INDUSTRIAL WORKSTATIONS DESIGN: A REAL CASE STUDY

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ABSTRACT
The research work advances the effective design of the most critical workstations belonging to a real industrial plant; to this end, the authors propose an approach based on the integration of Modeling & Simulation tools, several ergonomic standards and the most known work measurement tools. The Modeling and simulation tools allow to implement a three-dimensional environment capable of recreating, with satisfactory accuracy, the evolution over the time of the real workstations. The ergonomic standards consent to evaluate the ergonomic risks level within the system being considered. The work measurement tools permit to calculate the time required for performing all the workstations operations. The effective design of the workstations is achieved by using the simulation model for comparing workstations' alternative configurations. The comparison is based on ergonomic and time indexes related to the ergonomic standards and the work measurement tools. Such comparison allows to choose the workstations final configurations.

Keywords: industrial plants, industrial workstations design, ergonomic standards, work measurement tools

1. INTRODUCTION

Today, industrial workstations design continuously provides challenging problems in terms of interaction between operators and their working environment (ergonomics) and productivity enhancement as well. Let us consider the ergonomics within the industrial environment. The research works developed in the late '90 consider a single ergonomic performance measure, based upon a specific ergonomic standard for the ergonomic redesign of the workstation belonging to industrial plants. Among the ergonomic standards, the following have to be regarded as the most widely used: (i) the NISOH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for National Institute for Occupational Safety and Health); (ii) the OWAS for analyzing working postures (OWAS stands for Ovako Working Analysis System); (iii) the Burandt-Schultetus analysis for lifting tasks involving a large number of muscles; (iv) the Garg analysis for assessing the energy expenditure for performing an operation. Further information about the cited ergonomic standards can be found in Garg (1976), Schultetus (1980), Kharu et al. (1981), the Niosh Technical Report 81-122 (1981), the Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation (1991) and Waters et al. (1994). Examples of research works that propose an ergonomic redesign of industrial workstations based on a single or multiple ergonomic performance measure are Scott and Lambe (1996), Wright and Haslam (1999), Temple and Adams (2000), Waters et al. (2007), Russell et al. (2007), Cimino et al. (2009a). Let us consider now the workstations productivity enhancement within industrial plant workstations. There are many alternatives available for improving productivity. Clearly the effective design of work methods is one of the most important aspects of increased productive output (Cimino et al. 2008a). In this regards, Methods Engineering is a systematic technique for the design and the improvement of work methods, for the introduction of those methods into the workplace, and for ensuring their solid adoption (Zandin, 2001). Motion and time study is at the heart of methods engineering (Ben-Gal and Bukchin, 2002). As reported in Lawrence (2000) the motion study is to determine the best way to perform a job and the time study is to measure the time required for a job to be completed using the best method. As time study tools (also known as work measurement tools), the following have to be regarded as the most important: MTM (Methods Time Measurement) and MOST (Maynard Operation Sequence Techniques). Further information about the cited work measurement tools can be found in Karger and Bayha (1987), Zandin (2001), Cimino et al. (2008b).

Another important issue to take into consideration in the industrial workstations design is whether to analyze directly the real industrial system or by using computerized models. Usually analyzing directly the real workstations requires huge amount of money and time for testing all the workstations configurations, work assignments, work methods as well as "disturbs" processes and activities of the industrial plant. For this reason, researchers and practitioners very often use simulation as problem solving methodology for creating an artificial history of the system, analyzing its behaviour, choosing correctly, understanding why, diagnosing problems and exploring possibilities (Banks, 1998). Example of research works that propose the effective design of indutrial workstations using Modeling & Simulation tools are Bruzzone (1996), Wilson (1997), Feyen et al. (2000), Bruzzone et al. (2004), Bruzzone and Williams (2004), Santos et al. (2007) and Cimino et al. (2009b), Cimino and Mirabelli (2009), Longo and Mirabelli (2009).

The main contribution of the paper to the state of the art is to propose the effective design of the most critical workstations (Skinning and Assembly workstations) of an industrial plant devoted to produce high pressure hydraulic hoses. The authors propose an approach based on the integration of Modeling & Simulation tools (eM-Workplace and Pro-Engineer), several ergonomic standards (NIOSH 81, NIOSH 91, Burandt Schultetus, OWAS, Garg) and the most known work measurement tools (MTM, MOST). In particular, the simulation is jointly used with virtual three-dimensional environments in which observe the system evolution over the time. The ergonomic standards allows to evaluate the ergonomic risks level affecting the workstations and finally the work measurement tools consent to calculate the time related to each operation performed in the Skinning and Assembling workstations. After the workstations simulation model development, the authors propose several workstations modifications evaluating their effectivness in terms of both ergonomic risks level and time performace.

Before going into details of the study, let us give a brief overview of each section of the paper. Section 2 describes the industrial plant under investigation. Section 3 gives specific details on the workstations simulation model implementation and validation. Section 4 reports a brief description of the ergonomic standards and the work measurement tools. Sections 5 and 6 present the simulation results and the workstations effective redesign, respectively. The last section reports the conclusions that summarize the scientific contribution of the work and the research activities still going on.

2. THE INDUSTRIAL PLANT

The industrial plant considered in this research work manufactures ring nuts, fittings and high pressure hydraulic hoses for the following sectors: industrial, naval, aeronautical, construction, iron, mechanic and railway. The industrial plant was established in 1994 and it is located in the North of Italy covering a surface of about 3700 m^2. The plant-layout is subdivided into 4 different areas:

1. Raw materials warehouse;
2. Mechanical area;
3. Assembly area;
4. Final products warehouse.

A brief description of each area is reported as follows.

The Raw materials warehouse
Here the raw materials for manufacturing ring nuts, fittings and high pressure hydraulic hoses are stored in shelves and pallets located along the whole area. Note that the pallets are placed on the bottom level of each shelf in order to full use the warehouse area. The raw materials are manually moved by means of a multi order picking cart as well as several forklifts are used for the pallets placement. The storage area is 10 m high and covers a surface of 930 m^2.

The Mechanical area
It produces fittings and ring nuts; some of them are used for manufacturing the high pressure hydraulic hoses, the others are final products of the industrial plant. The workstation employs five operators and it is made by 5 numerically controlled machine. The workstation layout covers a surface of 350 m^2.

The Assembly area
It assembles rubber hoses with ring nuts and fittings in order to obtain the final high pressure hydraulic hoses. Note that each hydraulic hose is made by a rubber hose, two fittings and two ring nuts. The assembly area consists of 6 different workstations each one performing specific operations of the hydraulic hoses assembly process. The assembly area employs 12 operators and cover a surface of about 1112 m^2.

The Final Products Warehouse
Here the final products (ring nuts, fittings, rubber hoses and high pressure hydraulic hoses) are stored in shelves and pallets located along the whole area. As the *Raw Materials Warehouse,* note that the pallets are placed on the bottom level of each shelf in order to full use the warehouse area and the final products are moved by means of a multi-order picking cart as well as by using several forklifts. The storage area is 10 m high and covers a surface of about 1395 m^2. Figure 6 shows the plant layout of the warehouse.

2.1. The Skinning workstation and the Assembly workstation

A preliminary analysis carried out by the company top management shows that the Skinning and the Assembly workstations are characterized by several ergonomic issues as well as low productivity levels. In this context, the company top management asked us to redesign such workstations, from the one side, for preventing the workers' health, from the other side, for increasing their productivity and in turn, the industrial plant one. Before getting into details of the research study, let us present the work methods and the layout of both the workstations.

The Skinning workstation employs 2 workers performing the following operations:

1. They pick up the Shop Order sheet, read the information they need and put it back;
2. They set the skinning machine up;

3. They pick manually up a rubber hose located on a pallet 15 cm high;
4. They insert the rubber hose into the skinning machine, perform the security procedure and start the skinning phase;
5. They remove the rubber hose from the skinning machine and put it on a bin placed on a manual hand chart 30 cm high;
6. They set the status “end of the operation” on the company informative system;
7. They moves the rubber hoses to the successive workstation by means of a manual hand chart.

Note that the skinned rubber hoses are used for manufacturing the high pressure hydraulic hoses as well as are directly sold to the customers; in this context, some of them is moved to the assembly workstation, the others are moved to the final product warehouse.

Table 1 consists of description, dimensions (length, width and height) and quantity of all the objects of the Skinning workstation.

Table 1. Skinning workstation objects

Objects description	**Dimensions (cm) (L x W x H)**	**Quantity**
Empty bin	60 x 40 x 30	4
Rubber hose	Depending of Shop Order	Depending of Shop Order
Pallet	80 x 120 x 15	2
Skinning Machine	300 x 150 x 250	2
PC Worktable	100 x 65 x 95	2
Support Table	180 x 60 x 95	2
Manual hand chard	100 x 140 x 15	2

Figure 1 shows the objects position as it takes place in the Skinning workstation.

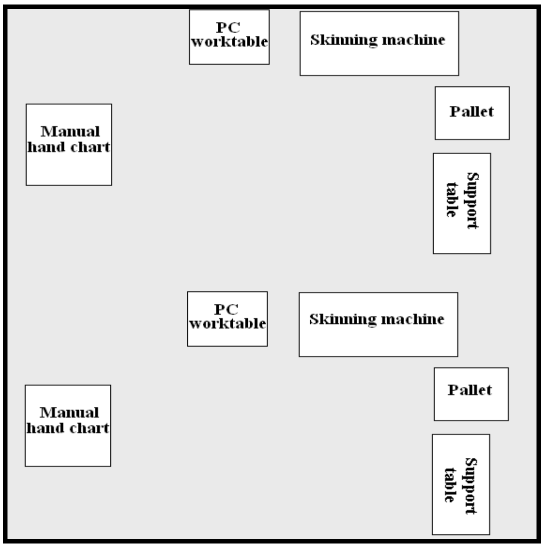

Figure 1**.** Skinning workstation layout

The Assembly workstation employs 2 workers and it presents the following work method:

1. The workers pick the Shop Order sheet up, read the information they need and put it back;
2. The workers picks manually up a rubber hose located on a pallet 15 cm high and bring it to the work table;
3. The workers pick manually two ring nuts and two fittings up from bins located on their backs and bring them to the work table;
4. The workers manually perform the assembly operation;
5. The workers move the assembled hydraulic hoses to a pallet located on a manual hand chart 30 cm high;
6. The workers set the status “end of the operation” on the company informative system;
7. The workers moves the hydraulic hoses to the successive workstation by means of a manual hand chart.

Table 2 consists of description, dimensions (length, width and height) and quantity of all the objects of the Assembly workstation.

Table 2. Assemvly workstation objects

Objects description	**Dimensions (cm) (L x W x H)**	**Quantity**
Ring nuts and fittings bins	20 x 15 x 15	98
Rubber hose	Depending of Shop Order	Depending of Shop Order
Pallet	80 x 120 x 15	2
Worktable	400 x 150 x 95	2
PC Worktable	180 x 60 x 95	2
Manual hand chard	100 x 140 x 15	2

Figure 2 shows the objects position as it takes place in the Assembly workstation.

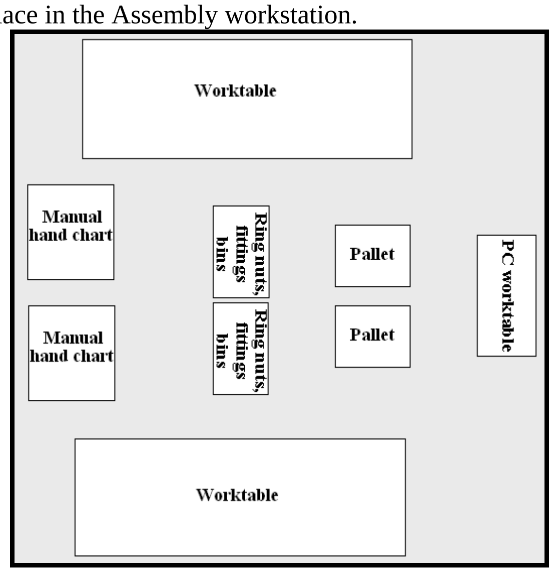

Figure 2**.** Assembly workstation plant layout

It is important to underline that the Skinning workstation productivity is higher than the Assembly workstation one. It generates a skinned rubber hoses inventory to be managed by the operators. The rubber hoses are stored by means of several shelves located between the two workstations and their management causes a notable reduction of the workstations productivity; for this reason, the company top management asked us to face and solve the problem in order to avoid such noteworthy loss of time.

3. SIMULATION MODEL DEVELOPMENT

Industrial plants workstations are very complex systems characterized by several design parameters such as objects dimensions, tools positions and operators work method. As a consequence, the workstations redesign process should be supported by an approach capable to correctly recreate the complexity of the real system. To this end, the authors decide to adopt an approach based on Modeling & Simulation supported by a three dimensional virtual environment. In this context, the first step of the research work was the development of a simulation model capable of recreate with satisfactory accuracy the evolution over the time of the Skinning and Assembly workstations. The steps to guide the model builder in the simulation study are reported as follows:

1. Data collection phase: collect data concerning the system under consideration;
2. Modeling phase: reproduce the real system from a geometric point of view;
3. Simulation phase: reproduce the real system from a work method point of view;
4. Validation phase: verify if the simulation model is an accurate representation of the real system.

Sections 3.1–3.4 get into details of the four phases of the simulation model development.

3.1. Data collection phase

As first step, the authors submitted a schedule of data requirement to the company top management. However the company top management indicated that the data required were unavailable. Therefore the authors spent a three months period at the Skinning and Assembly workstations collecting data and information about operators' characteristics (age, gender, height, weight and physical condition), dimensions (length, width and height) and weights of all the objects being modeled and analyzing the work methods used by workers for performing the manufacturing operations. Operators' characteristics were used for selecting human models capable of representing as much as possible the real workers. Objects' dimensions and weights were used for designing the geometric models of each workstation. The observation of the work methods was used for reproducing correctly in the virtual environment the manufacturing operations of each workstation.

3.2. Modeling phase

After the data collection phase, the second step was the reproduction of the Skinning and Assembly workstations from a geometric point of view. The geometric models of all the workstations objects were developed by means of the CAD software Pro-Engineer (Pro-E). The geometric models generated by using Pro-E contain all the information regarding dimensions, weights and type of materials. For each workstation the geometric models recreate the following elements: machines, equipment and tools, worktables, manual hand charts, raw materials, containers and cases.

Figure 3 and figure 4 show respectively the Assembly workstation worktable and a pallet with several rubber hoses.

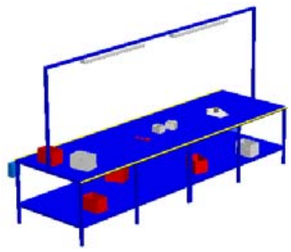

Figure 3. Worktable of the Assembly workstation

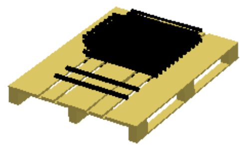

Figure 4. Pallet and rubber hoses

3.3. Simulation phase

After the modeling phase, the successive step was the reproduction of the Skinning and Assembly workstations from a work method point of view. The first step of the Simulation phase requires to import the geometric models into the virtual environment provided by the simulation software eM-Workplace.

Figure 5 and figure 6 provide a panoramic view of the Skinning and the Assembly workstation.

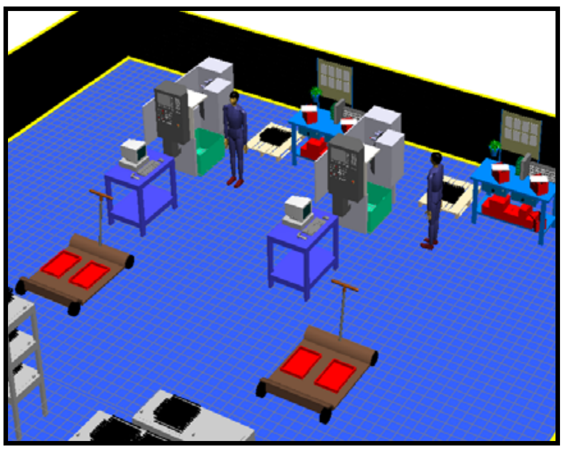

Figure 5. Panoramic view of the Skinning workstation.

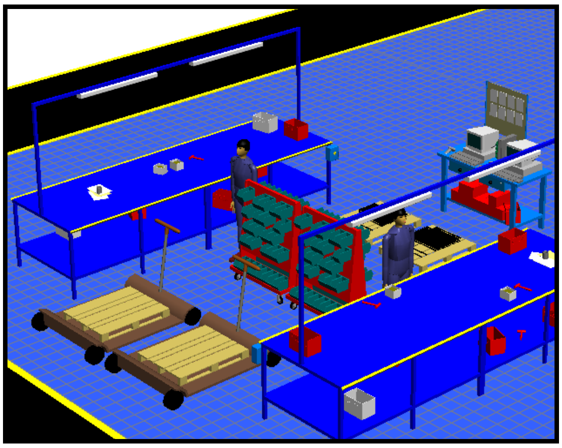

Figure 6. Panoramic view of the Assembly workstation.

The insertion and training of the human model are the successive steps required for completing the simulation phase. The eM-Workplace provides the user with different human models libraries. The selection of the human models takes into account the characteristics of the real operators (age, gender, height, weight and physical condition) with the aim of importing in the virtual environment human models as much as possible similar to the real workers. Table 3 consists of operators' characteristics in terms of age, gender, height, weight.

Table 3. Operators' physical characteristics

Operator ID	Age	Gender	Height (cm)	Weight (kg)	Workstation
Op-1	32	Male	172	73	Skinning
Op-2	29	Male	175	71	Skinning
Op-3	44	Male	169	74	Assembly
Op-4	39	Male	178	78	Assembly

Obviously each human model needs to be trained in order to perform the manufacturing operations. To this end, eM-Workplace provides the user with a programming language for teaching the basic motions of each operation.

3.4. Validation phase

The last step of the simulation model development is the validation that aims at determining if the simulation model is an accurate representation of the real industrial plant workstations.

The validation phase have been carried out by analyzing and discussing the simulation model with workers and employees of the industrial plants. With the help of the workers the authors checked all the basic motions of the human models and deleted some errors concerning the work methods (wrong working postures, wrong motions or redundant motions). At the end of this phase the simulation model was ''reasonable'' both to workers, company's engineers and technicians for its capability to recreate correctly the workstations layout and all the manufacturing operations as well.

4. MEASUREMENT AND STUDY OF WORK

The eM-Workplace simulation software provides the user with several ergonomic and time indexes based on the most known ergonomic standards and work measurement tools. The ergonomic standards allow the authors to establish the ergonomic risks level affecting the workstations; the work measurement tools consent to calculate the time required for performing the operation within the workstations being considered. As concerns the ergonomic standards, the Burandt Schultetus, NIOSH 81 and NIOSH 91 were used for evaluating the stress related to the lift operations, OWAS analysis for evaluating the stress associated to the working postures and finally the Garg analysis for calculating the energy expenditure associated to each activity. As regards the work measurement tools, the simulation model uses the MTM and the MOST for evaluating the process time of each operation.

Sections 4.1 – 4.6 present a brief description of the ergonomic standards and work measurement tools being used in this research work. Note that further information concerning the ergonomic standards can be found in Cimino et al., 2008c.

4.1. Burandt Schultetus

The analysis detects the maximum weight that a working person can lift (maximum permissible force). The analysis requires several input parameters regarding the physical conditions, age and gender of the worker, the load weight, the lifting frequency (measured in lifts per minute) and the total task duration.

4.2. NIOSH 81 and NIOSH 91

The NIOSH 81 method calculates the Action Limit (AL) and the Maximum Permissible Limit (MPL). AL is the weight value, which is permissible for 75% of all female and 99% of all male workers. MPL is the weight value, which is permissible for only 1% of all female and 25% of all male workers. Concerning the NIOSH 91 analysis, additionally to the NIOSH 81, it includes the Recommended Weight Limit (RWL) and the Lifting Index (LI). The RWL is the load that nearly all healthy workers can perform over a substantial period of time for a specific set of task conditions. The LI is calculated as a ratio between the real object weight and the RWL.

4.3. OWAS analysis

The analysis calculates the stress associated to each body posture and classifies them in one of the following four stress categories:

- *Category 1*: If the stress level is optimum, no corrective interventions are required
- *Category 2*: If the stress level is almost acceptable, corrective interventions are necessary in the near future
- *Category 3*: If the stress level is high, corrective interventions are required as soon as possible

- *Category 4*: If the stress level is very high, corrective
- interventions must be carried out immediately.

4.4. Garg analysis

The total amount of energy spent during the manual operations is calculated. The analysis splits up a specified operation into smaller steps calculating for each of them the EE; the sum of these separate steps represents the total EE for the activity.

4.5. MTM

The Method Time Measurement is the most widely used system of predetermined times (Rice, 1977). The MTM is a procedure for analyzing any manual operation or method by breaking out the basic motions required to perform it and assigning to each a predetermined standard time based on its nature and the conditions under which it is made (Karger and Bayh 1987). The total time for the manual operation is then calculated as sum of the time of each basic motion it is made by.

4.6. MOST

MOST concentrates on the movement of objects (Zandin and Kjell 1990). The primary work units are no longer basic motions, but fundamental activities (collection of basic motions) dealing with moving objects. These activities are described in terms of sub activities fixed in sequence. In other words, to move an object, a standard sequence of events occurs. Only three activity sequences are needed for describing manual work. Summarizing the MOST technique is made up of the following basic sequence models:

- The *general move sequence* for the spatial movement of an object freely through the air.
- The *controlled move sequence* for the movement of an object when it remains in contact with a surface or is following a controlled path during the movement.
- The *tool use sequence* for the use of common hand tools.

5. SIMULATION RESULTS

In this section the authors present the simulation results of both the Skinning and the Assembly workstations. In particular the authors use the simulation model, the ergonomic standards and the work measurement tools for evaluating the ergonomic risks level affecting the workstations and for calculating the total time required for performing the workstations operation as well. Note that the simulation runs consider the production of a typical industrial plant Shop Order made by 20 hydraulic hoses. Section 5.1 and 5.2 present the simulation results for the Skinning and the Assembly workstations, respectively.

5.1. Skinning workstation

The activities performed by the operators do not require heavy lifting tasks; in effect the Burandt Schultetus, the NIOSH 81 and the NIOSH 91 analysis do not reveal any particular lifting problem. Significant results for the effective design have been obtained in terms of uncomfortable working postures and Energy Expenditure (EE) respectively for the OWAS and the Garg analysis. When the OWAS analysis is applied to the Skinning workstation, the program assigns a category 3 (body posture characterized by high stress level) to the following operations:

1. picking manually up a rubber hose located on a pallet 15 cm high before the skinning operation (see section 2.1, operation 3 of the Skinning workstation);
2. putting a rubber hose on a bin located on a manual hand chart 30 cm high after the skinning operation (see section 2.1, operation 5 of the Skinning workstation).

Considering both the operations, the most affected body part is the workers' back.

The Garg analysis completes the ergonomic evaluation process calculating about 2340 Kcal as the total amount of energy spent during the whole shift.

Consider now the work measurement analysis. The operations performed in this workstation have been subdivided in 4 different groups (each group has to be regarded as a macro-activity), described as follows.

- *Macro-activity 1* – the operators set the workstation for starting the skinning operations;
- *Macro-activity 2* – the operators move the component (rubber hoses) into the skinning machine and start the skinning phase;
- *Macro-activity 3* – after the skinning phase the operators remove the components from the skinning machine and put them into a bin;
- *Macro-activity 4* – the operators complete the Shop Order and move the rubber hoses to the successive workstation.

The authors suppose to subdivide the macro-activities in two different categories: preparation operations (performed just once for the entire Shop Order) and cyclic operations. The macro-activities 1 and 4 (workstation set-up and Shop Order completion) belong to the first category. The macro-activities 2 and 3 belong to the second category. Table 4 and table 5 consist of process times for each macro-activity

Table 4. Process time evaluated by the MTM analysis

MTM analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	6.19
Macro-activity 4	184.97
Total Preparation Time	191.16
Cyclic operation	**Time (sec.)**
Macro-activity 2	222.04
Macro-activity 3	415.12

Total Cyclic Time	637.16
Total time for completing the Shop Order	**828.74**

Table 5. Process time evaluated by the MOST analysis

MOST analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	7.01
Macro-activity 4	185.52
Total Preparation Time	192.53
Cyclic operation	**Time (sec.)**
Macro-activity 2	222.94
Macro-activity 3	416.24
Total Cyclic Time	639.18
Total time for completing the Shop Order	**831.71**

As concerns the MTM, the total process time is 828.74 sec. (about 12 min and 8 sec.). As concerns the MOST, the total process time is 831.71 sec (about 12 min and 11 sec). Let us focus on the Skinning workstation productivity. It has been evaluated by taking into account the total time required for completing a Shop Order (process time), the 8 hours shift of the workstation and the operators' allowance for physiological needs, fatigue and delay (calculated as 20% of the process time). Regardless of the work measurement tools (MTM or MOST) used for the evaluation of the process time the workstation productivity is about 29 Shop Orders per day.

5.2. Assembly workstation

As the Skinning workstation, the activities performed by the operators do not require heavy lifting tasks and significant results for the workstation effective design have been obtained only in terms of uncomfortable working postures and Energy Expenditure. The OWAS analysis identifies the following operations as the most critical ones:

1. picking manually up a rubber hose located on a pallet 15 cm high before the assembly operation (see section 2.1, operation 2 of the Assembly workstation). The analysis classifies such operation within the OWAS category 3 and identifies the workers' back as the most affected body part;
2. moving the assembled hydraulic hoses to a pallet located on a manual hand chart 30 cm high after the assembly operation (see section 2.1, operation 5 of the Assembly workstation). As the previous operation, a high stress level affects the workers' back.

As concerns the Garg analysis, the total amount of energy spent for the whole shift is about 2870 Kcal.

Let us consider the work measurement analysis.

The operations performed in this workstation have been subdivided in 5 different macro-activities, reported as follows.

- *Macro-activity 1* – the operators set the workstation for starting the assembly operations;
- *Macro-activity 2* – the operators move the rubber hoses to the work table;
- *Macro-activity 3* – the operators move the ring nuts and fittings to the work table and start the assemby phase;
- *Macro-activity 4* – after the assembly phase the operators move the high pressure hydraulic hose to the pallet locate on the manual hand chart;
- *Macro-activity 5* – the operator completes the Shop Order.

As the skinning workstation, the authors subdivide the macro-activities in preparation operations and cyclic operations. The macro-activities 1 and 5 (workstation set-up and Shop Order completion) belong to the first category. The macro-activities 2, 3 and 4 belong to the second category. Table 6 and table 7 consist of process times for each macro-activity.

Table 6. Process time evaluated by the MTM analysis

MTM analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	8.14
Macro-activity 5	19.94
Total Preparation Time	28.08
Cyclic operation	**Time (sec.)**
Macro-activity 2	180.94
Macro-activity 3	584.54
Macro-activity 4	380.13
Total Cyclic Time	1145.61
Total time for completing the Shop Order	**1173.69**

Table 7. Process time evaluated by the MOST analysis

MOST analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	8.67
Macro-activity 5	20.74
Total Preparation Time	29.41
Cyclic operation	**Time (sec.)**
Macro-activity 2	181.78
Macro-activity 3	586.23
Macro-activity 4	380.96
Total Cyclic Time	1148.97
Total time for completing the Shop Order	**1178.38**

According to the MTM analysis the total process time is 1173, 69 (about 19 min and 33 sec). According to the MOST, the total process time is 1178,38 (about 19 min and 38 sec.). The Assembly workstation productivity (evaluated by taking into account the total time required for completing a Shop Order, the 8 hours shift, the operators' allowance for physiological needs, fatigue and delay and regardless of the work measurement tools) is about 20 Shop orders per day.

6. THE WORKSTATIONS EFFECTIVE DESIGN

In this section the authors achieve the effective design of both the Skinning and the Assembly workstations. Section 6.1 and section 6.2 present respectively the Skinning and the Assembly workstations redesign.

6.1. The Skinning workstation redesign

Let us present the changes the authors propose for reducing the ergonomic risks and for increasing the productivity level of the workstation.

- A manual dolly replaces the pallet being used for locating the rubber hoses before the skinning operations. This change allows the operators to avoid the continuous bending needed for picking the rubber hoses up. Figure 7 and figure 8 shows the actual configuration and the final solution, respectively.

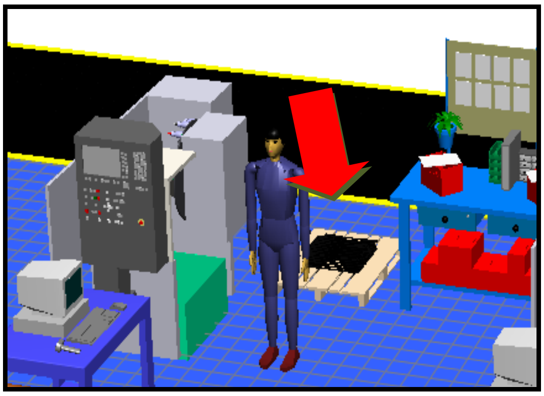

Figure 7. Actual workstation configuration for picking the rubber hose up before the skinning operation.

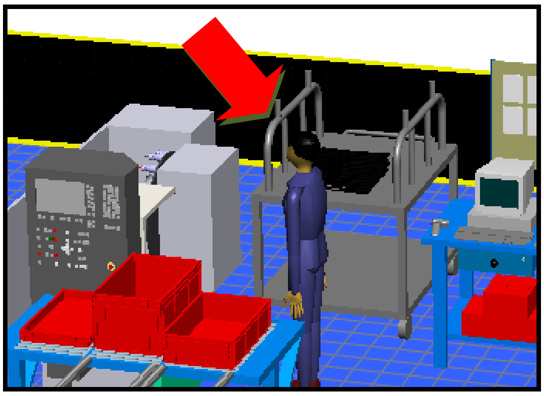

Figure 8. Final workstation configuration for picking the rubber hose up before the skinning operation.

- The PC being used by the operator for setting the status “end of operation” on the company informative system, has been moved to the support table. Note that such change allows to reduce the number of steps required by the operator for reaching the PC worktable; figure 9 and figure 10 show respectively the actual and the final workstation configurations.

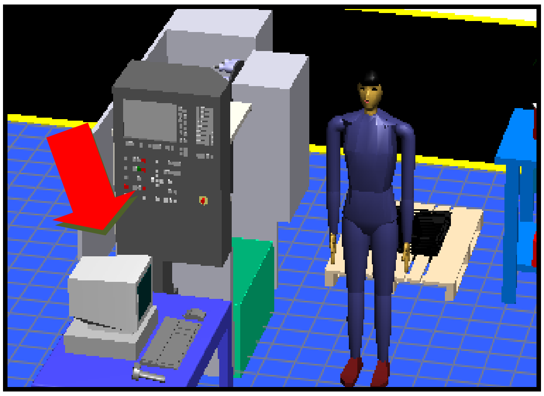

Figure 9. Actual workstation configuration of the PC location.

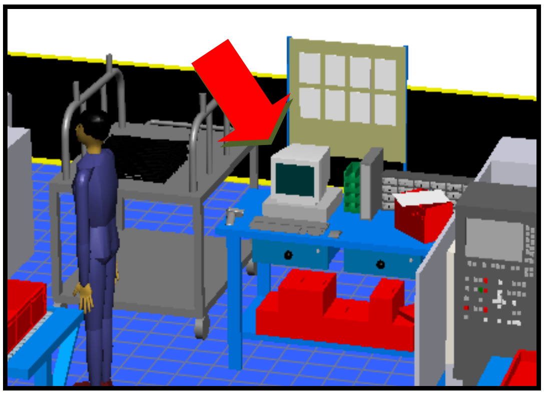

Figure 10. Final workstation configuration of the PC location.

- A manual conveyor replaces the manual hand chart for moving the skinned rubber hoses to the successive workstation. Such change allows to notably reduce the time required for performing this operation; in fact, after the skinning phase, the workers put the skinned rubber hoses on a bin located on the manual conveyor and then, providing a slight push to the bin, move the rubber hoses to the Assembly workstation. Moreover the new configuration consents to manage effectively and efficiently the rubber hoses inventory owing to the different productivity levels of the Skinning and the Assembly workstations; in effect, the rubber hoses can be directly stored into the bins placed on the manual conveyor, instead of being stocked on the shelved located between the workstations. Figure 19 and figure 20 show the actual configuration and the final solution, respectively.

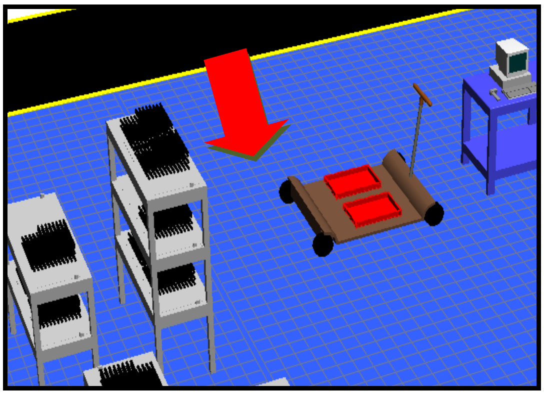

Figure 11. Actual workstation configuration for moving the skinned rubber hoses to the successive workstation.

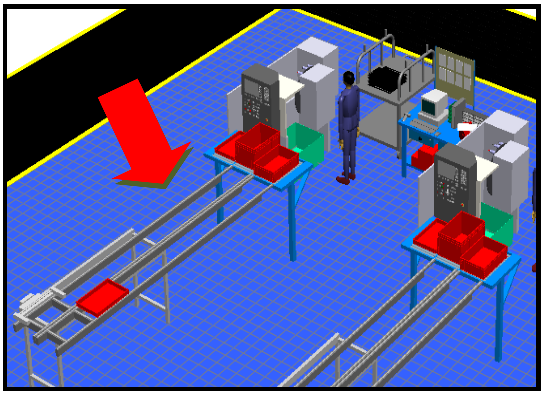

Figure 12. Final workstation configuration for moving the skinned rubber hoses to the successive workstation.

The workstation changes have been tested by means of the simulation model evaluating the ergonomic risk levels and the time required for performing the skinning operations within the new configuration. The ergonomic evaluation process did not detect any ergonomic problem. Moreover the new configuration requires to the workers about 1780 Kcal, as total amount of energy spent during the whole shift. Note that the EE reduction respect to the initial configuration is about 24%.

Concerning the work measurement analysis, Table 8 and table 9 reports the process times for each macro-activity performed within the new workstation configuration.

Table 8. Process time evaluated by the MTM analysis within the new Skinning workstation configuration

MTM analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	6.19
Macro-activity 4	70.16
Total Preparation Time	76.35
Cyclic operation	**Time (sec.)**
Macro-activity 2	192.04
Macro-activity 3	255.12
Total Cyclic Time	397.16
Total time for completing the Shop Order	**523.51**

Table 9. Process time evaluated by the MOST analysis within the new Assembly workstation configuration

MOST analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	7.01
Macro-activity 4	72.56
Total Preparation Time	79.57
Cyclic operation	**Time (sec.)**
Macro-activity 2	193.01
Macro-activity 3	256.32
Total Cyclic Time	449.33
Total time for completing the Shop Order	**528.9**

According the MTM analysis the total time required for completing the Shop Order is 523,51 sec. (about 8 min and 43 sec.). According the MOST analysis the total time required for completing the Shop Order is about 528,9 sec. (about 8 min and 48 sec.). Note that the process time improvement respect to the initial configuration is about 58%. The workstation producitity is 45 Shop Orders per day and the productivity improvement is about 56% respect to the initial workstation configuration.

6.2. The Assembly workstation redesign

Let us list the workstation changes the authors propose for reducing the ergonomic risks levels and for increasing the productivity levels within the workstation.

- A work table replaces the pallet being used for locating the rubber hoses before the assembly operations. This change allows the operators to avoid the continuous bending needed for picking the rubber hoses up. Figure 13 and figure 14 shows the actual configuration and the final solution, respectively.

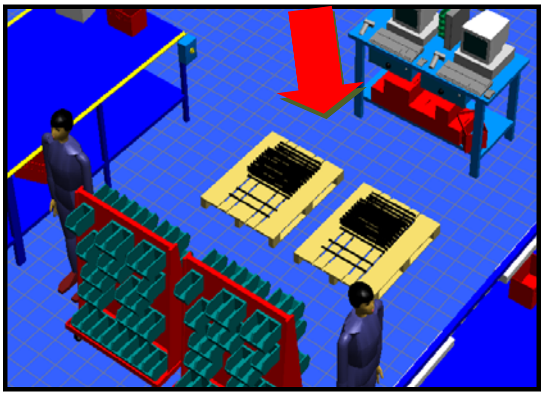

Figure 13. Actual workstation configuration for picking the rubber hose up before the assembly operation.

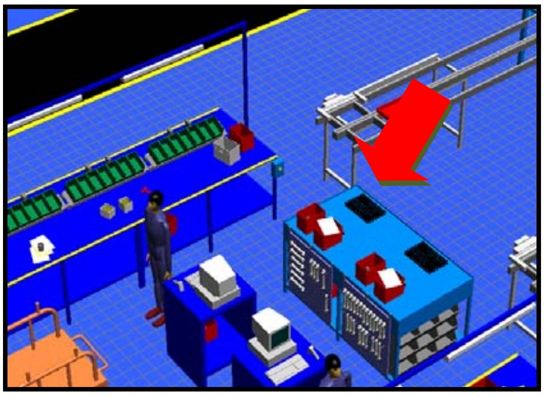

Figure 14. Final workstation configuration for picking the rubber hose up before the assembly operation.

- A manual dolly replaces the pallet being used for locating the high pressure hydraulic hoses after the assembly operations. Such change allows the operators to avoid the continuous bending needed for performing this operation. Figure 15 and figure 16 shows the actual configuration and the final solution, respectively.

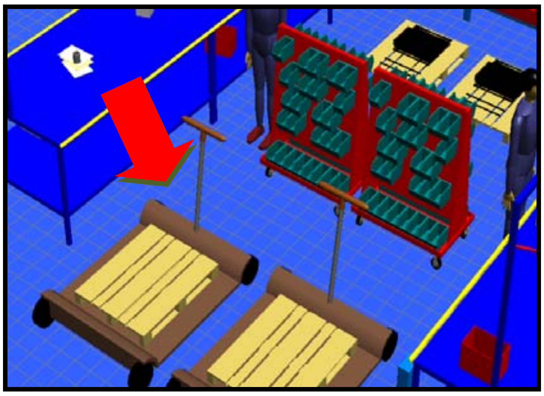

Figure 15. Actual workstation configuration for moving the high pressure hydraulic hoses to the successive workstation.

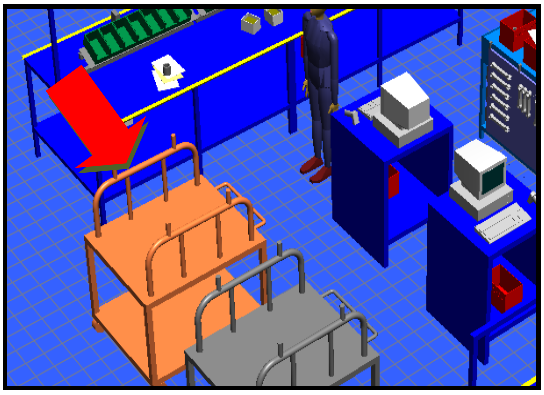

Figure 16. Final workstation configuration for moving the high pressure hydraulic hoses to the successive workstation.

- The PC being used by the operator for setting the status "end of operation" on the company informative system, has been moved closer to the assembly work table. Note that such change allows to reduce the number of steps required by the operator for reaching the PC worktable; figure 17 and figure 18 show respectively the actual and the final workstation configurations.

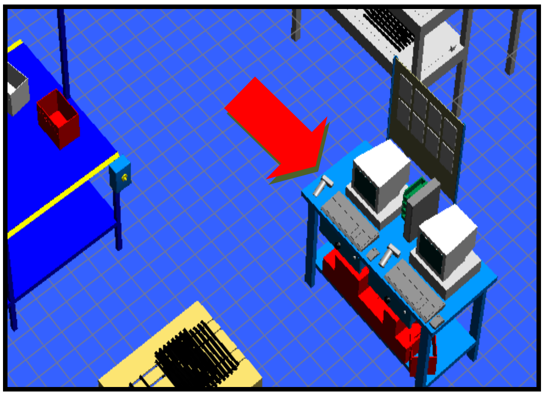

Figure 17. Actual workstation configuration of the PC location.

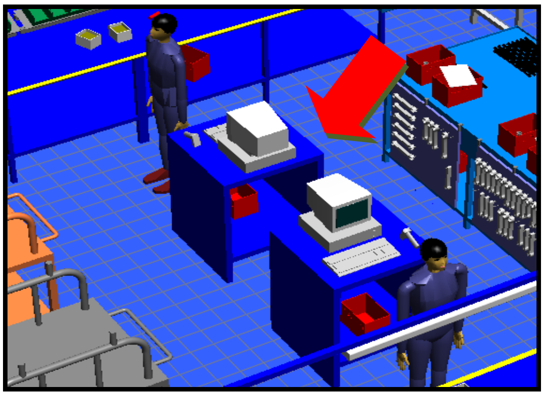

Figure 18. Final workstation configuration of the PC location.

- The ring nuts and fittings bins have been placed to the work table in order to reduce the time required to the operators for reaching and managing such components. Figure 19 and figure 20 show respectively the actual and the final workstation configurations.

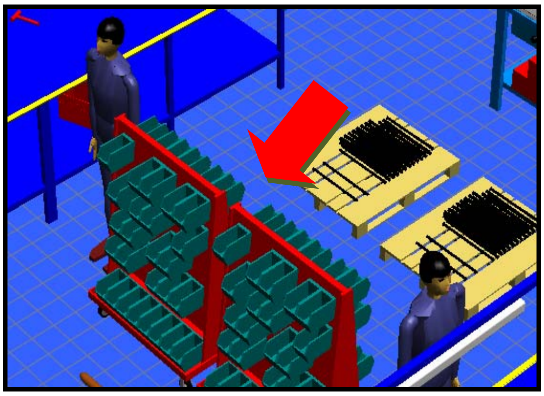

Figure 19. Actual workstation configuration of the ring nuts and fittings bins location.

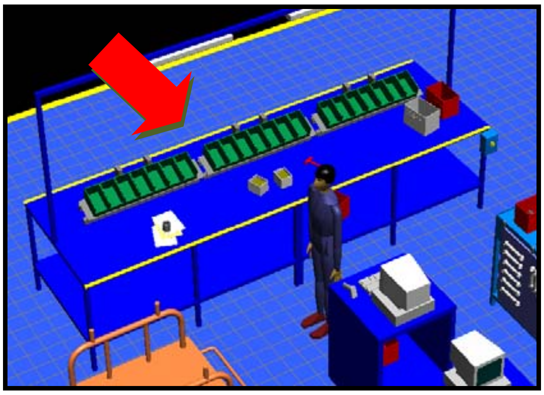

Figure 20. Final workstation configuration of the ring nuts and fittings bins location.

After the workstation changes implementation within the simulation model, the next step was the evaluation of the ergonomic risk levels and the calculation of time required for performing the assembly operations.

As the skinning workstation, the ergonomic evaluation process did not detect any problem related to the lifting tasks as well as no harmful body postures were identified. The total amount of energy spent during the whole shift is about 2340 Kcal. Note that the EE rduction respect to the initial configuration is about 18%.

Concerning the work measurement analysis, Table 10 and table 11 reports the process times for each macro-activity performed within the new workstation configuration.

Table 10. Process time evaluated by the MTM analysis within the new Skinning workstation configuration

MTM analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	8.14
Macro-activity 5	13.94
Total Preparation Time	22.08
Cyclic operation	**Time (sec.)**
Macro-activity 2	124.85
Macro-activity 3	368.57
Macro-activity 4	255.14
Total Cyclic Time	748.56
Total time for completing the Shop Order	**770.64**

Table 11. Process time evaluated by the MOST analysis within the new Assembly workstation configuration

MOST analysis	
Preparation operation	**Time (sec.)**
Macro-activity 1	8.67
Macro-activity 5	14.45
Total Preparation Time	23.12
Cyclic operation	**Time (sec.)**
Macro-activity 2	125.01
Macro-activity 3	369.05
Macro-activity 4	255.68
Total Cyclic Time	749.74
Total time for completing the Shop Order	**772.86**

According the MTM analysis the total time required for completing the Shop Order is 770,64 sec. (about 12 min and 50 sec.). According the MOST analysis the total time required for completing the Shop Order is about 772,86 sec. (about 12 min and 52 sec.). Note that the process time improvement respect to the initial configuration is about 53%. The workstation producitity is 31 Shop Orders per day and the productivity improvement is about 55% respect to the initial workstation configuration.

7. CONCLUSIONS

The paper advances the effective design of the most critical workstations (the Skinning workstation and the Assembly workstation) belonging to a real industrial plant. The authors propose an approach based on the integration of Modeling & Simulation tools, several ergonomic standards and the most known work measurement tools. The first step of the research work was the development of the workstations simulation model. The simulation model has been developed by using the CAD software Pro-Engineer and the simulation software eM-Workplace. After the simulation model validation, the ergonomic standards were accomplished for evaluating the ergonomic risks level affecting the workstations as well as the work measurement tools were used for calculating the time related to each operation performed within the Skinning and the Assembly workstations. The next step was the achievemnt of the workstations effective deisgn; in particular, the authors use the simulation model for comparing several workstations alternative configurations. Each workstations configuration was recreated within the simulation model and then all the configurations were compared by means of ergonomic and time indexes related to the ergonomic standards and work measurement tools used in this research work. Such comparison allows the authors to choose the workstations final configurations. The Skinning and the Assembly workstations final configurations do not present any ergonomic issue and are characterized by productivity levels higher than the initial ones. Further research activities are still going on (in cooperation with the same industrial plant) for analyzing the remaining workstations of the Assembly area.

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