Transdisciplinary Engineering: A Paradigm Shift
C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-349

An Ergonomics Study on Manual Assembly Process Re-Design in Manufacturing Firms

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Abstract. Nevertheless process automation is a global trend, some specific phases (i.e., assembly) in highly technological sectors (i.e., medical, pharmaceutical, diagnostics, dental) are still managed by human workers, due to high-precision tasks and low production volumes. In this context, operators are forced to work faster and adapt to not ergonomically workstations and workflows. As a consequence, human assembly is frequently the bottleneck of the entire process due a not ergonomic layout and process design. The study was conducted at a medical equipment manufacturer, leader of dental equipment production, and focused on the analysis of the assembly process of the dental units. Workers at the assembly line were observed by experts and involved also by interviews and focus groups to detect the assembly issues and process jam. The research provides a valuable example of how physical, cognitive and organizational ergonomic problems affect the final process performance and how human-oriented re-design actions can be easily defined according to the proposed analysis procedure.

Keywords. Human Factors, Ergonomics, Assembly workstation design, Human-centred design, Design optimization.

Introduction

High competitive markets, time pressure and high productivity rates are pushing modern manufacturing industry to improve process automation and to squeeze production time. However, in manufacturing industry a lot of processes are still manual for different applications, especially when high precision tasks are required and the overall product volumes are low due to the frequent market changes or customized production. In these cases, the majority of assembly operations, cannot be automated, or their automation would be very expensive and not convenient. In this context, the design of the workspace in terms of layout and workstation has a significant impact on the workers efficiency, the overall product quality, and the workers' wellbeing as well [1]. Furthermore, the entire assembly process has to be conceived in order to fit the production demands, flexibility and easy configurability. Usually workers spend a lot of time performing repetitive operations, assuming uncomfortable postures and living stressful conditions. Furthermore, some tasks at assembly workstations require human workers to stand for a prolonged period of time to assemble the products or to check

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that product specifications are respected. In addition, any mistake during the development phase of an assembly system can cause further problems, related not only to the assembly systems but also to the workers' wellbeing [2].

Ergonomics plays an important role in workers' productivity and process efficiency. Indeed, workstation layout and work design are two major factors of ergonomics of worker's efficiency [3]. Low attention to human factors brings to unnatural positions and dangerous actions executed by workers during their task, with consequent lower performances, higher production time, greater absence from work, and a general increase of Musculoskeletal Disorders (MSDs) with a consequence impact on national economies, in Europe as well as in other countries [4]. Different methodologies have been proposed to analyse and classify assembly workplace layout configuration in relation to technological and environmental parameters, and the workstation design [5-7], and numerous studies about the discomfort and stress experienced by workers during the assembly process have been published in the last ten years, all around the world [8-9]. However, only few works have been published about the combination between the detected ergonomics problems and effective re-design guidelines. It is mainly due to the lack of practical and easy-to-use procedures to define the re-design actions.

In this work, an ergonomic study about the manual assembly line of a leader company in the dental sector is presented. The assembly process has been analysed by direct observation and interviews by involving the workers, and modelled by task analysis carried out by a team of ergonomic experts. Furthermore, the workplace has modelled by 3D modelling tools and the assembly tasks dissimulated by digital manufacturing tools, and different design solutions have been considered and assessed with virtual manikins. The study demonstrated how the proposed procedure could easily support the ergonomic re-design to avoid awkward postures, too high cognitive workload and organizational issues, to finally improve productivity and workers wellbeing.

1. The ergonomic analysis procedure

Ergonomic analysis for assembly processes is focused on the assessment of the effectiveness and the efficiency with which activities and tasks are carried out, related to both physical and cognitive workload [10]. The present study proposed a structure procedure to carry out the assessment of the assembly process as described in Figure 1. It starts from the investigation of the assembly lines in order to study the workplace layout, constraints and conditions. After that, it proceeds with the direct observation of real workers during their task execution and their involvement by interviews. Subsequently, task analysis is carried our by experts and the assembly process is modelled by 2D and 3D representations, using schemes and CAD models. On the basis of data collected, the ergonomic assessment is carried out for each task identified considering some of the international standards about physical and cognitive ergonomics. About physical assessment, the study considered the norms about the static working postures (ISO 11226) [11] and the dynamic actions, such as lifting and transportation of loads (ISO 11228-1) [12], towing and pushing actions (ISO 11228-2) [13], high frequency tasks (ISO 11228-3) [14]. Furthermore, the international directive on safety of machinery - ergonomic design principles (UNI EN 614) [15] has been adopted. As far as the cognitive assessment, human interaction is analysed by the

ICAO SHELL model (ICAO 216-AN31) [16], which represents the different components of human factors. The SHELL model is a conceptual model defined in aviation to understand the human factor relationships between aviation system resources, environment, and people [17]. Such a model analyses four entities: the "hardware" that refers to the materials and tangible objects like devices and supporting tools, the "software" refers to intangible items like norms, procedures, and constraints, the "environment" refers to external factors that cannot be changed by changing the design, and finally the so-called "liveware" that indicates the people involved. It is rarely used in manufacturing, ever for cause of an accident. However, the systems perspective considers a variety of contextual and task-related factors that interact with the human operator and has been found very useful to study interactions occurring during complex assembly tasks. Furthermore, the ISO 100075 [18] and the UNI EN 894 [19] standards about cognitive ergonomics are referred. For human virtual modelling, the ISO 7250-1[20] standard about the basic human body measurements for technological design is adopted. As a result, for each analysed task the OCRA and NIOSH indexes are calculated action by action and the SHELL model is defined.

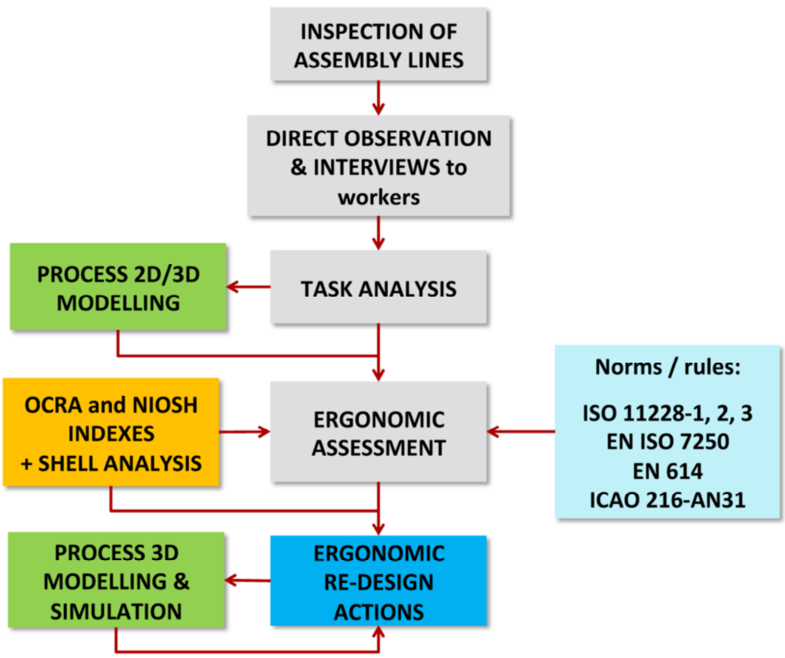

Figure 1. The procedure for ergonomic analysis of manual assembly process.

2. The industrial case study

2.1. The assembly process

The case study was developed in collaboration with an Italian company that is world leader in dental equipment design and production. In particular, the process under investigation related to the assembly of dental units. The dental unit usually comprehends: the hydro-unit, the swivel arm, the dentist's instrument board, the dentist's control console, the tray-holder module, the assistant's board, the assistant's board control console, the electrical box, the multifunction foot control, the cup water delivery spout, the bowl, the self-balancing arm, and the dental chair. Some devices such as the tray-holder module on assistant's board and an X-ray viewer can be included, as optional.

The specific line is composed by 25 workstations, 16 of them are dedicated to pre-assembly and 9 of them to assembly. The line can process a maximum volume of 16 units per day, with a takt-time of 30 minutes. The turnover is once a week. Figure 2 shows the line investigated in the case study. The pre-assembly phase consists of preparing the subassemblies, which to be assembled in the following assembly phase. Each cart refers to one dental unit. The carts are filled from the warehouse using RFID technology.

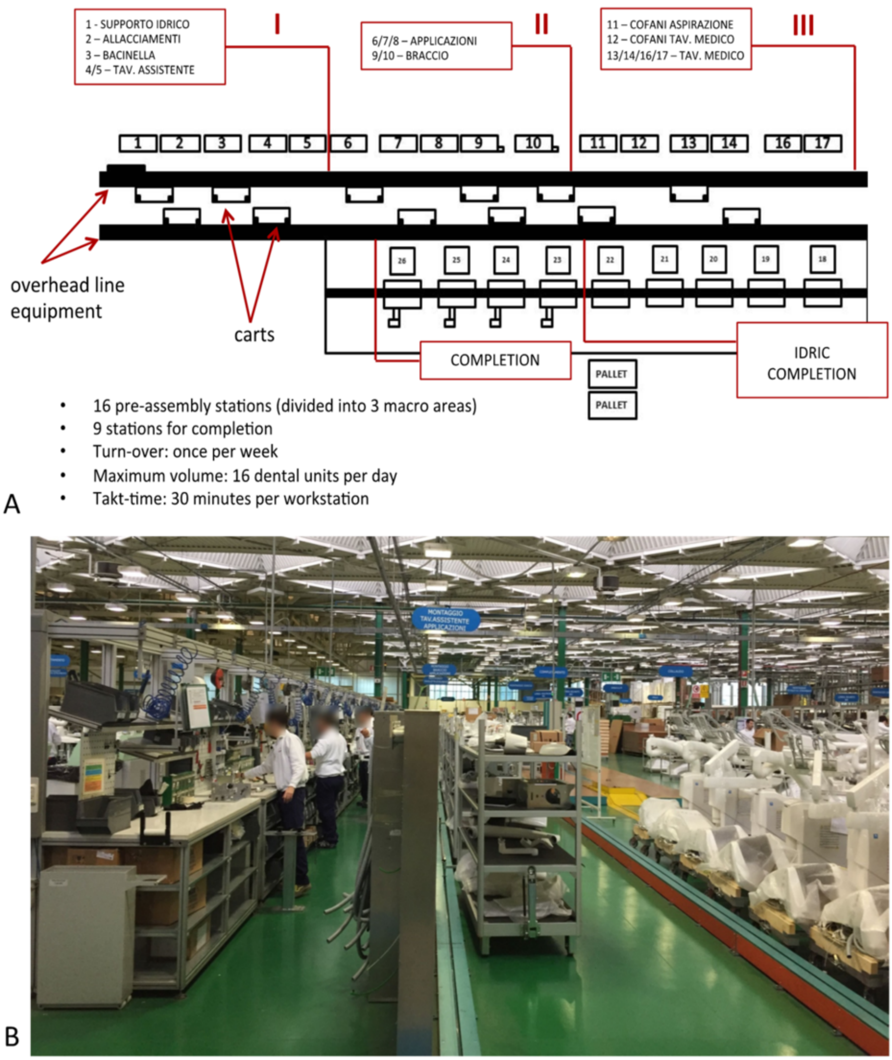

Figure 2. The assembly line for dental units: the 2D layout (A) and the real shop-floor (B).

The carts are organized according to a standardized procedure: the upper shelf of the carts are filled by the lighter components, the second shelf is a sliding shelf with the heavier components, the third shelf contains hydraulic parts and custom component, and the bottom shelf is filled by specific medical components. Such organization should guarantee that the heaviest components are handled in safety conditions, according to ISO 11226 and ISO 11228. The carts run along the overhead line equipment throughout the pre-assembly stations first, and the assembly stations secondly. When the pre-assembly is completed, the carts are positioned on the second overhead line equipment dedicated to assembly. This line is parallel to the first one, as shown in Figure 2. Each workstation is equipped with the necessary tools, from screws to supporting checklists to support the workers in their actions. Training videos are also available in some specific workstations. The most common tools are usually highly visible and easily accessible. Each workstation is also equipped with assembly manual. When the carts are full, they are pulled to the next station. Every two carts completed, the worker requests new material to the warehouse.

2.2. The process analysis

The process analysis started with a preliminary inspection of the line, followed by interviews to assembly managers and workers, and direct observation of operators at work. Workers were video recorded during task execution and interviewed in order to define their tasks, monitoring their actions, identifying the tools and the procedures adopted. After that, a more detailed task analysis was carried out by experts in physical ergonomics and human factors. Each workstation was described according to: 1) sequence of tasks and procedures (i.e., software), 2) equipment and devices used (i.e., hardware), 3) interaction and communication with other people, both managers and other workers (i.e., livewere), 4) problems elicited by the workers. Tasks were then listed into and excel file and a detailed task analysis was carried out. After that, the process as well as the task sequence were digitised by 2D and 3D models.

2.3. Main criticalities and re-design actions

The ergonomic study was based on the adoption of the proposed procedure as presented in Figure 1. A first inspection of the assembly line was carried out by two experts in ergonomics and human factors. Subsequently, experts spent two weeks at the shop floor to monitor and video recording the workers and interview both workers and managers to collect useful information. Workstations and tools were also analysed and measured.

The main criticalities identified are as follows (some of them are depicted in Figure 3):

- the workers are frequently ask to carry heavy parts to/from the carts to the workstation, requiring uncomfortable lifting actions and frequent trunk rotations (see Figure 3-A);
- the carts have a fix height so that shorter workers, usually female operators, difficultly access to the higher shelf. They need to tiptoe and they have an high stress on the arms (Figure 3-B);
- in the assembly stations the workers are seated and assume un-ergonomic postures to assemble some parts (Figure 3-C);

Figure 3. Examples of the human-related criticalities during the assembly process in the case study

- some supporting equipment available at the workstation, introduced to assist the workers in lifting parts or assemble complex groups, are not adjustable according to the user needs. As a consequence, they can be used comfortably only form middle-height workers (almost 50° percentile), while are not ergonomic at all for higher or lower percentiles of the population (Figure 3-D);
- the assembly checklist available at the workstation are not highly visible due to their position (inclined to the roof) and the dover material (that reflects the light) (Figure 3-E);
- some tools available at the workstation are not easily accessible for short workers, due to a wrong and not adjustable positioning (Figure 3-F);
- the task analysis also revealed a weak time organization and some problems in the activity synchronization among the workstations can occur, so that some stations are too early and others are late. It is mainly due to the high level of customization of the products that generates an extremely high variability of the assembly tasks.

Finally, the collated data allowed the creation of 3D models of the workstations and the simulation of the human interaction also by digital mock-ups. The most critical tasks were simulated and some re-design actions proposed and tested. During re-design, both product and process are involved in design changes. Indeed, the only process line optimization and workstation re-design can bring to limited benefits, due to the assembly constraints due to the product design. Only combined corrective actions on both process and product design can bring high advantages for the company, in terms of workers' wellbeing, product quality and process efficiency.

The main re-design actions carried out for the case study are as follows:

- workbenches' re-design according to physical ergonomic principles;
- carts' re-design, in particular by reducing their depth and having adjustable shelves;
- work re-organization in order to avoid lazy and too crowed workstations, mainly by modifying the assembly sequence of tasks in combination with part design changes;
- checklist supports' re-design, using adjustable and rotational supports, that each worker can regulate easily at the beginning of the shift;
- addition of adjustable auxiliary equipment to support the workers' actions;
- product modularization in order to re-organize its sub-assembly and to facilitate the assembly tasks.

Moreover, workers were directly involved in the re-design process according to participatory design principles. By observing the obtained results, the improved involvement and satisfaction of the workers greatly affected the process performance and the workers' safety and wellbeing. Experimentation is on-going and experimental results will be presented in future works.

3. Conclusions

The paper presents an ergonomic study about dental units' assembly process using a procedure to structure the analysis phases and to analyse easily physical and cognitive issues. The study highlighted the main ergonomic issues to be solved and demonstrate how human-oriented re-design actions can solve physical, cognitive and organizational problems, and improve the final process performance. Experimental results are still under investigation, and will quantify such preliminary results. Future works will be focused on the creation of human-centered immersive simulations by using virtual reality technologies and experimental set-up with users for a more impressive and realistic verification of re-design solutions [21][22]. Furthermore, biometrical sensors could be introduced to monitor the workers' physical and mental stress in order to define and test the more comfortable solutions [23][24][25].

Acknowledgement

The authors wish to thank you the Italian Society of Ergonomics and Human Factors (SIE) for the precious collaboration and CEFLA S.C. (www.cefla.com) for offering the industrial case studies.

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