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# A multimeasure-based methodology for the ergonomic effective design of manufacturing system workstations

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ABSTRACT

The paper proposes a multimeasure-based methodology that can be used by production engineers for the ergonomic effective design of workstations within industrial environments. In particular the authors achieve the effective ergonomic design of the workstations belonging to a real industrial plant by using an approach based on multiple design parameters, Design of Experiments (DOE) and multiple performance measures. The industrial plant being considered is made up by 8 different workstations, 14 workers and it manufactures high-pressure hydraulic hoses. The design methodology aims at considering both the interaction of the operators with their working environment and the work methods. To this end, the workstations' actual configurations are compared with several alternative scenarios by using a well-planned experimental design. As support tool for applying the design methodology the authors use Modeling & Simulation (M&S) and a virtual three-dimensional environment for recreating, with satisfactory accuracy, the evolution over the time of the real industrial plant.
*Relevance to industry*: The authors propose a methodology for the effective ergonomic design of workstations within industrial plants. The methodology based on multiple design parameters and multiple performance measures supports the design and the evaluation of workstations in terms of both ergonomics and work methods.



## 1. Introduction

The high complexity of the industrial plants (i.e. manufacturing systems) in terms of interactions between humans and their industrial working environment continuously provides challenging problems for researchers working in this specific field. In effect, during the last years, ergonomic problems became more and more important due to their effects on industrial plants efficiency and productivity. A number of different research works and scientific approaches have been proposed, trying to achieve the ergonomic effective design of the workstations belonging to industrial plants.

In the late 90s, the ergonomic effective design of manufacturing system workstations was mostly supported by videotaping systems used for data collection, i.e. the videotape of the worker performing the manufacturing operations is used for collecting informations about the work methods (Das and Sengupta, 1996; Kadefors and Forsman, 2000; Scott and Lambe, 1996). In order to achieve the ergonomic effective design of the manufacturing system workstations, such research works analyze the videotape of the work methods and assume a trial and error methodology (in effect the design methodology is never supported by a well-defined experimental design). The final ergonomic design of the workstations depends on researcher's experience and his/her knowledge about the manufacturing system. In addition, the design methodology is usually based on a single ergonomic performance measure (i.e. lift index, energy expenditure measure, work postures, etc.) related to a specific ergonomic standard such as the Ovako Working Posture analysis System (OWAS), the Burandt–Schultetus analysis, the NIOSH 81 and NIOSH 91 equations (NIOSH stands for National Institute for Occupational Safety and Health), the Garg analysis. Examples of research works that propose a design methodology for manufacturing system workstations based on a single ergonomic performance measure are Kharu et al. (1981), Engels et al. (1994), Temple and Adams (2000), Lin and Chan (2007), Waters et al. (2007). The integration of two or more ergonomic standards (design methodology based on multiple performance measures) was the successive step carried out by the researchers working in this specific area for achieving multiple and simultaneous ergonomic improvements. Examples of ergonomic standards integration can be found in Wright and Haslam (1999) and Russell et al. (2007).

Another important issue to take into consideration in the manufacturing workstations design is the relation between the concepts of work measurement and ergonomics. The measurement

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of the work aims at evaluating the time standard for performing a particular operation. On the contrary, the concept of ergonomics is often indicated as study of work (Zandin, 2001) and studies the principles that rule the interaction between humans and their working environments. In effect the work measurement and the ergonomics affect each other: ergonomic interventions affect the time required for performing the operations as well as any change to the work method affects the ergonomics of the workplace. Laring et al. (2002) and Udosen (2006) take into consideration in their research works both ergonomics and work measurement aspects.

Finally the last important aspect is whether the ergonomic effective design is carried out by analyzing directly the real manufacturing workstations or by using computerized models. Usually the analysis of the real workstations is quite expensive (in terms of money and time) because it requires to "disturb" processes and activities of the manufacturing system. According to Banks (1998), in this context simulation is a problem solving methodology for creating an artificial history of the system, analyzing its behaviour, carrying out what-if analysis. Furthermore, simulation can be jointly used with virtual three-dimensional environments. A virtual three-dimensional environment is a powerful tool for observing the workplace evolution over the time, detecting ergonomic problems that, otherwise, would be difficult to detect. Wilson (1997) proposes an overview on attributes and capabilities of virtual environments devoted to support ergonomic design; Longo et al. (2006) use M&S in combination with 3-D virtual environments, ergonomic standards and work measurement for supporting the effective design of an assembly line still not in existence.

The contribution of the paper to the state of the art is twofold: (i) the authors propose a methodology for achieving the ergonomic effective design of workstations within industrial environments and (ii) apply such methodology to the workstations belonging to a real industrial plant that manufactures high-pressure hydraulic hoses. The methodology is based on multiple design parameters, Design of Experiments (DOE) and multiple performance measures. It takes into account both the interaction of the operators with their working environment and the work methods and it is supported by Modeling & Simulation (M&S) and virtual three-dimensional environments for creating a simulation model of the real manufacturing plant. In particular, the simulation model is used for comparing the actual workstations with workstations' alternative configurations by carrying out a well-planned Design of Experiments based on multiple design parameters. The choice of the workstations final configuration is made according to multiple ergonomic and time performance measures.

The paper is organized as follows. The explanation of the design methodology is made contextually to its application within a real industrial environment (a manufacturing system). To this end, Sections 2 and 3 respectively describe the manufacturing system and the implementation of the simulation model of the workstations. Section 4 explains the design methodology: how to define the multiple design parameters and the multiple performance measures and how to use the Design of Experiment (DOE) for testing a comprehensive set of workstations' different configurations. Section 5 presents the application of the design methodology and the achievement of the ergonomic effective design of the workstations. The last section reports the conclusions that summarize the scientific and academic value of the work.

## 2. The manufacturing system

The industrial plant considered in this research work manufactures high-pressure hydraulic hoses. The manufacturing plant, AlfaTechnology s.r.l., is located in the South of Italy (Calabria) and covers a surface of about 13,000 $m^2$. The plant layout is subdivided into two different manufacturing areas. The first one, the Mechanical area, produces fittings and ring-nuts (and some other components used for hydraulic hoses assembly). The second one, the Assembly area, assembles rubber hoses with fittings and ring-nuts in order to obtain the final product.

A preliminary analysis carried out by the company top management shows that the productivity of the Assembly area (evaluated on monthly basis) falls always below the target level causing, as a consequence, delays in Shop Orders (S.Os) completion. The Assembly area consists of 8 different workstations each one performing a specific operation of the hydraulic hoses assembly process. Most of the workstations are characterized by manually performed operations, therefore, the company top management decided to carry out a research study on the ergonomic effective design of the workstations. To this end, the authors propose a design methodology that takes into consideration both ergonomic issues and work measurement. The operations performed in each workstation are described as follows.

1) *Preparation workstation*: according to the S.Os information, the operator takes the main components from the raw materials' warehouse shelves and defines the length of the rubber hose.
2) *Seal Press workstation*: the operator prints on ring-nuts and fittings the quality and traceability identifying numbers by using the Seal Press machine and places the components inside apposite boxes.
3) *Cutting workstation*: the operators take rubber hose rolls from the raw materials' warehouse shelves and cut the rolls according to the S.Os requirements (by using an automated or manual cutting machine).
4) *Skinning workstation*: the operators eliminate a part of rubber at the ends of each hose in order to guarantee a good junction with the fittings.
5) *Assembly workstation*: the operators manually assemble the rubber hoses with fittings and ring-nuts.
6) *Stapling workstation*: the operators tighten the ring-nuts on the hoses by using the stapling machine.
7) *Pressure Test workstation*: the operators test the hydraulic hoses by using a pressure machine (setting a pressure value higher than the nominal value).
8) *Check and packaging workstation*: the operators compare the S.Os requirements and the hoses' characteristics (quality controls), they also put the hydraulic hoses in the shipping cases.

At the end of each operation, the operators set the status "end of the operation" on the company informative system and move the materials to the successive workstation by using a manually operated dolly. Please note that in the remaining part of the paper the term workstation is being used for indicating the place where a specific operation is performed (i.e. assembly workstation, pressure test workstation, etc.) while the term workplace for indicating the entire Assembly area (made up by the workstations before described).

## 3. The development of the workstations simulation model

The authors believe that a methodology for achieving the effective design of workstations within an industrial environment must take into account all the design parameters affecting the performance measures related to work measurement and ergonomics. However a manufacturing system workstation is a quite complex system characterized by different design parameters (i.e. objects dimensions, tools position, operator work methods). As a consequence, the design methodology should be supported by an approach capable of recreating the complexity of a real manufacturing system workstation. To this end, the authors