Human Factor in Sustainable Manufacturing

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Abstract. This article describes sustainable manufacturing (a part of a sustainable development concept) and the role of human factor/ergonomics (HFE) in achieving it. This includes consideration of relevant human factor issues in advancing manufacturing operations and processes from the point of view of product life cycle phases.

Keywords: Human factor/ergonomics · Sustainable manufacturing · Product life-cycle

1 Introduction

One of first and most cited definitions of sustainability was coined in 1987 by the Brundtland Commission, which defined sustainable development as development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs' [3]. Transferring this general definition on a corporate level leads to the concepts of ―corporate sustainability. Wayne Visser [50] defined corporate sustainability as a values - laden umbrella concept, which refers to the way in which the interface between business, society and the environment is managed. It implies that the manufacturing organizations have to be seen as social partners not just as profit centres promoting the economic interests of their shareholders, but also as business entities having obligation towards various stakeholders including the employees in providing decent, safe and healthy working conditions [35]. The objective of sustainable development confronts business enterprises with three sustainability challenges:

- Ecological challenge: increasing ecological effectiveness
- Social challenge: increasing social effectiveness
- Economic challenge to environmental and social management: improving eco-efficiency and/or social efficiency.

In the article [17] the analysis reveals that six enablers 'Commitment from top management', 'Eco-literacy amongst supply chain partners', 'Corporate social responsibility', 'High level of supply chain integration', 'Waste management' and 'Logistics organization ensuring goods safety and consumer health' are ranked as Independent

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enablers as they possess the maximum driver power. This implies that these variables are key barriers in the successful implementation of sustainability in the Supply Chain. The most important among them are 'Eco-literacy amongst supply chain partners', 'Commitment from top management' and 'Corporate social responsibility'. In the article [18] authors presented the model of the identification of enablers of sustainability collaboration between logistics partners. The results of this research can help in strategic and tactical decisions for a company wanting to create sustainability collaboration between logistics partners. The main strategic decision relies on 'Common business goals' and 'Training'. These enablers are the most important enablers that initiate strategic activities.

Enterprises must manage all these conflicting aspects of sustainability in an integrated manner, focusing not only on environmental or social performances, but also on sustainability of business.

On corporate level social sustainability is realized in concepts such as preventive occupational health and safety, human-cantered design of work, individual and collective learning, employee participation, workplace well-being and work-life balance [44]. The promotion of workplace well-being in the framework of sustainable development can be seen as a challenge and opportunity for organizations to achieve goal such as 'the ability of future generations to meet their needs'. Workplace well-being is considered by the International Labor Organization [22] as what is related to the aspects of working life, including safety and quality of the physical environment, workers feeling about their work and workplace, and their satisfaction level of work organization. According to this definition, workplace well-being aims at ensuring the workers are safe, healthy, satisfied, and engaged at work. Potential solutions or options to promote well-being at work may rise from the learning of ergonomics [36]. Human Factor/Ergonomics (HF/E) contributes to socially sustainable development and often also fosters productivity and effectiveness [43]. Steimle and Zink [43] encouraged ergonomists to make contributions through: understanding employment practices, complementing the design process of sustainability-oriented products, designing more efficient work systems, ensuring the safe operation of complex systems that may result in ecological and economic disasters, and through community ergonomics.

Sustainability is a topic that continues to gain the attention of safety, health, and environmental professionals. Legislative regulations provide an impetus to change from non-sustainable to more environmentally friendly operations, but their influence should be not overestimated. Sustainable manufacturing helps to overcome the problems resulting from increasing cost of energy, raw materials and waste disposal [12, 13]. Typically a board-level issue, sustainable growth strives to balance social, economic, and ecological issues. At their most basic level, sustainability and safety are really about the same thing: conserving resources. In the case of sustainability, those resources are typically thought of as environmental. In the case of safety, the resources are human. Despite this common ground, discussions of sustainability are only beginning to give attention to safety.

This article describes sustainable manufacturing (a part of a sustainable development concept) and the role of human factor/ergonomics (HFE) in achieving it. This includes consideration of relevant human factor issues in advancing manufacturing operations and processes from the point of view of product life cycle phases.

2 Human Factor

Human factors is not as directly about "humans" as the name might suggest. But it is about understanding human limitations and designing the workplace and the equipment we use to allow for variability in humans and human performance more efficient, safe, comfortable and satisfying [1]. Matching skills to the tasks performed is a priceless value in the long-term perspective of business management and strategy implementation [14]. As a discipline, human factors is concerned with understanding interactions between people and other elements of complex systems. All these complex systems need support, maintenance, monitoring, redesign and utilization, and this to be efficient requires a depth knowledge of ergonomics [5]. Human factors applies scientific knowledge and principles as well as lessons learned from previous incidents and operational experience to optimise human wellbeing, overall system performance and reliability [31]. The discipline contributes to the design and evaluation of organisations, tasks, jobs and equipment, environments, products and systems [6]. It focuses on the inherent characteristics, needs, abilities and limitations of people and the development of sustainable and safe working cultures. Human factors, can simultaneously affect a company's safety culture, and at the same time being a factor influencing job satisfaction [4, 15]. As suggest [30] 'The central focus of human factors relates to the consideration of human beings carrying out such functions as:

1. the design and creation of man-made objects, products, equipment, facilities, and environments that people us;
2. the development of procedures for performing work and other human activities;
3. the provision of services to people; and
4. the evaluation of the things people use in terms of their suitability for people.'

The term human factor has been used synonymously with ergonomics (Human Factor and Ergonomics – HFE), and evolves a unique and interdependent discipline that focuses on the nature of human – artefact interaction, viewed the unified perspective of the science, engineering, design, technology, and management of human-compatible systems, including a variety of natural and artificial products, processes, and living environment [41]. HFE focuses on systems in which humans interact with their environment. The environment is complex and consists of the physical environment ('things'), the organizational environment (how activities are organized and controlled), and the social environment (other people, culture) [53]. Today's ergonomics is an established discipline where professionals with interdisciplinary backgrounds work together in the designing socio-technical systems with the common goal of fitting them to human needs and well-being. From manufacturing companies context it recognizes that any complex technological system that involves people is critically dependent on the organizational and social context in which it operates. The objective is to ensure systems are designed in a way that optimises the human contribution to production and minimises potential for design-induced risks to health, personal or process safety or environmental performance.

For several years, there are discussions ongoing on the role and opportunities for active support of the pre-takings by HFE to meet the challenges of sustainable

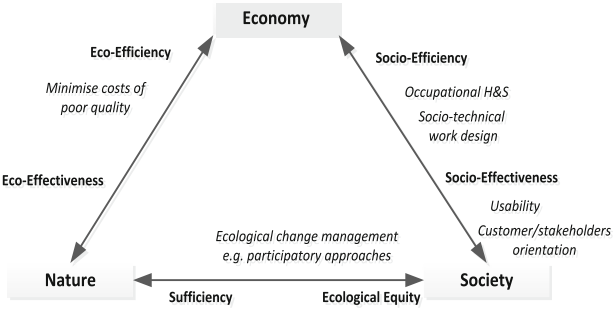

Fig. 1. Triadic model of sustainable development and ergonomics interventions [52]

development [7, 10, 11, 23, 32, 40]. Stanton and Stammers [42] argue that there is a natural link between ergonomics and sustainable development. Steimle and Zink [43] drew specifically on the WCED definition and the 'triple bottom line' approach. Steimle and Zink [43] encouraged ergonomists to make contributions through: understanding employment practices, complementing the design process of sustainability-oriented products, designing more efficient work systems, ensuring the safe operation of complex systems that may result in ecological and economic disasters, and through community ergonomics. Zink, Steimle and Fischer [52] extend on the triadic model to demonstrate the ways that existing human factors interventions have contributed to sustainable development (Fig. 1).

In the literature such terms as ergoecology, eco-ergonomics, green ergonomics [9, 20, 45] can also be found. According to [46] 'green ergonomics is focused on the bi-directional connections between human systems and nature. This involves looking at (1) how ergonomics design and evaluation might be used to conserve, preserve, and restore nature and (2) how ecosystem services might be harnessed to facilitate the improved wellbeing and effectiveness of human systems'. But regardless of how we define the scope of the relationship between human factor and sustainable development, human characteristics, behaviour and performance, and human interactions with technology are vital elements of sustainable development practices. There exists, it would seem, a natural synergy between these areas and ergonomics, with its goal of understanding and optimising the outcomes of human-system interactions. Ergonomic approach to the design of new and modification of existing products and processes is an approach aimed at meeting the requirements of both those who are users of the products or actors which resulted in the formation of these products as well as future users and participants of the manufacturing processes. The use of ergonomic requirements, described in conjunction with the human factor allows users to achieve the desired level of prohumanistic adjustment [16]. Than it should be noted that each product and the process of its implementation affects not only the direct users but also the local community and the environment, and company stakeholders.

Thus, ergonomics should also be seen as a stakeholder oriented approach.

3 Sustainable Manufacturing

Sustainable manufacturing is part of a larger concept, sustainable development, which emerged in the early 1980's in response to increased awareness and concern over the environmental impact of economic growth and global expansion of business and trade. The U.S. Department of Commerce defined sustainable manufacturing as 'the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound' [47]. Quinn et al. [37] define sustainable manufacturing as 'systems of production that integrate concerns for the long-term viability of the environment, workers health and safety, the community, and the economic life of a particular firm'. A more technical definition is given by Rachuri et al. [38] which define sustainable manufacturing as a 'system approach for the creation and distribution (supply chain) of innovative products and services that: minimizes resources (inputs such as materials, energy, water, and land); eliminates toxic substances; and produces zero waste that in effect reduces greenhouse gases, e.g., carbon intensity, across the entire life cycle of products and services'. Here Sustainable Manufacturing is defined as the essence of business, whose main purpose should be the creation of wealth throughout its whole system. Since there is no universally accepted definition for sustainable manufacturing, Javahir [24] describes it as a process that leads to: (i) improved environmental friendliness, (ii) reduced cost, (iii) reduced power consumption, (iv) reduced wastes, (v) enhanced operational safety, and (vi) improved personnel health.

Sustainable manufacturing implies that the processes and practices used for producing products meet the requirements for all three pillars of sustainability (….). From environmental perspective, sustainable manufacturing targets the consumption of less resources and generation of less hazardous materials in order to less jeopardize the environment by reducing global warming, climate changes and toxicity. From economic perspective, the economic advantages of sustainable manufacturing can be acquired by minimizing the cost through less material, energy, resource, and time consumption, and from social perspective, for better employment, well-being of the employees and livable communities; sustainable manufacturing considers workers' health and security with improved working conditions.

Taking into account such a wide spectrum of issues, sustainable manufacturing requires a holistic approach to the manufacturing process that monitors inputs and outputs in order to reduce the amounts of materials and energy being consumed, improve health and safety, and reduce the life-cycle impact of products. To achieve this, a successful approach to sustainable manufacturing must address all phases of product life-cycle e.g. design, production, exploitation and disposal (Fig. 2) and all stakeholders.

From Fig. 2, one can conclude that, sustainable manufacturing is extremely important to sustainability, and all phases of product life–cycle should be analysed and improved to meet the requirements of sustainability completely. Sustainable manufacturing is all about minimising the diverse business risks inherent in any

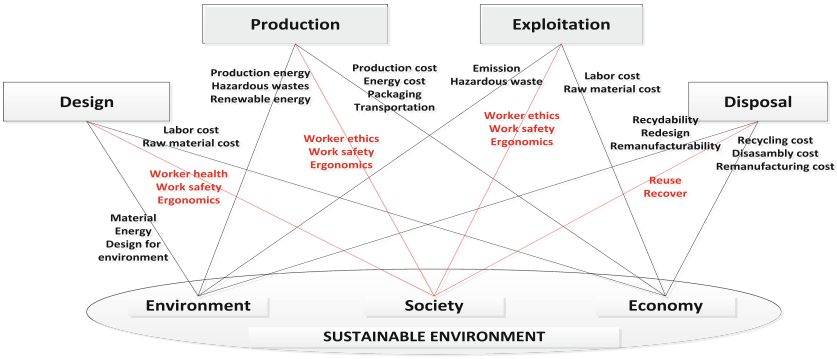

Fig. 2. Manufacturing contribution to sustainable environment [2]

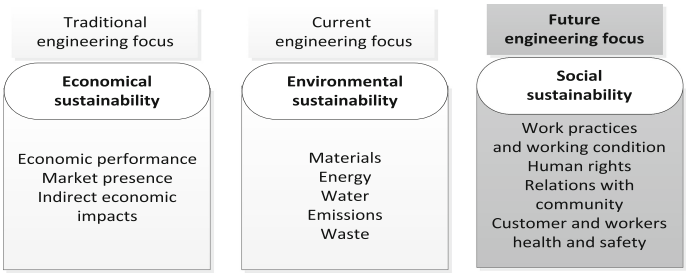

Fig. 3. Future engineering focus

manufacturing operation while maximising the new opportunities that arise from improving processes and products. Learning and practicing the new concepts, processes, methods and tools of sustainable manufacturing can be an exceptional opportunity for practitioners (engineers, ergonomists, etc.) that apply their knowledge and experience in developing new and improving existing products and systems of work friendly and safe for current and future users (Fig. 3).

One of example can be simulation of the transport tasks realization with taking into account different disturbances on process. By analyzing this process including different disturbances and impact of them to the whole process, the efficiency and an sustainability of the supply chain can be presented. Moreover, this approach includes human, ecology and other factors as disruptions (for example driving work time, congestion, suddenly weather changes) [21]. Traditionally, the scope of manufacturing is referred to product and production processes. However, the shift from management paradigm to sustainable development resulted in a change of the manufacturing paradigm towards of product life cycle management; as well as taking into account economic, environmental and social aspects.

4 How to Enable Human Factor in Sustainable Manufacturing?

The paradigm of thinking in product life cycles explains the importance of a holistic long-term planning and management approach to reaching a maximum product benefit over the entire life cycle and supports manufacturers in shaping successful products. The life cycle system is a sequence of phases, each containing tasks, covering the total life of a system from the initial concept to decommissioning and disposal. The purpose in defining the product life cycle is to establish a framework for meeting the stakeholders' needs in an orderly and efficient manner. The many decisions made during the process of a product design, manufacturing, exploitation and disposal directly influence the effect and outcome on the human well-being.

The first phase of the product's life cycle is its design. The conventional role of a product design in manufacturing firms has been to ensure that the product meets its desired objectives based on customer preferences taking into consideration performance, efficiency, ergonomics and aesthetics. However, with increased focus on sustainable manufacturing, the product designer is encumbered with additional responsibility of his decisions. This is due to, among others, the fact that the present definition of the customer goes beyond the classic 'customer as an organization or person that receives a product' [ISO 9001]. Starting from the definition of sustainable development and the challenges to be met by the company to meet the definition of an adequate customer seems to be suggested by J. Juran. Juran [25] defined customer as 'anyone who is affected by the product or by the process used to produce the product' where the customer can also be a local community, the environment, and even future generations. This broad definition of 'client' is close to the notion of 'stakeholder'. According to [8]: 'a stakeholder is any person or group that can affect or is affected by the achievement of the organization's objectives'. Product stakeholders are the people who are affect or are affected by the product during its life cycle. Thus, it becomes imperative for the designer to first acclimatize himself with the various issues concerning sustainability. From the point of view of sustainable manufacturing it is important to establish environmental and social (e.g. ergonomics) requirements and to apply a holistic view at product level as early as possible because, in early design phases of new products changes are less costly and easier to make than are late changes to the product, the work, or the workplace design. In addition, changes are increasingly difficult to make the closer it is to production start, and they become much more costly. When designing a product, not only the requirements for functionality and security should be taken into consideration, but also ergonomics. These requirements can be taken into account even at the stage of development of the concept of the product [33]. Thanks to such ahead in relation to the next stages of implementation of the project (construction of a prototype, serial production) so called thick errors can be avoided and significant savings of resources and time can be provided. Subsequent application of these requirements is burdened with too many risks, both financial (cost of improving the structure of already produced batch or serial), social (risk of hazards, accidents at work and occupational diseases users) and legal (legal consequences arising from marketing or putting into service of the product not in accordance with legal requirements) [34].

At this stage, aspects of the further phase, which is a production process should also be considered. Product design and engineering can benefit from the applications of ergonomics in both the design of the product for the end user and in design of a product that is easy to produce. Design for Assembly (DfA), or Design for Manufacturability (DfM), is an approach by which the ergonomics of assembly is considered in the product design stage. By considering production ergonomics in the product design phase it is possible to avoid all costs associated with corrective ergonomics processes, with little extra investment in the design phase. The aim in the production phase is to realise the design as physical components. Workers often pay the price for economic pressures on manufacturers to cut corners in order to meet demand for low cost products. Even if toxic inputs are eliminated from a product design, workers may be subjected to unhealthy working conditions, such as poor air quality, poor ergonomic design of work stations, involuntary overtime, and excessive pace. A product that is safe for consumers but presents significant hazards for those involved in its production is not a fully sustainable product. Similarly, a product that is polluting in its production and therefore harms the local community is not a fully sustainable product, even if this impact occurs far from where the product is consumed/used. How to ensure that working conditions are as safe as possible and humane? We spend eight hours a day at the workplace. Properties and workplace conditions have a significant impact on mental and physical health, not to mention the motivation of the employees [39]. The working environment may also play a significant role in both preventing the formation of non-conformity as well as the challenge of non-compliance of the product (economic aspect). Among the factors that may cause non-compliance of the product and human errors in the workplace the following are often cited: procedures, equipment, supervision, knowledge, time pressure, organization, fatigue [29].

In the literature of the subject, including ergonomics in this phase of the product life cycle is a shown to in the context of improvement activities most often carried out in system of continuous improvement. Lillrank et al. [26] defined CI as ‘a purposeful and explicit set of principles, mechanisms, and activities within an organisation adopted to generate ongoing, systematic and cumulative improvement in deliverables, operating procedures and systems’. Realizing the program of joining employees in workstation improvement companies usually benefit from “Kaizen events” system for initiatives introduction. Initiatives of employees are mostly focused on various aspects of work processes and production. Participation of employees on all levels in the development of work and work environments is an important concept in modern ergonomics. The most common methods used in enterprises are 5S practices, machinery maps, process mapping, etc. [7, 27, 28, 49].

Including ergonomics in the design of work and workplaces may support productivity and quality, promote the health of the employees and also attract new employees. But most ergonomic interventions are designed to reduce relevant risk factors impacting the individual worker, ignores the potential health consequences of measures to improve competitiveness and productivity [51]. A shift for a more macro-approach should be expected from ergonomics interventions because they ‘may have a better chance of success by focusing on insights that help balancing production performance and worker wellbeing, thereby moving towards more sustainable production systems’ [51].

The next phase in the life cycle of the product is exploitation. In this phase, except of the obvious comfort of the device user it is necessary to draw attention to the comfort and safety of those who carry out maintenance and repair work. Generally the fact that maintenance operations involve some specific risks and that their operators are exposed to potential chemical, biological, physical (etc.) hazards that may influence their safety and health more than other workers is not taken into consideration. Repair work requires sustained awkward postures of the back, neck, and shoulders as well as repetitive manipulations and awkward postures associated with hand tool use. Sustained awkward postures restrict blood flow and can cause muscle fatigue as well as place the employee at risk of developing Work-Related Musculoskeletal Disorders. Repeatedly performing tasks in such positions imposes increased stress on the muscles and joints. Employees are exposed to contact stress to the hands from using small tools, while a lack of task lighting can increase eye strain and induce awkward postures as employees try to adequately view a part. The issues of ergonomics and safety at work of employees of the technical services is rarely subject raised in the literature. However, due to the automation of manufacturing processes on the shop floor more often we see the maintenance technician than the machine operator. A role of maintenance staff in the sustainable production is special.

The last phase of the product life cycle is liquidation. Waste from consumer products can be drastically reduced by adopting a design approach that facilitates: re-use of components in subsequent designs; the benign return of components to the environment through use of completely natural, no- or low-processed materials; and/or ease of recycling by ensuring the components are made from minimally processed, single type materials. In this way, we will cause that man is not only the participant in these processes, but mostly the involuntary recipient of their impact on the environment in which he lives will be better protected and his well-being will be assured.

5 Conclusion

Just as ergonomics benefits are often difficult to quantify, so too is ‘selling’ the benefits of sustainability. The goal is for both ergonomics, and sustainability, to become a central part of all phases of product life cycle. To do this it is necessary to show that by incorporating these practices both quality and productivity can be enhanced. A product designed to be usable and useful to the customer can contribute to companies’ profit (economic perspective of sustainable manufacturing). Good ergonomics can be defined as appropriately applied ergonomics technology that also is cost-effective. According to [19, 48], most economics analysis of ergonomics and health interventions made clear that, from the company perspective, they are worth undertaking because they result in positive net values, benefit-to-cost ratios greater than 1, and relatively short pay-back periods.

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