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The relation between cognitive and organizational factors in the production environment

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Abstract

The adoption of I4.0's technologies in the work cells accompanied by societal changes calls for new approaches to manage the current production systems. Nevertheless, the current models simulating the behavior of the work cells limit the representation of the operators to the average human, without regard for their individual characteristics, cognitive abilities or psychosocial state. The aim of this paper is to achieve two objectives: firstly, the authors propose a conceptual model for enhancing a human-centered production environment. Secondly, the paper summarizes how the literature characterizes the different dimensions of relations between cognitive and organizational factors. By integrating the collaborative, psychological, social, cognitive, organizational and system performance dimensions, the proposed model focuses on the relationships between these dimensions. Thus, operational models should be closer to the real production environment to improve the design choices of the manufacturing systems.

Keywords: Human-machine interaction, modeling, human-centered approach, cognitive and organizational factors, psychosocial work environment.

1. INTRODUCTION

Working conditions have been profoundly changed by the adoption of innovative technologies in the industrial context during the last decades. New technologies such as smart wearable solutions, virtual reality, and cobots have clearly redefined the role of humans and machines within production processes. The most prominent innovation is probably the concept of Industry 4.0's technologies (Cunha et al. (2022)). It promised a competitive advantage for the companies by increasing productivity due to an enhancement in flexibility.

In contrast to this techno-centered approach, a human-centered one emerged. It pointed out that the human operator is the key element to a reliable use of such tools, thus introducing what is now known as Industry 5.0 (I5.0) (Panagou et al. (2023)).

The traditional models of the work cells do not consider human factors or their effect on the performance of the system. In addition, even if the models available in the literature have begun integrating human factors, they remain focused, on a superficial level, on factors like human error, fatigue, or musculoskeletal impairments (Farid and Neumann (2019), El Mouayni (2020), Petronijevic et al. (2023)).

The present study synthesizes the available knowledge in the literature by developing a new conceptual model of the production systems. This model strengthens the integration of the different dimensions that should be considered in the representation of the manufacturing process. Moreover, it seeks to synthesize the relationships between the various parameters and the variables that explain the behavior of the system.

In doing so, the purpose of this paper is to conceptualize a model that can be used as a base for the development of an operational model that mimics the behavior of the real-world production system. In practice, this conceptual model serves as a valuable starting point to be used by the research community to identify relationships between factors that influence the operators in the workplace. These relationships can be implemented in available simulation tools to predict the future state of operators in design scenarios. Such a tool can be used by designers, managers, and decision makers to plan and control production systems by finding better practices for a human-centered management.

The paper addresses several challenges, such as the production systems in the presence of collaborative technologies and the interaction between humans and machines (Sgarbossa et al. (2020)). To elaborate, human centered modeling should integrate the main domains of ergonomics (security issues), and, organizational and cognitive factors (Cunha et al. (2022)). Available models where the humans are represented as costs or resources with processing time should be enriched to guide the decision makers. Hence, this review addresses the following research question: "How does the literature characterize the different dimensions of relations between human and organizational factors in the production environment?"

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Taking these considerations into account, the paper is organized to describe in Section (2) the research methodology that was followed and to discuss the most influential dimensions. Section (3) describes the language used for the concept diagram in all its layers. Section (4) addresses the model dynamics of the relationships between the factors that lead the behavior of individuals and teams. The last section proposes improvements that could be integrated into the concept diagram. Throughout this paper, gaps in the literature are discussed while providing some normative ideas and directions for future research.

2. THE DRIVING CONCEPT OF THE LITERATURE REVIEW

2.1 *The search and modeling strategy*

As a first step, the scope of the article was defined by articulating the research questions to provide focused guidance for the review:

R.Q.1 - What are the dimensions that play a role in the production environment?

R.Q.2 - What is the nature of the relationships and interactions between the different parameters?

R.Q.3 - What is the influence of these parameters on the outcomes of the production environment? How are these various interactions modeled in the literature?

The next step consisted of searching for the literature to be considered in the review. Various fields were considered, such as: psychology, sociology, management, computer science, and industrial engineering. For the research, the cross-disciplinary database Scopus was used, as it is the main database for peer-reviewed publications, Research Gate, Google Scholar, and HAL open science. The search was based on multiple scoping and systematic reviews that exist to minimize the biases' impact. According to the dimensions identified, the search was expanded to enclose the group of studies in which parameters, and relationships between them could be identified. For the literature review, a combination of keyworks were used to describe modern manufacturing workplaces ("industry 4.0", "production", "manufacturing", "workplace", "industry 5.0"), human-machine interactions ("human-machine interaction", "human-robot collaboration") and wellbeing ("mental health", "wellbeing", "safety").

The following step consisted of screening the material. Articles were included if they (i) were written in English, (ii) were fully available online, (iii) discussed physical, psychological, and social factors for the well-being of the human Operator.

As a final step, the extracted data from the articles was re-organized into a conceptual model which is a meaningful way to summarize the data for its implementation in a simulation model of the human-centered production system, and a starting point for the researchers who want to locate their work in such an area of design. It was thought best to adapt a conceptual diagram which is similar to node-linking mapping methods (e.g., UML, Unified Modeling Language, class diagram). The concept map was chosen because it is the easiest available modeling language.

2.2 *The methodology behind the model*

To create the class diagram of the conceptual model in Fig. 1, the software Microsoft Visio was used. The diagram aims to objectively represent the integration of cognitive and organizational factors based on the literature review. Nevertheless, the model is to a certain extent subject to the personal insight of the authors by determining the elements to include in the diagram, deciding the relationships between the circles and defining the actions, behaviors and interactions of the different classes and components.

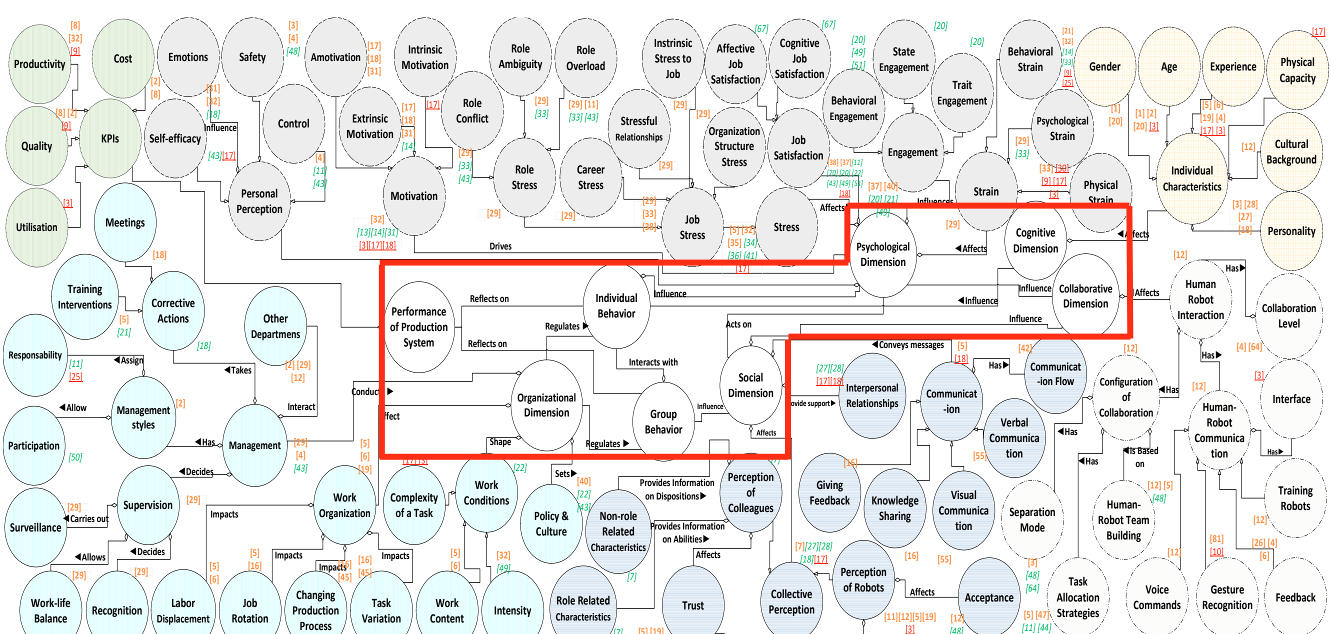


Figure 1 : Conceptual Model for the Integration of Cognitive and Organizational Factors in the Production System (first layer)

In order to draw the class diagram of the conceptual model, first, the main classes were identified. Then, attributes were associated with each class to provide relevant details such as instances. After, the relationships between classes were determined including association, aggregation and inheritance (Table 1).

2.3 The Dimensions for a human-centered modeling.

The analysis of the 61 selected papers allowed us to identify the different dimensions that affect the human-machine interaction in the workplace. These dimensions, which are in the red frame of the conceptual model of Fig. 1, were chosen based on the classification of the factors studied in the selected literature. To elaborate, variables and parameters who are similar in their attributes were clustered together to form the following dimensions.

2.3.1 The organizational dimension (addressed in 26% of the selected papers):

In the current context of mass customization and the adoption of innovative technologies, the tasks can be described as varied and unstructured in a dynamically changing production process (European Commission (2013), Dubey et al. (2017)). Labor is displaced (Moniz (2013)) since the operators can now transfer some parts of the tasks to machines for instance, which leaves them the opportunity to perform other tasks that require more skills. Change in the work organization will impact the work conditions, therefore, the intensity and the complexity of the task, and even modify the work content (Moniz et al. (2022)).

2.3.2 The symbiosis of Humans and Machines: the collaborative dimension (addressed in 46% of the selected papers):

In current manufacturing workplaces machines and humans interact, or in some cases they collaborate. The teams of machines and humans coordinate through complex interfaces (Fruggiero et al. (2020)), and problems in the team should be thought of like in the human ones, i.e., leading and following roles or the task allocation. Most literature mentions that security issues are a major concern to avoid injuries, and collisions (Storm et al. (2022)).

2.3.3 The psychological dimension (addressed in 49% of the selected papers):

The research field limited the modeling of the Human Operator's cognitive, sensorial, physical, and interaction abilities to the technology being used which is somehow limiting. However, given the vision of the operator in I5.0, mental well-being, and psychological occupational health count as much as physical well-being (Breque et al. (2021), Carayon (2021), C.L.A.I.R.E. (2019), El-Haouzi et al. (2021)).

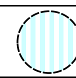
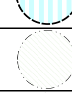
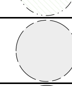
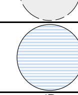
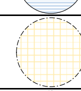
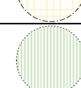
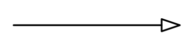
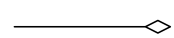
2.3.4 The social dimension (addressed in 31% of the selected papers):

The operator in Industry 5.0 (I5.0) (Breque et al. (2021), El-Haouzi et al. (2021), Moniz et al. (2022)) is a skilled operator capable of collaborating with machines. In social organizations, the literature stressed the need to study the relation between social operators, social machines (Moniz and Krings (2016)), and social software (Storm et al. (2022)). Yet, the social dimension of work is still considered residual when compared to the promised benefits of AI technologies (Cunha et al. (2022)).

2.3.5 The individual characteristics: the cognitive dimension (addressed in 23% of the selected papers):

Another dimension in the models is related to the individual characteristics of the operator in the workspace. The techno-centered approach is criticized for considering the human factor in a blurry manner, in other words, gender neutral, non-aging, skillful and fully capable of making up for the limitations of technologies by an omnipresence to ensure a seamless functioning of the production (Sgarbossa et al. (2020), Cunha et al. (2022)).

Table 1: The Legend of the Concept Diagram

	Parameter belonging to the organizational dimension.
	Parameter belonging to the collaborative dimension.
	Parameter belonging to the psychological dimension.
	Parameter belonging to the social dimension.
	Parameter belonging to the cognitive dimension.
	Parameter belonging to the system performance dimension.
	Inheritance: "is a kind of" relationship.
	Aggregation: "containment" relationship.
	Association: the most abstract way to describe the relationship.
◄ Influence	Verbs describing the link with arrows pointing the direction.
→ **[13]** -	Negative relationship: the variables move in opposite directions.
→ **[13]** +	Positive relationships: the variables move in the same direction.
→ **[13]** NL	Non-linear relationship: when there is a relationship between the variables but not in a linear way.
[13]	Reference proposing a study on the factor.
[13]	Reference proposing a model for the factor without a simulation.
[13]	Reference proposing a simulation for the factor being studied.

2.3.6 The production system's performance dimension: The KPIs (addressed in 34% of the selected papers):

It was noted in the literature the use of traditional KPIs (Dantan et al. (2020)) assessing productivity of the work cell (e.g., cycle time), the quality of production (e.g., number of defects), utilization of humans or machines, and cost. While other papers proposed the use of new KPIs to evaluate the processes, for instance data management, transparency and connectivity, and product management, and team performance (Panagou et al. (2023)).

3. THE CONCEPTUAL MODEL

3.1. The first layer of the model

The conceptual diagram consists of circles representing parameters and variables that belong to a certain dimension as shown in Fig. 1. And next to each circle, the respective references are added taking into consideration whether they propose a study, a model or a simulation. Table 1 sums up the legend of the artifacts displayed in the model.

In the first layer of this diagram, the abstract interactions between the different dimensions are represented using Associations linking some circles in white accompanied by verbs to precise the action and an arrow pointing the direction of the reading of the verb. Aggregation and Inheritance relationships linking the different parameters together are distinguished. The inheritance relationship, where a subclass inherits functionality from the superclass, is represented in the concept diagram as an arrow pointing towards the superclass of the dimension, while aggregation is represented by a solid line with a diamond on the owning side. In Fig. 1, inside the red frame, the individual behavior of an operator is considered as an aggregation of the group behavior, while in Fig. 2, role conflict, role ambiguity, and role overload are considered "a kind" of Role Stress. As an extension of the logic adopted in this example, the other relationships were defined based on the statements of the cited articles.

3.2. The additional layer

Another layer was added to the diagram to represent the relationships between the different parameters which are based on the articles studying the influence they have on each other.

First, the positive relationships can be distinguished by the use of "+" sign, and it means that when one element increases, the second one increases as well, while the negative relationships are the ones with "-" sign which means an increase in one element results in the decrease of the other element. In Figure 2 for example, an increase in role conflict results in an increase in role stress, and an increase in the collaborative level decreases the role overload.

Second, the non-linear relationships are the ones marked by "NL" and it means that a constant change in one element does not cause a constant change in the other element. For instance, (ElKosantini and Gien (2009)) acknowledge that Stress has a non-linear effect on Motivation: an increase of Stress in moderate level can boost motivation but in excessive levels, it decreases motivation.

4. THE BEHAVIORAL MODELS

4.1. The modeling of the causal loops

The use of assistive technologies in the workplace helps reduce the load on the human operator and increases the performance (Fruggiero et al. (2020)), freeing the operator for more skilled labor. In Fig. 2, it is shown that job displacement (Storm et al. (2022)) for maintenance, quality control, programming and data handling roles causes role-related job stressors like ambiguity and role conflicts that can be further increased with job rotations (Sgarbossa et al. (2020)). In addition, the re-skilling of the operators causes stress and leads to question the success of the adoption of these technologies if the human factors are not considered in the design phase (Moniz et al. (2022), Village et al. (2013)).

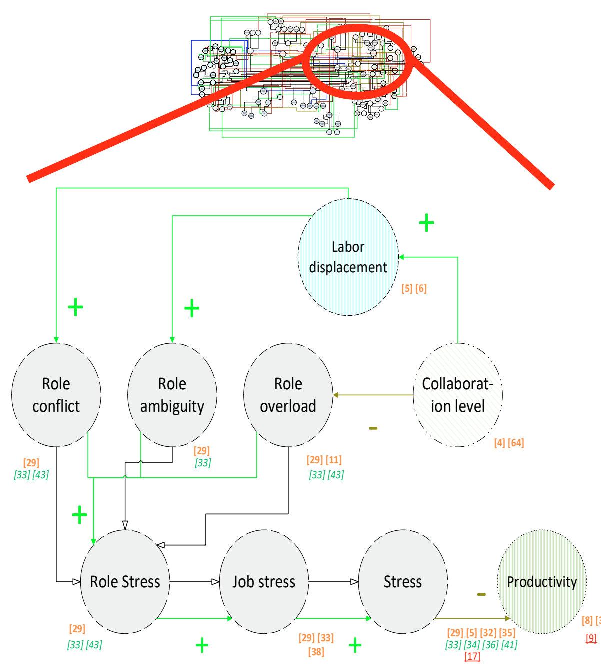


Figure 2: Zoom-in view on the Conceptual Model, showing a section of both layers 1 and 2

In addition to that, it should be noted that in collaborative scenarios, various questions arise such as how to allocate the tasks between humans and machines for optimum performance, safety and well-being? Or, what are the impacts of such organizational change on the motivation and cognition of operators? Aspects of these questions were already raised for instance by Tsarouchi et al. (2017) who proposed a method of task allocation considering the resource suitability, availability and operation time in a hybrid assembly cell allowing a decrease of the flow time, thus increasing the productivity of the production system.

The results also show impressively that the interaction of humans and machines in one cell does not necessarily imply a collaborative scenario. In the case of HRC (human-robot collaboration) (Quenehen et al. (2020)), only in the Cooperating mode, can we find the human and robot agents working side by side on the same task without physical or temporal separation.

Organizational structures settle the responsibility, the leeway, and the participation in the decision-making of the operators (Carayon (2021)). These parameters deeply influence the feeling of belonging of the operators, hence their engagement and consequently limiting the turnover which has many downsides to the performance such as decreasing the productivity and exploding the costs of production. Such factors are known to influence the motivation factors described by Herzberg in his two-factor model and even in the pyramid of needs of Maslow (ElKosantini (2015)).

The performance of the manufacturing work cell is linked to the social ties and interactions between the human collaborators. For instance, the behavior of a human and his decision to collaborate with the team to achieve the goals isn't always a logical process. It should be clearly expressed in new models of HMI that the perception of machines, colleagues and superiors is a complex process and will be the basis of either collaboration or conflict in the team. Other factors such as friendship bonds can have a double effect by increasing productivity or creating an atmosphere of loafing (ElKosantini (2015)).

Nevertheless, the social dynamics in the collaborative cell is in no way only limited to the ties with other humans. The adoption of machines in the workplace is accompanied by a lot of social challenges. Such implementations are challenged by the human perception of the technology used, namely their trust (Moniz and Krings (2016), Sgarbossa et al. (2020)). In a hybrid workstation, other factors have a major role on the social dynamics like action and intention recognition between humans and robots and the number of social cues used by the cobots to name a few (Moniz and Krings (2016)).

4.2. Discussion

The model shows that the traditional risk assessment and physical aspects of the strain of the operators are extensively simulated and studied in the literature (Farid and Neumann (2019), El Mouayni (2020), Petronijevic et al. (2023)), although they are still not always included in the design of workstations. At the same time, the mental wellbeing of the operators remains understudied.

The relationship between the use of assistive technologies and team behavior, subsequently influencing the collective performance of the team within the work cell, and its effect on the psychosocial state of the operator is still under-represented in the conceptual model, due to the low number of articles studying the matter (Panagou et al. (2023)). In addition, to remedy behavioral issues, organizational practices should be further considered in future research (Donohue et al. (2020)).

These gaps are probably due to the lack of attention paid to phantom profits in industry. As a matter of fact, for the implementation of Industry 4.0's technologies a great importance is given to the profits made from the improvement of the system performance and the decrease of secondary costs like injuries which lead to absenteeism. Nevertheless, designers should account for other Human Factors which will help predict the real investment costs in assistive technologies. Therefore, this area could benefit greatly from multidisciplinary research emphasizing simultaneously on the integration of individualized solutions, mental as well as physical wellbeing, and operational performance.

5. LIMITATIONS

The current review has been limited by the adopted perspective which is the integration of the cognitive and organizational factors. If the same conceptual model was to be developed to help synthesize the knowledge acquired to integrate the pure cognitive factors like the mental load, the motor response, or the decision-making processes, other relationships would have been identified which have impacted the outcome of the model. In that case for example, the model would have shown the effect of Perception on Motor Response and the influence of both Long-Term and Working Memory on the Information Processing Model.

Another limitation is the focus on Human-Robot Collaboration which is due to the research program's aim of integrating cognitive and organizational factors in collaborative scenarios specifically including cobots. While the factors and variables are relevant to study the human-centered environment in general, the examples primarily focus on cobots. In fact, the future step of this work is to propose an operational model of the production system based on the conceptual model discussed in this paper. It will be tested in a laboratorial environment where the variable sets will be used to assess the relations between different factors in the manufacturing environment. The purpose is to provide empirical evidence on the potential design of collaborative cells.

6. CONCLUSION

The successful adoption of Industry 4.0's technologies in the manufacturing environment calls for a human centered design. The aim of this work is to characterize the relationship between cognitive and organizational factors by developing a conceptual model adjusted to be like a class diagram. Based on the literature review, factors and variables influencing the wellbeing of the operators in their workplace were identified, and the relationship between them was defined.

Several points on the factors influencing the quality of the human work were discussed. The integration of the individual characteristics of the operators such as age and gender to handle the increasing diversity in the workshop is a must. It was also brought to light the importance of orienting future research towards the human factors for the mental wellbeing as much as the physical one and linking them with the operational performance for a better adoption in the industry. The proposed model serves as the basis for an operational model to guide designers in the process of making workplaces more human centric. It is as well an important step for the researchers of the community wishing to locate their work in the area. A part of the work that can be done in the future to improve the conceptual model is to integrate in the diagram, the uncertainties of certain variables and to translate a part of this static model into an operative and dynamic one.

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