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Human Model For Industrial System And Product Design In Industry 5.0: A Case Study

Arnaud Allemang--Trivalle[a,b,c], Jérémie Donjat[a,b], Gaëlic Bechu[a,b], Gilles Coppin[a,b], Oliver W. Klaproth[d], Andreas Mitschke[d], Arnd Schirrmann[d], Mathieu Chollet[e,f], and Caroline G. L. Cao[a,b,g]

[a] Department of Computer Science, IMT Atlantique, France
[b] Lab-STICC, UMR CNRS, France
[c] Haptic Intelligence Department, Max Planck Institute for Intelligent Systems, Stuttgart, Germany
[d] Airbus Central R&T, Hamburg, Germany
[e] LS2N-CNRS, France
[f] School of Computing Science, University of Glasgow, Glasgow, United Kingdom
[g] Future Industries Institute, University of South Australia, Australia

Abstract

Human performance models can be included in industrial system models to improve the design of the industrial system, manufacturing processes, and product design. In our use case, a critical process in the production of a new airplane was being considered for automation. This process requires the highest quality assurance and is normally performed manually. Robot assistance could improve quality and efficiency. A human performance model focused on worker fatigue was developed, taking into account characteristics of the workers, robots, and tasks. Two different automation scenarios (fully manual, semi-automated), with different worker characteristics such as skill, age, motivation, etc. were studied. Using historical production line data in the fully manual scenario, and simulated data for the semi-automated scenario, global fatigue scores and graphical visualization were generated by the model for each scenario, allowing the system architects to understand the effects of the future production system on workers, including errors, time lost, costs and overall resilience of the system.

Keywords
Industry 5.0, Production and manufacturing, Simulation model, Worker fatigue

1. Introduction

In the current digital transformation, also known as Industry 4.0, automation, artificial intelligence, and the internet of things are promising higher product quality, system efficiency and safety. Major efforts are being devoted to developing industrial system models to improve the design of manufacturing processes, products, etc. However, workers have largely been neglected in the process, leading to suboptimal outcomes in the smart factory. In contrast, Industry 5.0 focuses on workers' wellbeing, envisioning a positive symbiosis between workers and technological augmentation in future smart factories. This is of particular importance to the aviation industry, such as at Airbus, where manufacturing processes still rely to a large extent on manual labor and processes. Thus, we demonstrated that consideration of human performance can aid in the selection of new industrial system designs at Airbus.

2. Approach

Human performance models needed to be developed and integrated with system models that allow simulation and comparison of alternative industrial design concepts, such as when choosing the right level of automation for production lines. It was assumed that the performance of industrial systems depends on the workforce. For example, a workforce with high turn-over and little training would not be suited for a factory with high degrees of automation requiring highly specialized skills. In this case study, we modelled worker fatigue resulting from workload experienced when performing the Orbital Joint Assembly Task. Parameters that impact worker fatigue are the workers themselves (e.g., age, gender, experience), the task (e.g., complexity, number of repetitions, weight of the tools), or the environmental (e.g., noise, light). To simplify the modelling effort, we selected three parameters: age, skill level, and motivation of the workers, based on a modified version of Jaber et al.'s general fatigue model [1]. Our framework was designed in a flexible way that makes it easy to add more parameters, formulas and adapt it to different scenarios in the future. Based on interviews with subject matter experts at the Airbus plant, we modelled the workers and determined different levels of task demands, expertise of workers (superworker, average worker, basic worker), and automation (manual, semi-automated) as inputs to the model. An interactive visualization tool was also designed to facilitate the understanding of worker fatigue and to provide insights on how to minimize worker fatigue by manipulating the input parameters and weights. Error probability due to fatigue can also be visualized.

3. Results

Our model was used to simulate two scenarios: 1) Fully manual assembly line, and 2) Semi-automated assembly line. The task was decomposed into 240 subtasks performed by 5 teams of 4 workers, all working simultaneously, over a 7-hour shift. For the simulation of the fully manual scenario, the workforce was composed of a mix of super workers, basic workers, and average workers in various combinations in each team. This was to demonstrate the effect of low-skill teams versus high-skill teams. Figure 1 shows the development of worker fatigue over each shift, with super workers tiring more slowly than average workers and basic workers. Breaks during shift are represented by "white spaces". In the semi-automated scenario, robots were added to the model, changing the team compositions and fatigue effects on workers and production line performance.

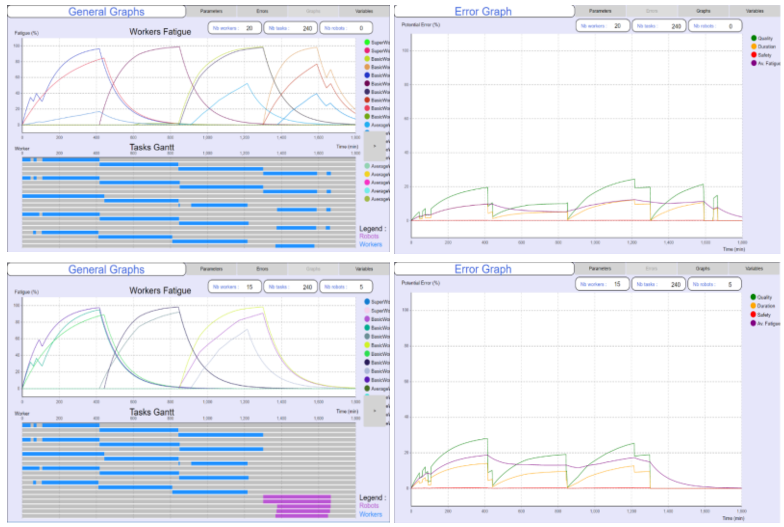

Figure 1: Simulation results from the fully manual scenario (top) and semi-automated scenario (bottom).

4. Discussion

In the simulations, the model was sensitive to changes in type of workers, team composition, and task demands. The amount of fatigue computed per worker was positively correlated with task difficulty. Moreover, the correlation between the average fatigue among workers and the impact on the probability that an error occurs which in turn impacts the quality, duration, or safety supports the insights derived from expert interviews. Even though the scenarios were for demonstration purposes only, comparing the fully manual and semi-automated assembly lines revealed an overall decrease in fatigue for the workers when robots are integrated into the process. This leads to a reduction in error probability. What this use case did not address are cognitive fatigue due to the need to monitor the robots during operation, and accidents due to working in close proximity with the robots, and the effects of boredom of lack of engagement when robots take over workers' tasks, etc. Furthermore, fatigue is not the only human performance aspect to consider and integrating robots in the industrial design may alter other variables of interest, such as worker engagement, sense of autonomy, trust and wellbeing. Therefore, more work is needed to provide system architects with adequate and appropriate human performance models to worker wellbeing in Industry 5.0.

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