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FOREWORD

Twin transformation aims at synergetic interaction and mutual reinforcement of the digital and sustainable transformation of manufacturing enterprises and associated value-added chains. This introduces several challenges and opportunities for cross- and interdisciplinary research on establishing sustainable, smart, resilient and human-centered manufacturing and supply chain of the future.

Information Control Problems in Manufacturing (INCOM) is a triennial symposium organized by the International Federation on Automatic Control (IFAC). The IFAC Coordinating Committee on Cyber-Physical Manufacturing Enterprises (CC 5) sponsors INCOM, which equally involves Technical Committees on Manufacturing Plant Control (TC 5.1), Management and Control in Manufacturing and Logistics (TC 5.2), Integration and Interoperability of Enterprise Systems (TC 5.3), and Large Scale Complex Systems (TC 5.4).

Technische Universität Wien (TU Wien) and Fraunhofer Austria are delighted to organize the 18th edition of INCOM in Vienna, Austria in August 28-30, 2024. Hosted by the Austrian Federal Economic Chamber (WKÖ), INCOM 2024 has provided a great forum and unique opportunity for exchanging knowledge and discussing theoretical advances, emerging topics and industrial experiences under the **flagship** topic of "**sustainable transformation towards autonomous manufacturing systems**".

Academic and industrial experts joined the event and shared their research results and empirical insights focusing among others on: digital twin, green factories and logistic networks, federated manufacturing platforms, virtualization, global manufacturing, autonomous and self-learnable systems, data-driven industrial engineering, Industry 4.0/5.0's strategies, models, and technologies, human interaction in robotics and cyber-physical systems as well as new advances in additive manufacturing, Physical internet, predictive maintenance, robotics and conversational AI applications in manufacturing and supply chain. At INCOM 2024, five outstanding keynote talks were delivered:

- Prof. Torbjørn H. Netland, ETH Zürich, Switzerland, "Augmented Intelligence for Next-Level Manufacturing Excellence"
- Prof. Dmitry Ivanov, Berlin School of Economics and Law, Germany, "The Future of Supply Chain Simulation and Digital Twins"
- Prof. Alexandre Dolgui, IMT Atlantique, France, "Information Control Problems in Manufacturing: History of IFAC INCOM Symposium"
- Prof. Andreas Kugi, TU Wien and AIT Austrian Institute of Technology, Austria, "Advanced Control for Sustainable Autonomous Manufacturing"
- Caroline Viarouge, EIT Manufacturing, France, "How European Manufacturing is shaping our Greener and Digital Future?"

INCOM 2024 intended to foster synergies among all participants and establish dialogues. To this end, two panels have been organized. The first panel focused on "Smart and Sustainable Manufacturing", with participation of academic experts from IFAC community, and also industrial experts from UNIDO, Infineon Technologies Austria, and EIT Manufacturing. The second panel was dedicated to CC5 involving TC chairs, where the discussion focused on "Resilient, Digital and Sustainable Manufacturing and Supply Chain". Offering a Doctoral Workshop on "Advances in Manufacturing and Logistics Management and Control Problems" as a pre-conference event on August 27, 2024, INCOM 2024 also highly acknowledged the value of next generation scientists and industrial experts. This is also reinforced by delivering Young Author Awards and Best Paper Awards.

To sum up, 360 submissions were reviewed, out of which 218 were accepted and presented at the symposium (acceptance rate: 60.5%). The paper were presented from 39 nations in front of the audience of 340 people. The conference received 42 session proposals, out of which 28 proposals with at least five accepted papers have been appeared on the symposium program. Further, the Doctoral Workshop involved 31 PhD candidates presenting their research proposals and progress to 10 senior advisors.

The current proceeding stores all the papers presented during the INCOM 2024 symposium, representing the current trends and evolution in twin transformation of manufacturing and supply chain. The INCOM 2024's editors would like to acknowledge the efforts of all contributors, namely authors, reviewers, technical associate editors, session organizers and chairs, as well as all IPC and NOC members. During the review process and planning the symposium program, we have been committed and humbly put efforts to assure scientific quality and significant contributions of the IFAC community to the body of knowledge in manufacturing and supply chain.

We, on behalf of all contributors of INCOM 2024, sincerely hope that the present proceedings inspires you on creating, sharing and implementing new ideas towards shaping manufacturing and supply chain of the future. We wish you a pleasant reading.

Vienna, August 2024

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INCOM 2024's Editor and NOC Co-Chair

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Human Factors in Healthcare operations: A Case Study in Italian Emergency Rooms

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Abstract: Human factors (HFs) play a crucial role in healthcare operations, influencing care quality and operators' well-being. This paper focuses on comprehending the relationships between HFs in healthcare processes and operations and their impact on the quality of care and workers' well-being in the emergency room (ER), one of the hospital's most critical and high-pressure departments. A literature review was conducted to identify relevant HFs in the healthcare sector. The analysis also includes a review of ER key performance indicators (KPIs) to determine how well they reflect the importance of HFs. The relationships within and among them are examined, and a causal loop diagram model is created to underline these relationships. The diagram provides a valuable tool for understanding and improving ER operations. It can be used to identify potential interventions that address the root causes of HFs issues, leading to improved quality of care, increased worker well-being, and enhanced efficiency. Future research should focus on validating the causal loop diagram and developing KPIs that specifically reflect worker well-being and support decision-making processes.

Keywords: Human factors, Healthcare 5.0, Emergency room, Healthcare Operators, System Thinking

1. INTRODUCTION

Doctors' and nurses' roles have received much attention in recent years, particularly in the aftermath of the COVID-19 outbreak, when health personnel was forced to work under extreme conditions, with exhausting shifts and, in many cases, without the necessary protective equipment. The working conditions of health personnel were already critical before the pandemic and this condition has exacerbated the situation. Some estimates portray that after the pandemic period, two out of five nurses are considering leaving their jobs due to burnout (Mayes et al., 2023). The situation is even more critical in emergency medicine, being the ward in which the shifts are more intense, more stressful, more at risk of having legal problems and an even higher probability of being assaulted by patients. Consequently, in the US, the proportion of medical students seeking emergency medicine residencies fell by 16.8% from 2021 to 2022 and 18.1% from 2022 to 2023. This sudden reduction may impact how the healthcare system offers emergency treatment in the future (NRMP, 2023). However, the situation is already severe, with most of the emergency services operating understaffed. According to the Italian Society of Emergency Medicine, 4,200 physicians are missing from emergency services, and 600 doctors have resigned in six months, between January and July 2022 (Simeu, 2022). To determine the areas in which interventions are most needed, it is crucial to consider the reasons for these criticalities. Besides legislative and policy issues, the emphasis is on workers' cognitive and physical well-being. To address these issues, the discipline of Human Factors (HFs) must be considered. The principles of HFs focus on understanding the interaction between humans and other system elements, which, combined with environmental analysis, aids in designing products, processes, and systems that improve safety, efficiency, and quality (Lagorio et al., 2021). HFs discipline is based on the fact that human behaviour is sensitive to organisational and cultural contexts and rejects the idea that humans are primarily at fault when making errors, postulating that the responsibility for errors occurrence is preferable to a system that is not well-designed (Cafazzo & St-Cyr, 2012). Given the wide presence of personnel, HFs play a crucial role in healthcare operations, influencing care quality and patient safety. Understanding the relationships between these factors is essential for evaluating the central point of care considering patients' and workers' mental and physical health (Piffari et al., 2022). This understanding is crucial for enhancing patient care and overall healthcare outcomes. Despite advancements in understanding HFs in healthcare sector, a significant gap remains. This paper focuses on understanding the relationships between HFs in healthcare processes and operations and their impact on care quality and workers well-being, specifically within the emergency room (ER), one of the hospital's most critical and high-pressure departments. The analysis also includes a review of ER key performance indicators (KPIs) to determine how well they reflect the importance of HFs. To do so, a System Thinking model is created as a tool to underline these relationships, potentially useful when defining new healthcare processes or improving the existing ones, and implementing preventive measures about workers' health. Using a System Thinking approach, the healthcare sector will benefit from opportunities to reform the care delivery system by reducing unnecessary complexities and unexplained practice variations. The result of the approach is not only to identify a set of cause-effect relationships, but the ultimate objective is to build a safe environment where all the stakeholders can discover the

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hidden consequences of their collective actions that could support more effective decision-making processes.

2. METHODOLOGY

This paper is structured around three central points: i) the literature review regarding the HFs in the healthcare sector, ii) the literature review regarding the ER KPIs, and iii) the development of the System Thinking model. The research method is represented in Figure 1. The first steps (discussed in Section 3) concerned the literature review, performed to clarify the problem's key components, and provide the background for developing the subsequent steps. The literature review led to the identification of HFs already analysed in healthcare environments (to gather more information, we decided to look for HFs in healthcare rather than in the ER) and the KPIs necessary to evaluate the general performances of the ER. Following these analyses, each item is categorised and rearranged, and the relationships within and among them are examined (Section 4). These relationships enable the further creation of a System Thinking model, specifically a Causal Loop Diagram (CLD) (Section 5), using the software Vensim. System Thinking is a problem-solving approach that emphasises the interactions between different parts of a system (Sterman, 2000). The developed model depicts all the relevant HFs and KPIs and the underlying relationships and loops that will emerge and require special attention. Loops show the causal links among variables with arrows denoting the causal influences among them. They can be reinforcing or balancing. Reinforcing loops represent a situation where an increase in one element leads to a subsequent increase in the same element, creating a self-reinforcing cycle. On the other hand, balancing loops depict a scenario where changes in one element trigger adjustments in the opposite direction, maintaining equilibrium within the system (Sterman, 2000).

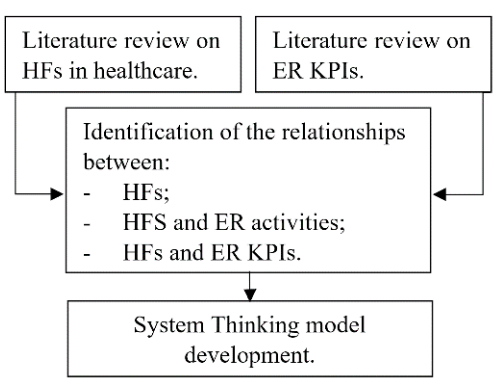

Figure 1. Research flow.

3. LITERATURE REVIEW

This section reports the literature review results. Section 3.1 provides a brief description of a generic process within the ER, as a preliminary step to understanding which HFs are relevant and the optimal KPIs for measuring performance. The steps described refer to an Italian ER. Section 3.2 describes the most relevant HFs within the ER and provides a classification. Section 3.3 describes the KPIs used to measure the performance of the ER.

3.1 Emergency room processes

ER is the healthcare system's most significant patient first contact point. It specialises in emergency medicine, offering treatments to address illness and injuries. The main workers involved are nurses and physicians, but administrative staff is also important in managing the waiting patients and their activities. Nurses mainly have the role of conducting the triage while physicians oversee the patients' visit and diagnosis. Nurses could also help in these steps.

The process starts when a patient arrives at the ER. The first thing that happens is the registration and the triage, where a code is given to each patient based on the severity of the emergency. After the triage, a visit with the doctor follows, where the patient is examined in more detail. During the visit, more specific exams may be needed. The possible outputs of the visit are hospitalisation, discharge, treatment, or prescription of additional exams. It is important to note that a waiting time is present between each step, and some bottlenecks could be present, making everything slower and inefficient. ER are often subject to overcrowding problems that increase waiting times and are often associated with increased morbidity and mortality, medical errors, and increased cost (Plunkett et al., 2011). These factors also affect healthcare personnel, worsening the quality of work and increasing burnout and drop in performance (Savioli et al., 2022).

3.2 *Human factors in healthcare operations*

HFs are commonly classified into three domains: physical, cognitive, and organisational (IEA, 2019). The first includes all structural factors related to how the human body interacts with work design and physical activities. The cognitive domain refers to how individuals' mental processes interact with other system elements. The organisational domain focuses on how individuals and teams interact with each other and the system. Based on this classification, the HFs belonging to the healthcare sector found in different studies have been collected. To simplify the understanding of the most relevant HFs, we grouped all HFs into six macro-categories (Table 1). Indeed, HFs are not independent of each other; many of them are interrelated and influenced by other HFs. Among these categories, burnout and workload stand out for the number of citations in the literature. Burnout is defined as a pathological syndrome that develops in response to prolonged occupational stress (Brown et al., 2009). The prevalence of occupational burnout among physicians nearly twice the rate of the general US working population (Han et al., 2019). Physician burnout is significant because it negatively impacts patient care, physicians' health, and the healthcare system costs (West et al., 2018). Workload is an organisational HF, defined in terms of staffing ratios (i.e., number of patients per number of nurses available) (Holden et al., 2011). The prominence of burnout and workload can be explained by the fact that they can be considered as *umbrella terms*, since numerous psychological and non-psychological factors influence their occurrence.

Reviewing literature, it is possible to state that burnout is the most influenceable category, as every other HF might impact workers' mental health, ultimately contributing to burnout. Burnout, in turn, can contribute to prolonged fatigue. Excessive workload and musculoskeletal pain can cause prolonged fatigue, as excessive work combined with pain can lead to exhaustion.

Table 1. Healthcare HFs

Domain	Human factors' category	Human factors	Reference
Physical	Musculo-skeletal pain	Lift heavy loads; Work in awkward positions.	(Gray-Toft & Anderson, 1981; van der Doef & Maes, 1999; Brown et al., 2009; Elder et al., 2020; Piffari et al., 2022)
	Prolonged fatigue	Sleep deprivation; Long working hours; Night/weekend call duties	
	Layout	Old equipment/machinery; Lack of equipment; Lack of adequate light; Noisy workplace; Risk of accidents; Lack of personal protective devices	
Organisational	Excessive workload	Time pressure; Overcrowding; Bureaucratical duties; Lack of human resources (understaffing); Lack of adequate ICT competence and training	(Gray-Toft & Anderson, 1981; Brown et al., 2009; West et al., 2018; Elder et al., 2020; Piffari et al., 2022)
	Inefficient teamwork	Negative leadership; Conflicts with other operators; Poor learning environment; Lack of communication-coordination	
Cognitive	Burnout and depression	Lack of support from family and colleagues; Taking life-prioritising decisions; Being exposed to critically ill patients and medical catastrophes; Depersonalisation and emotional exhaustion; Uncertainty about future career options; Sense of low personal accomplishment; Feeling inadequately prepared	(Maslach & Jackson, 1981; Gray-Toft & Anderson, 1981; van der Doef & Maes, 1999; Brown et al., 2009; West et al., 2018; Trbovich, 2014; Elder et al., 2020; Piffari et al., 2022)

3.3 Emergency room key performance indicators

HFs influence workers' well-being and consequently the overall efficiency and efficacy of the hospital and the ER. However, there is a lack of understanding of the direct and indirect impacts of HFs on ER efficiency and efficacy. Hospitals and ERs often use KPIs to measure the wards' performances over a predefined period. Using them to track and maintain ER performance within optimal ranges is standard practice. While numerous KPIs are described in the literature, we selected and reported the most important ones that can be easily connected to the HFs. Specifically, we focused on waiting times and patient numbers, as they are affected by various categories of HFs and are visible indicators of an inefficient system. The KPIs selected are *i*) Average daily ER visits; *ii*) Length of Stay (LOS); *iii*) Average arrival-to-triage time; *iv*) Average triage-to-doctor time; *v*) Average door-to-doctor time; *vi*) Percentage of ER patients with LOS higher than 6 hours; *vii*) Percentage of leaving without being seen (Khalifa & Zabani, 2016). These KPIs allow us to measure each step of the patient's journey through the ER and identify where bottlenecks occur. However, understanding the underlying factors behind each value is challenging, as the causes of KPI variations are not always straightforward. For instance, the average daily visits are influenced by the availability of physicians and nurses, required equipment, complications, and workers' exhaustion. Furthermore, none of the existing KPIs directly reflects the operators' behaviour. The great majority of KPIs reflect the waiting periods that patients must face or the output of the ER. The operators' efficiency could be measured only indirectly. HFs influence the value of each KPI. These relationships will be further analysed in the following section.

4. RELATIONSHIPS

4.1 Human factors and emergency room activities

The ultimate purpose of this study is to determine where to intervene with preventive and/or corrective measures to improve the healthcare personnel working conditions and quality of care towards patients. To accomplish this, it is vital to comprehend the relationships between the HFs and the activities performed in the ER, that in turns, enables the identification of relationships between HFs and KPIs. As discussed, prolonged fatigue and burnout can influence each activity of the ER processes described in Section 3.1. They influence the mental health of individuals, causing a reduction of interest and motivation, and a general slowdown in completing activities. The slowdown is a minor inconvenience, but it can also cause errors in the prescription of exams, the final diagnosis, and the therapy. Concerning the first step, the triage, the layout influences it. Having waiting rooms and visiting rooms far away from each other and far from the entrance can cause useless movement inside the hospital with associated risks. For the same reason, the layout also influences the exam step. The position of some machineries or, even worse, the lack of them and the need for more alternative exams can cause delayed diagnosis. Musculoskeletal pain is joint among nurses and doctors, and it can cause a slowdown in examinations or the need for more people to perform an exam. Teamwork can influence the treatment administration. Once the diagnosis has been defined, there must be a dialogue between the doctor who made it and the nurses/other doctors who must perform the therapy. Also, coordination among different workers could be needed.

4.2 Human factors and key performance indicators

The found KPIs do not directly reflect the operators' performance or a single HF. Consequently, it is important to understand the link between the KPIs and the HFs to proceed with the analysis and the model. Although there is no direct correlation, certain KPIs indirectly indicate the influence of HFs. The following relations were formulated deductively by jointly analysing the process, KPIs, HFs and their relationships. Therefore, future research must concentrate on validating them. All HFs influence LOS and average daily visits; physical, cognitive, and organisational problems can slow down the activities carried out by doctors and nurses, resulting in an increase in LOS and a decrease in daily visits. For example, doctors experiencing burnout may be less motivated to complete tasks and less attentive to patients, leading to the need for more breaks between patients. From a physical perspective, musculoskeletal pain can slow down doctors' activities. Additionally, an inefficient layout can cause unnecessary movement for doctors and patients. Waiting time is another KPI impacted by the healthcare HFs, significantly workload and layout. If doctors are overloaded with patient visits and complementary duties, the time between activities increase. Similarly, if doctors are provided with outdated equipment that does not function properly, appointments will take longer, resulting in higher waiting times. It is important to note that the chosen KPIs are not independent of each other; they influence one another. For example, having many patients may lead to longer waiting times if the demand is not met promptly, increasing LOS. Consequently, there is an increase in the percentage of patients leaving without being seen or experiencing excessively long LOS. At the same time, long waiting times can decrease the number of daily visits.

5. CAUSAL LOOP DIAGRAM

Lots of relationships have been highlighted between HFs' categories and HFs, between HFs and ER activities, and between HF and ER KPIs. These relationships have been formalised in the System Thinking model, simplifying their interpretation and understanding. This model also identifies explanatory loops of causal relationships between the different factors represented (Section 5.1). The HFs are represented as plain labels (i.e., rectangles without borders) in the diagram. Most HFs only affect the specific HFs category into which they are classified (Table 1). The blue arrows depict the relationships between HFs, their corresponding HFs category, and the relationships between different categories. These relationships were already summarised partially in Section 3.2. However, some HFs influence other HFs within the same or different categories, represented with the pink arrows. For instance, in the burnout class, feeling insufficiently trained for certain tasks leads to uncertainty about personal accomplishment. Similarly, dissatisfaction with the chosen career arises from working without long-term contracts or in environments with limited growth opportunities. Sleep deprivation is influenced by long working hours and night or weekend call duties during prolonged fatigue. With excessive workloads, a lack of human resources leads to overcrowding and increasing time pressure. Finally, the risk of accidents and infections is influenced by inadequate lighting, which is fundamental when reading prescriptions and performing treatments and exams. The risk of accidents is also influenced by prolonged fatigue, as it impairs concentration, and by excessive workload, which hinders the ability to maintain the same level of attention and concentration.

HFs are represented within dotted rectangles. Among them, burnout is the most influenceable. All classes of HFs can independently influence burnout, regardless of the worker's role. Prolonged fatigue can result in burnout from a cognitive standpoint. Musculoskeletal pain can impact decisions and burnout because tasks may be too challenging to execute properly, resulting in ongoing pain and a perception of inefficiency. The physical influence also includes the layout in terms of work difficulty and frustration. An optimised spatial layout makes work easier and less frustrating, allowing workers to move quickly within the ER. Increasing the level of safety also gives workers more freedom to carry out their regular duties. In terms of organisational HFs, excessive workload, and inefficient teamwork negatively influence burnout. A difficult working relationship with colleagues and supervisors makes the days mentally less bearable. Prolonged fatigue is linked to burnout, excessive workload, and musculoskeletal pain, all with positive polarity. Excessive workload stems from spatial comfort and inefficient teamwork. Inadequate or malfunctioning equipment can lead to redundant procedures, prolong examination times, and exacerbate workload burdens. Conversely, enhancing these factors consistently reduces workload strain. Moreover, inefficient teamwork can result in duplicated tasks and increased exertion to match pace with colleagues. Musculoskeletal pain is influenced by three key factors – prolonged fatigue, excessive workload, and spatial comfort. Prolonged fatigue increases susceptibility to injuries and general discomfort due to muscle weakness and reduced resilience. Excessive workload reduces the body's ability to resist pressure, increasing the risk of pain. Conversely, improving spatial comfort mitigates musculoskeletal pain by providing ergonomic support for the body's natural posture and movements. Regarding inefficient teamwork, burnout and excessive workload are the two influencing factors. Burnout impairs mental function, leading to difficulties in maintaining social interactions. Excessive workload, characterised by many tasks, can significantly hinder coordination, organisation, and overall team efficiency. Regarding layout, an improvement in spatial comfort leads to a safer environment. The other HFs do not influence the layout because they include ER structural elements not impacted by human activity.

Dashed rectangles represent KPIs, and green arrows depict the relationships between HFs and KPIs. The KPIs measure different stages of the ER process and, except for the "percentage of leaving without being seen", all of them can impact the LOS. LOS is determined by the time required for a patient's visit and admission or discharge. For the sake of simplicity, the time KPI described in Section 3.3 (average arrival-to-triage time, average triage-to-doctor time, and average door-to-doctor time) have been summarised in a single KPI named "overall processing time". Long processing times increase the likelihood of being unable to visit all patients in need. Three KPIs are connected to the HFs previously described.

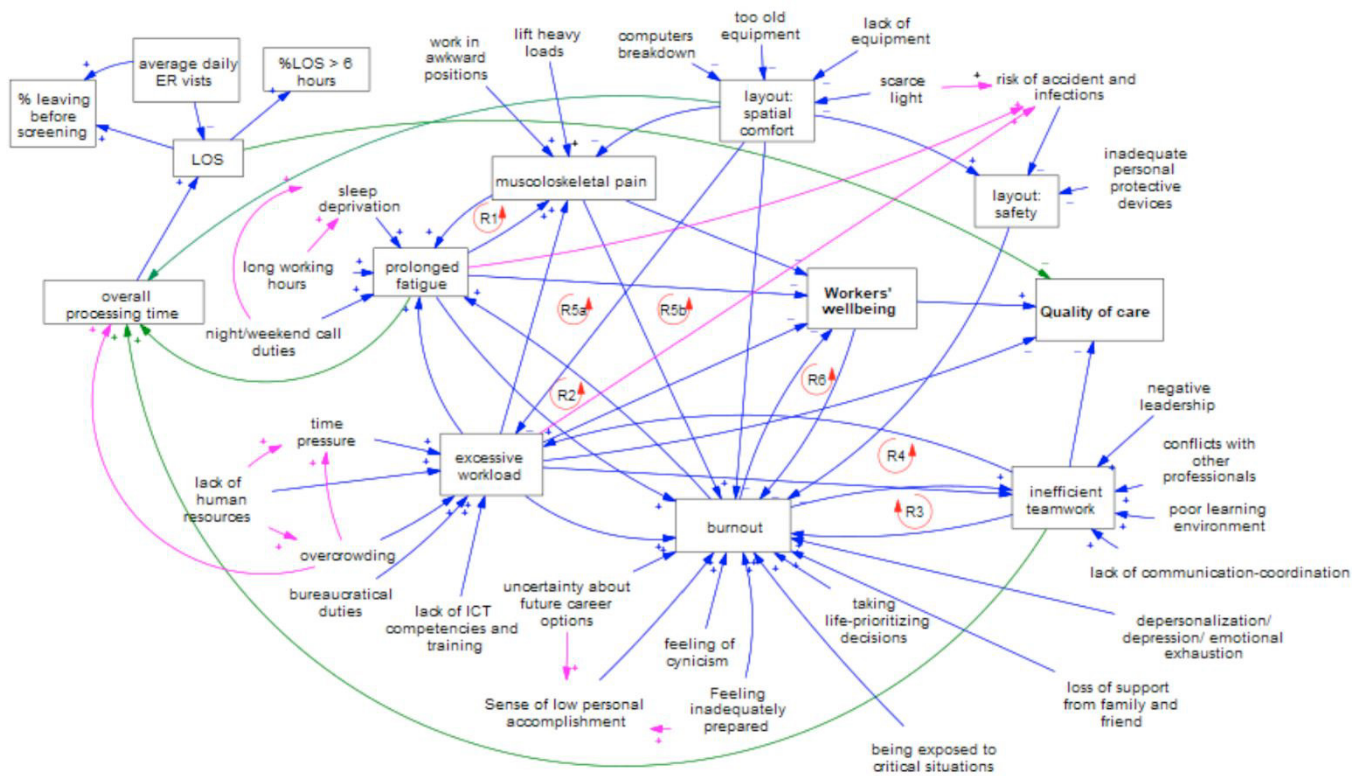

Figure 2. Causal loop diagram.

Inefficient teamwork can lead to longer processing time, thus increasing the LOS. Spatial comfort and prolonged fatigue increase processing time. This is because problems with spatial comfort (e.g., missing or obsolete equipment) can lead to more extended visits. Prolonged fatigue also influences processing times, primarily due to workload, burnout, and musculoskeletal pain, which can slow down doctors' and nurses' ability to work and increase the time needed for triage and visits. The central points of the model are workers' well-being and quality of care. Workers' well-being includes both physical and psychological well-being, while quality of care includes both quality intended as an outcome for the patient and quality as medical services offered by the hospital. Workers' well-being and quality of care are bolded in the CLD. Indeed, once the possible relationships between HFs and KPIs have been analysed, we can focus on the two most critical central points. Four main factors influence workers' well-being and quality of care. Workers' well-being is negatively linked to musculoskeletal pain, prolonged fatigue, excessive workload, and burnout. As previously mentioned, well-being encompasses both physical and psychological aspects. Physically, it is influenced by the physical pain workers experience and the lack of sleep. Psychologically, burnout plays a significant role. It is important to note that ER KPIs have no association with this outcome. The quality of care is multifaceted, influenced by a combination of factors, including LOS, workers' well-being, excessive workload, and inefficient teamwork. LOS can negatively influence the quality of care, precisely the service quality. Prolonged waiting reflects process inefficiency and results in a worse perception of the patient's overall care. Workers' well-being is paramount as they are the primary providers of care. When workers experience compromised mental and physical health, their ability to deliver optimal care is significantly impaired. The negative effects of excessive workload and inefficient teamwork further exacerbate this detrimental impact on workers' well-being. Excessive workload strains workers' physical and mental health, restricting the time they can dedicate to each patient. Reduced attention and care can decrease patient satisfaction and potentially adverse health outcomes. Inefficient teamwork hinders communication and coordination among healthcare professionals, increasing the likelihood of errors and patient dissatisfaction.

5.1 Causal loops

In the model, seven reinforcing loops are present. The first loop (R1) is between prolonged fatigue and musculoskeletal pain. Physical pain or tiredness makes the completeness of tasks more tiring and more physically difficult, leading to fatigue. Prolonged fatigue, in turn, can cause musculoskeletal pain. It is a reinforcing loop because the increase of the first leads to the increase of the second and vice versa. In loop R2, burnout can significantly impact an individual's ability to perform daily tasks, leading to increased fatigue and reduced productivity. Fatigue can further exacerbate mental health issues, potentially causing more severe burnout episodes. R3 is a reinforcing loop highlighting that burnout leads to difficulty in social interactions. At the same time, working in a bad environment harms mental health. R4 shows the relation between excessive workload and inefficient teamwork. An excessive amount of work can lead to difficulties in coordinating the team, and, in turn, inefficient teamwork could cause errors and a repetition of tasks. Two critical loops are R5a and R5b. The first includes burnout, prolonged fatigue, and workers' well-being. The second includes also musculoskeletal pain along with the other three. The first could be considered a cognitive reinforcing loop, while the second has a physical meaning. Fatigue, caused by burnout, can take the form of cognitive fatigue, directly influencing workers' mental well-being. Fatigue can also be understood in a physical sense that can result in musculoskeletal pain and reduce physical well-being. For these reasons, they are considered under the same loop of R5 but have two different connotations. Finally, R6 is a reinforcing cycle that links employee well-being and burnout: if burnout increases, well-being decreases, which causes burnout to increase even more. This damaging reinforcement can only be stopped by applying external corrective measures. For example, managers can mitigate burnout and fatigue by fostering a positive work environment and promoting effective workload management strategies. Implementing ergonomic practices and offering support for mental health can also contribute to reducing musculoskeletal pain and improving overall employee well-being.

6. CONCLUSIONS

This research provided an extensive analysis of HF relationships in the healthcare sector. It aimed to fill the gap in the literature by understanding how different HFs can impact the quality of care and the well-being of workers. From a theoretical perspective, creating the CLD makes it possible to intuitively understand these complex relationships, while managerial implications of this study concern the identification of the main HFs affecting performances, that is useful to set strategies for improving ER processes. The main limitations are related to the lack of relevant literatures on HF in healthcare. The literature is rather scarce and there are no papers relating ER performance to HFs. Consequently, the creation of the CLD is only an initial stage of research that needs validation. Future research should validate this model and the proposed relationships through the implementation of questionnaires or interviews. The research should explore how certain HFs affect operators differently depending on their roles. In this regard it is essential to propose KPIs that reflect worker well-being, as this topic is currently under-explored and could provide a support in decision-making processes concerning the workforce involved in healthcare operations activities.

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