthermore, questions arise with respect to the exploitation of data for ZDM in terms of safety and privacy, which should be further investigated.

**Acknowledgements.** The presented work was partially supported by the Automation Region Research Academy (ARRAY) school founded by The Knowledge Foundation (KKS) and the projects RE4DY, Eur3ka, TALON and PLOOTO, EU H2020 projects under grant agreements No 101058384, 101016175, 101070181 and 101092008 accordingly. The paper reflects the authors' views, and the Commission is not responsible for any use that may be made of the information it contains.

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