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A new Human-centric Factory Model

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Abstract

The traditional manufacturing concept puts tasks at the center of the production system and the workers' role is rather passive. However, the workplaces of the future will be worker-centric instead of task-centric, and the role of the workers is expected to increase, leading to an optimization of the production performance. In this manner, it is of paramount importance to define new social sustainable workplaces where the human dimension is a key cornerstone, highlighting the requirements for shifting from a traditional task-centric production to a worker centric production. The idea of this study is to design the workplaces of the future and to understand how the worker's role will change in the next years, focusing on the workers' perspective to create workplaces that fit to their needs. The study therefore highlights a new human-centric factory model and provides a taxonomy of the aspects to be considered in designing these worker-centric factories of the future. The EU-Funded Man-Made Project is used for the development and validation of the concepts of the research work utilizing case studies in the transportation and white-goods industries.

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Keywords: Human-centric factories; social sustainable workplaces; context-aware factory; anthropometric workplace; sustainable manufacturing

1. Introduction

The current context in which factories are placed puts the tasks at the center of the production system whereas the role of workers is considered rather passive. Besides, organizations are market driven considering the primary goals to achieve such as profitability targets, development, market leadership, social objectives, price targets, financial stability objectives and customer satisfaction. However, the environmental and social factors move into a new direction nowadays. Companies pay more attention to the worksite analysis, hazard prevention and control, training and education for the employees. Many companies, especially the large ones, tend to declare in their websites and their annual reports to what extent they pay attention towards all the company's stakeholders and specifically employees' behavior. In this sense, a set of directives have been issued in Europe considering safety and health at work environment to improve the worker conditions which in turn aims at reducing the risk of accidents to eventually create an appropriate environment with higher quality of life for workers [1].

The workplaces of the future will be worker-centric instead of task-centric, and the role of the workers is expected to increase, leading to an optimization of the production performance. In this new setting, it is the job that suits the skills, the experience and the features of each worker, and a worker centric system is useful to improve the knowledge and the capabilities of workers regardless of age and role. The manufacturing sector thus needs to react and adapt to the emerging sustainability trend, not only in environmental and economic dimensions, but also by addressing social issues. In that vein, the factory and the workers have been tackled in a setting in which the human dimension is at the cornerstone of the production system. Hence, employees should be effectively involved in the job design and task balancing processes. Workers are not static elements of a hierarchical complex system but are people with competences and skills to give an active cooperation to the society where they live and to the company they work.

The advantages of shifting the paradigm from the task-centric organization to the worker-centric factory are ground-breaking. In this manner, it is of paramount importance to

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define new social sustainable workplaces where the human dimension is a key cornerstone. Consequently, highlighting the requirements for shifting from a traditional task-centric to a new worker-centric production system becomes a key necessity. The overall purpose of this research work is therefore to increase understanding on human-centric organizations in order to improve satisfaction of workers and their integration into social environment.

The particular idea of this study is to design the workplaces of the future and to understand how the worker's role will be changed in the next years, focusing on the workers' perspective to eventually create workplaces that fit to their needs. The study therefore highlights a new human-centric factory model and provides a taxonomy of the aspects to be considered in designing these worker-centric factories of the future.

2. State of the art

This section provides the state of the art focused on different concepts of the worker-centric organization. The review of the pertinent literature has been carried out to evaluate and synthesize the information in the wide literature in line with the concepts of this study which aims at identifying the research gaps.

The main question triggering this research was to investigate 'how we can create the human-centric workplaces of the future'. This idea led us to critically examine the relevant literature to come up with a structured view of the studies carried out, allocating the studies in the literature to identified main streams in this area and consequently to prioritize them based on the viewpoints and needs of both the academia and the industry. The specific research question to be addressed in this phase is: "What are the characteristics that define a human-centric organization, and what are the gaps between the traditional organization and the worker-centric factory?".

Bibliographic databases were used as the main source for review, due to their ability to allow fast and customized searches. Based on the analysis of the relevant studies, we came up with a critical evaluation of what has been published on different arguments related to this field of interest, leading us to specific research gaps to address accordingly.

In this context, ergonomics becomes a fundamental field of study to define and discuss the interaction among workers and other elements of the factory system in order to improve human well-being and the overall system performance. The principles of ergonomics are not only applied to increase the productivity, to improve health and safety of workers, to reduce worker's claims, or to fulfil government regulations. The ultimate goal is to achieve higher job satisfaction [2]. The literature review on this topic is focused on the worksite analysis, hazard prevention and control [3]. Companies are realizing ergonomic changes to reduce injuries and cost: either they pay now or they should pay much more for ergonomic changes in the long term, and they also possibly sacrifice the quality of workers' life. Considerations about these crucial issues are also consistent with international quality assurance activities (ISO 9000). The themes mentioned in the literature review are anthropometry, workplace principles, manual materials handling and cumulative trauma disorders, etc. [2]. The first gap that is derived by analyzing the literature is the wide distance between workers' needs and safety. What has not been said so far about ergonomics is the important role of this discipline to increase the motivation and satisfaction of employees.

A different view of ergonomics as a discipline to understand modern interacting systems was conceived by Wilson [4]. He proposed a holistic approach for ergonomics to understand complex interacting systems involving people and the exploitation of such understanding to improve human's well-being and performance. In this view, ergonomics is rather engaged with the interactions between workers, tasks, equipments and environment. Hence, it becomes fairly crucial to move our point of view towards the theme of ergonomics related to the production planning. This implies a change in the role of the people that possess ergonomic knowledge into companies.

The approach to human-centered design is focusing on the design of the production processes in order to establish a dialogue between designers and planners of technology on the one side and social scientists on the other [5], [6]. A human-centric production system is characterized by permitting a unification of planning and implementation, expecting the user to be in control of the work process and the technology, fostering the utilization of human competencies, and ultimately ensuring a healthy and socially interactive working environment [7].

These goals have been developed to include different complementary criteria for evaluating production systems, including activities such as time-structure, the possibilities of free movements, social relations, responsibilities and flexibility of control, qualifications and stress control. These criteria are linked to a phase-based model of the Jensen [8]. In his research work which is based on an evaluation of a Swedish research program about the intervention studies on musculoskeletal diseases, the author integrates ergonomics into the planning activities of the enterprises. From an organizational point of view, it is important to establish or increase the organizational platform for ergonomics. This aim could be attained through different approaches.

In general, many relevant issues are discussed in organization theory. A few authors have explicitly addressed the management of ergonomics, human factors, occupational health and safety for working environment. They do not present highly operational concepts linked to simple causal chains, but single out the concepts and relations necessary for introducing changes. The understanding may be based on common sense achieved through industrial practice, but the theory opens up for a more profound reflection on practice. So, it is important to develop studies on what might be called management of ergonomics, and an orientation towards organizational development should be part of the professional knowledge. The second gap found in the literature review is that concepts like ergonomics and anthropometry have been used in a stand-alone way. This research work thus integrates existing tools and ideas to derive a framework for designing the human-centric workplaces of the future.

3. Research Framework

The role of workers in manufacturing is becoming one of the main issues for policy-makers, industries and society. The research work, which is focused on studying and developing the human-centric workplaces of the future, perfectly fits within the social sustainable manufacturing research stream in a broader sense. During the development of this research study, the milestone has been the human-centric vision in order to know the workers from their point of view.

The research has been carried out based on a conceptual framework and in turn, a taxonomy has been defined to consider the main aspects in designing the workplaces of the future. The adoption of this approach foresees a deep knowledge of Worker, Factory, and Context as highlighted in the below Figure 1.

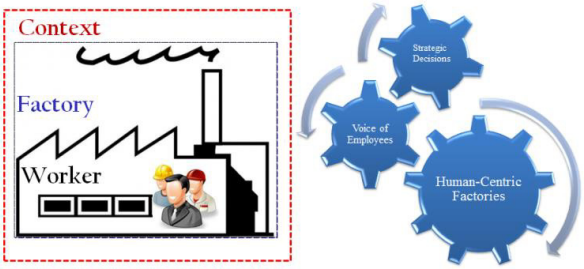

Figure 1. Research Framework

The research framework provides a holistic view on all the aspects to be considered for implementing a worker-centric model in manufacturing. By exploitation of the proposed framework, it is possible to detect the main pillars in the research work: the first is the identification phase based on knowledge which would be inserted in the second phase that concerns the development. The first phase allows defining a human-centric taxonomy on the following aspects:

- Worker - research has been devoted to identify critical characterizations based on three dimensions: worker's anthropometry, functional capabilities, and knowledge/skills/expertise
- Factory - research identifies critical characteristics of the factory using a workers' perspective;
- Context - research analyses the three dimensions of sustainability (i.e. economics, social and environmental) in which factories are placed.

4. Research Methodology

Starting from the context shown in the research framework section and in order to better clarify the main goal of this study, the following main research question has been formulated:

Main RQ: "How can we create the human-centric workplaces of the future?": to answer this question thoroughly and to frame an appropriate outline for the research work, an additional number of sub-questions have been formulated:

RQ 1: "What are the characteristics that define a human-centric organization?" - To design the workplace of the future based on the worker role in the factory, it is necessary to define what are the main features of a worker-centric organization.

RQ 2: "What are the gaps between task-centric and worker-centric organizations?" - This question is fundamental to develop this research work. The knowledge on the traditional factory models is mandatory to develop a different human-centric model.

The study firstly presents an outlook of the problem statement, and then defines the research questions and the objectives which have been developed by an extensive literature review on the subject of human-centric workplaces both from an ergonomics and job assignment point of view. Afterwards, it focuses also on the whole socially sustainable workplaces subject in a broader view. Subsequent to the literature review, the research questions have been refined with the addition of some sub-questions in order to investigate the new gaps which have been found during the analysis. The below Figure 2 illustrates the research process.

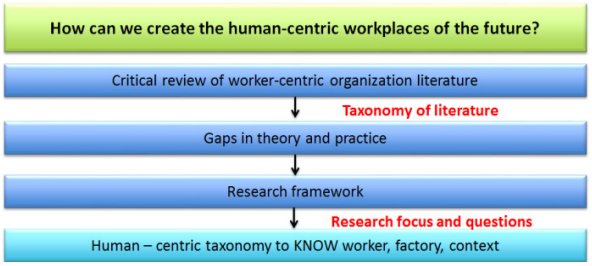

Figure 2. Research Process

Based on the framework, an interview has been organized to address manufacturing companies in Europe, to investigate how companies are currently practicing to integrate a worker-centric model in their manufacturing processes. Moreover, the likelihood of the model has been investigated through interviews to reveal the gaps between theory and practice. Finally, two case studies have been carried out in order to validate the concepts of the research work in the white-goods and transportation industries.

5. Human-centric taxonomy

The first step to develop a framework for a human-centric workplace is the analysis and the knowledge about workers, factories and context. The requirements are identified as follows:

- Development of techniques and tools for worker characterization, applicable in real factory settings: for this aim, the model has been characterized anthropometry of the workers, functional capabilities, and knowledge/skills/ expertise of the workers involved in production related processes.
- Development of tools and procedures for a factory representation from the worker's perspective, establishing a formalized representation of the key risk factors to be integrated in the factory model;
- Establishing a worker-factory assessment model aimed to optimize technical and organizational strategies taking into account design and development of the production processes;

• Analysis of the territorial context in which factories are located to support context strategies in terms of economic, social, and environmental sustainability.

5.1. WORKER Analysis

One of the requirements of designing human-centric workplaces is the development of conceived methodologies and tools to represent evolving profile of the workers, through their characterization under four dimensions.

• Anthropometry: Anthropometric characterization of the workers should be done with the identification of critical anthropometric dimensions to be considered in the design of the tasks and workplaces. This characterization should be completely realized with the support of non-invasive data capture systems such as sensors, video/image motion capture, and body scanning aimed at collecting relevant anthropometric dimensions of the worker.

• Functional capabilities: Functional capacities of worker can be distinguished into three areas: physical, sensorial, and cognitive. Physical capacities are focused on a general force capacity that is the capability to undertake the physical tasks of daily living [9]. Physical capacities are, for instance, standing, sitting, kneeling, walking, climbing, etc. These abilities influence the capacity to manipulate and control objects, strengths, balance, and coordination. Sensorial capacities influence visual, auditory and speech perception. These abilities are, for example, hearing, localize sounds, read, write, speak, smell, etc. Cognitive capacities are fairly important because they represent the process by which the sensory inputs are transformed, elaborated and utilized in practice for the acquisition and application of knowledge in problem solving. Cognition is the mental processing that includes the attention of working memory, understanding and speaking a language, calculating, reasoning, problem solving, and decision making.

• Knowledge: Knowledge is the understanding of concepts, such as facts, information, descriptions, or skills, which is acquired through experience or education by perceiving, discovering, or learning. Knowledge can be referred to a theoretical or practical understanding of a subject. It can be implicit (as with the practical skill or expertise) or explicit (as with the theoretical understanding of a subject); it can be rather formal or systematic [10]. Knowledge acquisition involves complex cognitive processes: perception, communication, association and reasoning whilst knowledge could also be related to the capacity of acknowledgment in human beings [11]. Knowledge can be defined for instance in scientific and technological areas relevant to the production processes of companies: electronic or mechanical engineering, ICT tools, materials, statistical analysis, industrial design, vibrations, etc.

Knowledge of each worker who is involved in production-related processes should be assessed. For this aim, it is required to adopt a properly developed knowledge dynamic profiler enabling the careful representation of both skills and expertise gained in worker's life. It is also a crucial element to identify required skills in the execution of specific tasks and expertise obtained and proved in previous activities, tasks and jobs.

Personal needs are related to the workers' private life and are addressed in the provision of services in order to improve work-life balance. The list of critical dimensions for worker is shown in the Table 1 below.

Table 1. Worker's characteristics

Worker
1. ANTHROPOMETRY - Human dimensional aspects
1.1. Standing height
1.2. Elbow height
1.3. Sitting height
1.4. Shoulder height (sitting)
1.5. Shoulder height (standing)
1.6. Elbow height (sitting)
1.7. Shoulder (bi-acromial) breadth
1.8. hip breadth
1.9. Popliteal height
1.10. Tight clearance
1.11. Button-abdomen depth (sitting)
2. FUNCTIONAL CAPABILITIES
2.1. Physical
2.1.1. Raising a weight
2.1.2. Carrying a weight
2.1.3. Hold a tool
2.1.4. Grip strength
2.1.5. Pinch strength
2.1.6. Standing balance
2.1.7. Bending over
2.1.8. Pushing or pulling objects
2.1.9. Frequency of repetitive motion
2.1.10. Sitting
2.1.11. Walking
2.1.12. Standing
2.1.13. Kneeling
2.1.14. Climbing
2.2. Sensorial
2.2.1. Hearing power
2.2.2. Localize sounds
2.2.3. Distinguish colors
2.2.4. Tridimensional sight
2.2.5. Width of sight
2.2.6. Power of sight
2.2.7. Smell
2.2.8. Touch
2.2.9. Precision of movements
2.2.10. Pressure perception
2.2.11. Body balance
2.2.12. Position of body parts (proprioception)
2.2.13. Perception of temperature
2.2.14. Read
2.2.15. Write
2.2.16. Speak
2.3. Cognitive
2.3.1. Memory
2.3.2. I.Q
2.3.3, Understanding writing
2.3.4. Perception
2.3.5. Association
2.3.6. Language
2.3.7. Analytical thinking
2.3.8. Processing visual stimulation
2.3.9. Attention
2.3.10. Pattern recognition
2.3.11. Problem solving
2.3.12. Calculating;
2.3.13. Decision making
2.3.14. Responsibility
2.3.15. Cooperation/working with others
2.3.16. Initiative
2.3.17. Capacity for concentration
2.3.18. Autonomy

3. KNOWLEDGE - Skills acquired through experience or education
The theoretical or practical understanding of a subject
3.1. Skills - The ability to do something
3.1.1. Training
3.1.2. Coordinate groups
3.1.3. Negotiation
3.1.4. Marketing
3.1.5. Languages
3.1.6. Specific software tools
3.1.7. Specific equipment
3.2. Expertise - High level of knowledge or skill
4. PERSONAL NEEDS - Related to private life
4.1. Family composition
4.2. Physical activity
4.3. Mobility
4.4. Leisure
4.5. Diet

5.2. FACTORY Analysis

The factory is often analyzed by considering production capacity, productivity, lead times and many other economic and financial-driven KPIs. This point of view is changed in the worker-centric organization, and the factory is analyzed from the worker's perspective. This is addressed through identifying potential interactions between worker and elements of the working environment with which one interacts during his job performance. All the elements are the basis to create a reliable, evolving and worker-centric representation of the factory.

The list of the critical characteristics for factory representation is shown in the Table 2 below.

Table 2. Factory characteristics

Factory
1. ECONOMIC KPI CHARACTERISING PRODUCTION
1.1. Scraps
1.2. Assembly yield
1.3. Labor efficiency
1.4. Material efficiency
1.5. OEE - Overall Equipment Effectiveness
1.6. FPY - First Pass Yield
1.7. FOR - Fall of Rate
1.8. Quality
1.9. Defects
1.10. Service
1.11. Schedule
1.12. Absenteeism
1.13. Accident rate
2. SHIFTS
2.1. Shifts start
2.2. Shift stop
2.3. Shift duration
2.4. Availability for Saturday work
2.5. Availability for overwork
2.6. Summer closure
2.7. Holidays
2.8. Vacation
2.9. Training
3. PROCESSES
3.1. Number of operations
3.2. Dislocation
3.3. machine uptime
3.4. Machine failure
3.5. Machine delays
3.6. Transportation
4. ORGANIZATIONAL STRUCTURE
4.1. Hierarchical arrangement
4.2. Right and duties of an organization
4.3. Roles and responsibilities
4.4. Information flows between different levels
5. WORKPLACES SHAPES AND PLACING
5.1. Layout of workstation
5.2. Golden zone
5.3. Setup time
5.4. Way out
5.5. Safety barriers
6. CORPORATE SERVICES
6.1. Business services
6.2. Company incorporation
6.3. Finance and banking
6.4. Accounting and tax services
7. PHYSICAL WORKLOADS
7.1. Noise level
7.2. Lights
7.3. Chemicals
7.4. Temperature
7.5. Bending
7.6. Stress
8. SAFETY EQUIPMENTS
8.1. Safety glasses
8.2. Goggles
8.3. Filter lenses
8.4. Gloves
8.5. Lab coat
8.6. Respiratory protection
8.7. Hearing protection
8.8. Helmet
9. ORGANIZATIONAL INCENTIVES
9.1. Merit pay
9.2. Profit sharing
9.3. Bonus
9.4. Pay for knowledge
9.5. Share ideas
9.6. Conventions

5.3. CONTEXT Analysis

In this section, the environmental and social context in which factories are located has been analyzed through the development of stakeholder-specific relationship management approaches. As a result, the analyses have been characterized in the three dimensions of sustainability: i.e. economic, social and environmental. This allows a complete understanding of the territories and trends in which the factory is located, by providing valuable inputs to a dynamic decision making support system that:

• Connects and manages demand and supply;

• Gathers demands from factories, workers and population near factories;

• Manages solutions provided by the population, workers or companies.

This task provides the identification of characteristics of the territorial context in which factories are located to support context aware strategies which should be developed in terms of production, social and environmental sustainability. The production aspect includes required customers, suppliers and distributors to satisfy companies' needs related to their production processes.

The social dimension takes into account personal needs of workers to improve their quality of life: physical activity, healthy nutrition, leisure activities, mobility, education centers, support to family, etc. The environmental cluster considers key factors related to the impact of the factory in its environment: pollution, sensitive sites, etc. The characteristics for context assessment are listed in the Table 3 below.

Table 3. Contextual characteristics

Context - Three dimensions of sustainable development
1. ECONOMIC
1.1. Customers
1.2. Distributors
1.3. Suppliers
1.4. Time
1.5. Cost
1.6. Price
1.7. Quality
2. SOCIAL
2.1. Support to family
2.2. Worker conditions
2.3. Mobility
2.4. Schools and education centers
2.5. Training
2.6. Entertainment centers
2.7. Parking
2.8. Shopping centers
2.9. Nursery
2.10. Sporting centers
2.11. Hospital
2.12. Pharmacy
2.13. Library and museums
3. ENVIRONMENTAL
3.1. Transport
3.2. Pollution
3.3. Sensitive sites
3.4. Quality of air
3.5. Level of lighting
3.6. Level of noise
3.7. traffic congestion
3.8. Green areas
3.9. Presence of radiation
3.10. Weather conditions
3.11. Seismic areas
3.12. Probability of natural disaster

6. Conclusion

This study demonstrates a new human-centric factory model and provides taxonomy of the aspects to be considered in designing the worker-centric factories of the future. These aspects have been classified in three dimensions: worker, factory, and context.

One of the remarkable insight of this study is that the applications of worker-centric model, tools and methods are limited in the traditional enterprises. Beyond the lack of social culture in the enterprises, the problem stems from the human-centric model which have not been designed with any tailored tools to integrate them into the enterprises' organization. Although a lot of tools consider existing ergonomics and anthropometric factors, there is a lack of consideration about the aspects which consider worker at the center of the production systems.

The Figure 3 which is derived based on the synthesis and understanding of this research study, highlights the components and requirements of a human-centric workplace of the future.

In particular, further developments might suggest an extension of the scope of the analysis considered in this methodology. An important future work could be the analysis of the manufacturing systems, trying to consider new case studies, in order to gather new information on the behavior of different systems. These systems can be again assembly lines or maybe other kind of systems which can be studied in conjunction with the development of new tools for human-centric factories such as worker-centric job designer, job allocator and training needs detector.

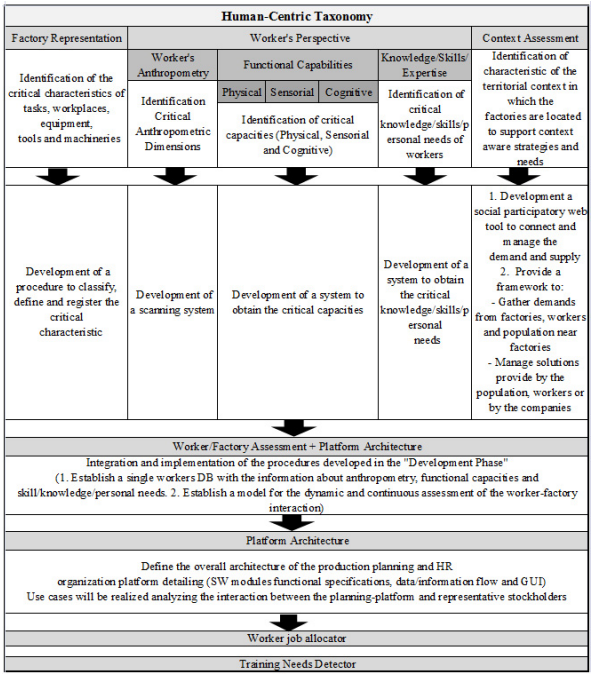

Figure 3. Human-centric factory model

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