Proceedings of the 2006 Winter Simulation Conference
L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds.

EFFECTIVE DESIGN OF AN ASSEMBLY LINE USING MODELING & SIMULATION

Francesco Longo
Giovanni Mirabelli
Enrico Papoff

Dept. of Mechanical Engineering
University of Calabria
Rende (CS), Via P. Bucci, 87036, Italy

ABSTRACT

The paper presents the results of a research work regarding the effective design of an assembly line for heaters production. Considering that the real plant still doesn't exist, simulation has been used as cognitive tool. After the modeling and the VV&A phases the simulation has been used for carrying out ergonomic analyses for each assembly line workstation. The simulation results highlight problems concerning high stress levels for some workers (due to legs bending) and ergonomic risks related to lifting tasks.

1 INTRODUCTION

The effective workplaces design must take into consideration both the study and analysis of working methods (by means of work measurement) and the ergonomic risks (by means of specific ergonomic analysis).

The design of an assembly line and its workstations is characterized by two critical factors, the line balancing and the ergonomic optimization of each single workstation. The line balancing is strictly related to the number of workstations, process and set-up times, type of operations (hand operated or automated). The ergonomic analysis allows evaluating potential hazard, musculoskeletal disorders, risks related to excessive weights as well as specific risk factors concerning lifting tasks or energy expenditure for the operation being performed.

One of the most important approaches for studying line balancing (with workstations characterized by manual operations) is work measurement. Well known methodologies in such context are MTM-1, MTM-2, MTM-3 (the acronym MTM stands for *Methods-Time Measurement*) and MOST (the acronym stands for *Maynard Operation Sequence Technique*). The objective of work measurement is to evaluate times standard for performing operations. The time standard is defined as the time required by an average skill operator, working at a normal place, to perform a specific task using a prescribed method, allowing time for personal needs, fatigue and delays (Zandin 2001).

The Methods-Time Measurement (MTM-1) is the most widely used system for evaluating times standard for manual operations. The official definition of MTM is: Methods-Time Measurement is a procedure which analyzes any manual operation or method into the basic motions required to perform it and assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made (Maynard et al. 1948).

MTM-2 and MTM-3 were developed to fulfill specific needs of practitioners. MTM-2 was developed in Sweden and offers to the user a lower degree of precision (for practical purposes the precision offered by MTM-1 is too high). MTM-3 can be used in presence of high variation of working methods. It is not appropriate for measuring highly repetitive work cycles.

MOST, the youngest methodology, concentrates on movement of objects (Zandin 1990) recognizing specific models to describe manual works. In particular the object movement can be a "general move" (movement trough the air from one point to another), a "controlled move" (the object remains in contact with a surface or the object path is controlled) or a "tools use sequence" (describing the manual tools that can be used during an operation).

Let's consider now the second issue in assembly line design problems, the ergonomic analysis of the workstations belonging to the assembly line. Several and different standards have been proposed in this field.

The National Institute for Occupational Safety and Health (NIOSH) has proposed two analyses for lifting tasks. The "NIOSH 81" evaluates the Maximum Permissible Limit or, in other words, the admissible weight that can be lifted and transported only by 1% of women and 25% of men (Niosh Technical Report 81-122).

The "NIOSH 91", an up-to-date of the previous one (Waters et al. 1994), evaluates the Recommended Weight Limit (RWL) in correspondence of two different instant of time (grasp and release). The Lift Index is obtained as ratio between RWL and the object weight. The Lift Index can be accepted if the value is lower than 1.

The "Burandt-Schultetus" analysis (Shcultetus 1980, Siemens AG 1981) allows evaluating the load limits for a specific working posture (keeping into consideration the weight of the grasped objects).

The "Garg" analysis (Garg 1976) calculates the total amount of energy spent during the manual operations (expressed in Kcal).

The "OWAS" (Owako Working posture Analysis System) gives information about the physical stress recorded in correspondence of each working posture of shoulders, harms and legs and in relation to the weights handled during the operations (Karhu et al. 1977, Karhu et al. 1981).

As previously mentioned both work measurement methodologies and ergonomic analysis allows an effective design of workstations and assembly lines. In such context simulation plays, for sure, a critical role giving the possibility to execute analysis on virtual three-dimensional workplaces and lines, test different operative scenarios and transfer the final results into the real system, saving time and money. In this paper the authors proposes an integration of Modeling & Simulation and ergonomic analysis to support the effective design of an assembly line made up by 4 workstations for assembling heaters.

2 ASSEMBLY LINE DESCRIPTION

The assembly line analyzed in this research work is still in the design phase. The line will be equipped to assemble heaters starting from the main components. Figure 1 shows the heater designed by mean of parametric CAD tools (Mirabelli et al 2002).

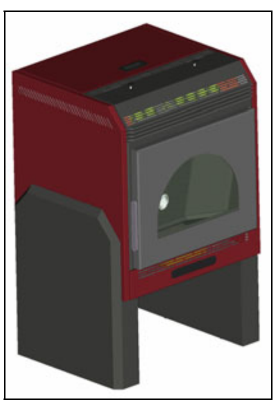

Figure 1: Heater CAD Design

The assembly operations have been subdivided in four different workstations. In figure 2 are shown all the main components that opportunely assembled forms the final product.

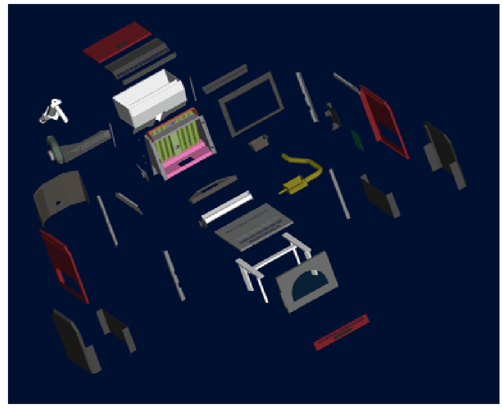

Figure 2: Heater Main Components

In the first workstation the operator places the heat exchanger inside the main frame, adds the door framework and inserts the combustion chamber.

In the second workstation the operator places the tank for combustible. The operation is quite difficult because the combustible transportation system must be opportunely assembled in correspondence of the tank hole in order to move the combustible from the tank to the combustion chamber during the normal functioning.

The worker of the third workstation performs all the operations required to assemble electric circuits, control systems and security systems.

In the last workstation, characterized by two workers, the heater is completed adding all the shells and protective covering.

In addition to the operations performed in each workstation two different transportation tasks are required to complete the heather assembly process. The first one regards the transportation of the heater main frame in correspondence of the first workstation (such task is performed by means of hand operated dollies and overhead traveling crane). The second one is the movement of combustible tank from the warehouse shelves to the second workstation (manually performed by an operator).

In figure 3 are summarized the most important information characterizing the assembly line.

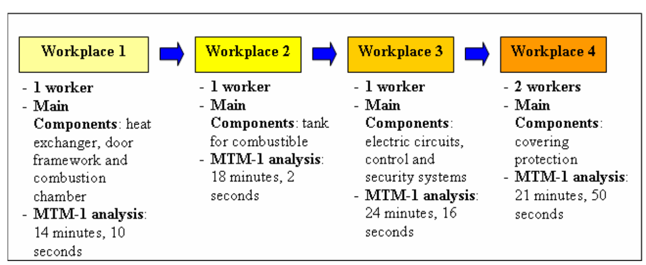

Figure 3: Assembly Line Characteristics and MTM-1 Results

Figure 3 reports also the results of the MTM-1 analysis for each workstation. These results have been obtained applying the MTM-1 in a previous analysis using the same simulation model (for the assembly line simulation model refers to the next paragraph). Thanks to MTM-1 analysis the line has been opportunely balanced adding the second operator in the last workstation.

3 ASSEMBLY LINE SIMULATION MODEL

The assembly line simulation model recreates all the operations previously described in a three-dimensional virtual environment, see figure 4, by means of commercial simulation package (eM-Workplace by Tecnomatix Technologies).

The modeling phase can be subdivided in two main steps:

- plant lay-out generation;
- human models inserting and characterization.

The plant lay-out has been designed using CAD software, importing and directly opening all the generated files in eM-Workplace. The plant lay-out organization reflects the results obtained applying one of the traditional methodologies for plant lay-out study and analysis (Longo et al 2005).

For what concern human models they can be imported from software libraries and inserted in the simulation model.

At the beginning the human model is only able to stand in his waiting position. In order to recreate all the assembly operations it is required to "train" the human model. Each operation is subdivided in basic motions and for each basic motion the software asks to the user to insert specific code consequently allowing the human model to perform the required operations. Particular attention must be paid for information regarding grasp and release operations and the relative human model concentration index as well.

The intrinsic difficulty of such modeling approach is due to the high quantity of information and data required to properly set the human models and the plant lay-out elements.

In fact in addition to the motions sequences it's required to insert data regarding:

- age, gender, physical characteristics, health conditions, skills, efforts, consistency and performances of each human model;
- weights and dimensions of objects together with grip quality;
- weight and dimensions of tools used during the operations;
- worker posture at the origin and destination of lifting operations;
- frequencies and duration of lifting tasks;
- process and set-up times of operations not performed by human models.

After the modeling phase the successive step was the validation.

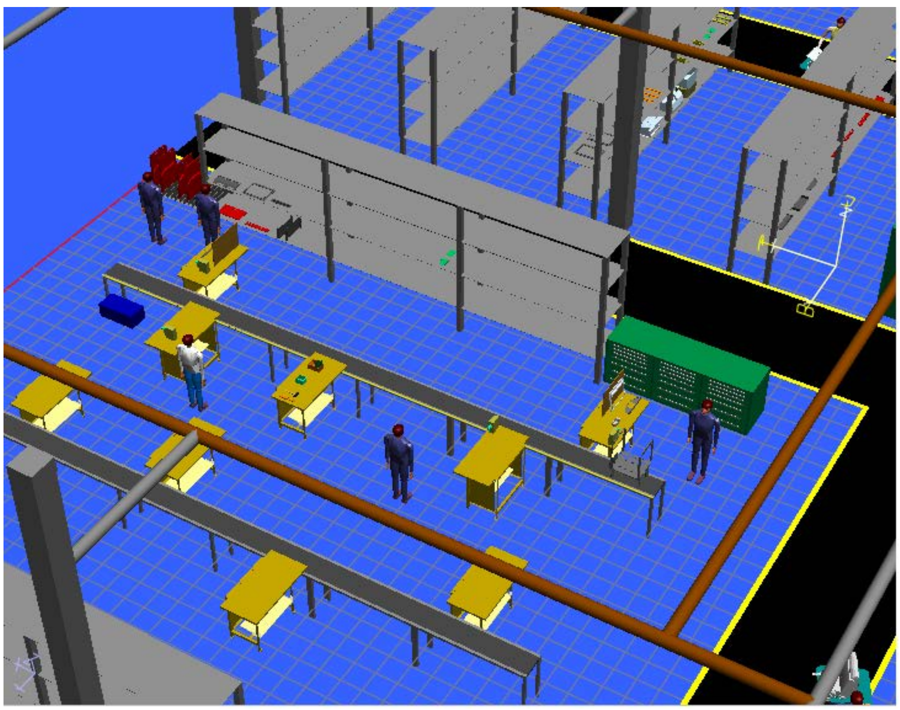

Figure 4: Simulation Model of the Assembly Line

As before mentioned the real system doesn't exist so simulation in this case is a cognitive tool. There is no possibility to compare the simulation model results with data deriving from other models or existing systems. Anyway, in order to conduct the validation phase, simulation results (in terms of times standard) have been discussed and analyzed with system's experts, managers and operators usually working in similar workstations.

Each single sequence motions has been analyzed in accordance with operators' advices and completed with movements previously not considered. Repeating interactively such procedures the times standard (reported in figure 3), evaluated by means of MTM-1 analysis, have been accepted (following experts' opinions) as reliable results.

The animation during the simulation shows all the assembly operations and transportation tasks as well.

In figure 5 is shown the operations performed into the workstation 1 while figure 6 shows components transportation from the warehouse to the assembly line (manually performed by an operator).

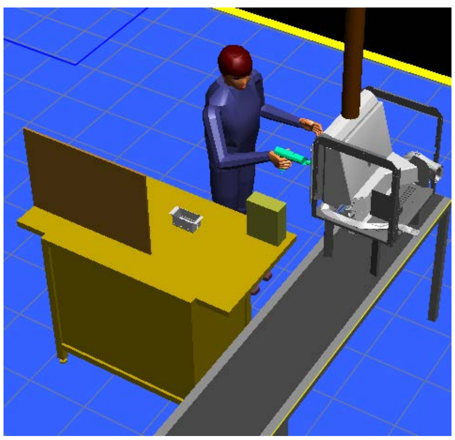

Figure 5: Assembly Operations in the First Workstation

Figure 6: Transportation Task Manually Performed

4 ERGONOMIC ANALYSIS

The objective of the simulation model is to carry out ergonomic analyses on the four workstations of the assembly line by means of the simulation model. The analyses performed are the following:

- Lift analysis (based on Niosh 91 and Niosh 81);
- Burandt-Schultetus analysis;
- Garg analysis;
- OWAS analysis.

The Lift, the Burandt-Schultetus and the Garg analyses have been executed on workers that manually move the heater main components from the warehouse to the manual operated dolly (see figure 6) and from the dolly to the assembly line.

The simulation model proposed in this paper can be considered as static and deterministic. All numeric quantities such as process times, transportation times, frequencies and so on, are previously inserted by the user or evaluated by means of the MTM-1 method (for manual operations) as before explained. So it's not required any specific methodology for conducting the simulation experiments (two consecutive simulation runs give the same results).

Table 1 reports analysis results in output from the simulation model (except for the OWAS analysis).

Table 1: LIFT, Burandt-Schultetus and GARG analyses

LIFT Analysis (Niosh 91)	
Lift Index, Origin	LI = 1.24216
Lift Index, Destination	LI = 1.05490
LIFT Analysis (Niosh 81)	
Action Limit	AL = 12.30852 Kg
Max. Permissible Limit	MPL = 36.92555 Kg
BURANDT SCHULTETUS Analysis	
Permissible Limit	PL = 140.40000 N
GARG Analysis	
Energy Expenditure	EE = 1.80860 Kcal

The Lift Index, LI, evaluated by means of NIOSH 91 analysis, estimates the physical stress of two handed manual lifting tasks. A lifting task is defined as grasping an object with two hands and lifting it vertically through space without any assistance (Zandin 2001) as in figure 6 for the case proposed. The NIOSH 91 analysis calculates the Recommended Weight Limit (RWL) (refer to Waters et al. 1994 for further explanation about Niosh formulas) and compares it with the actual weight being lifted (in other words the lift index is the ratio between RWL and the actual weight).

In correspondence of the origin point (lifting and transportation from the shelf warehouse to the manual operated dolly) the Lift Index is equal to 1.242 (greater than 1). An analogous problem has been found for the destination point (lifting and transportation from the dolly to the assembly line conveyor). In this case the Lift Index is equal to 1.054 (slightly greater than 1). The Composite Lift Index (CLI) is obviously grater than 1 (CLI= 1.242).

As suggested by NIOSH 91 analysis such Lift Indexes in output from the simulation model are greater than one and cannot be accepted, so the transportation tasks are unacceptable ergonomic risks.

The lift analysis based on NIOSH 81, keeping under consideration the frequency of lift operations, the lifting range as well as all the input data described in the previous paragraph, gives as results acceptable weights to be handled.

The Action Limit, AL, is equal to 12.30 Kg (psychophysical studies suggest over 75% of women and over 99% of men can lift loads equals to Action Limit).

The Maximum Permissible Limit, MPL, is equal to 36.92 Kg (psychophysical studies show that about 25% of men and 1% of women are able to lift load greater than MPL).

NIOSH 81 results asses that for the described context lifting tasks above the MPL cannot be accepted, lifting tasks in the range of AL and MPL must be kept under control (for instance alternating lifting tasks with recovering times), whilst lifting tasks under AL can be accepted as nominal ergonomic risks.

The Burandt-Schultetus analysis is applied to two hands lifting activities in which a large number of muscle groups are involved (as in the case analyzed). It gives as result the maximum weight (Permissible Limit, PL) that the worker can lift. From table 1 the PL is equal to 140.4 N.

The Garg analysis measures the amount of energy expended during the manual activity analyzed (refer to Garg 1976 for further information about formulas used). The energy expenditure is equal to 1.80 Kcal that is 7.53 KJ. High values of energy expenditure mean high stress rate for that manual activity.

The OWAS analysis results, as mentioned into the introduction, expresses the stress level associated with working postures. The simulation can give as output 4 different stress levels:

- stress level equals to 1; it means that the stress level is optimum, no corrective interventions are required;
- stress level equals to 2; it is required a corrective intervention in the near future (the worker could have some problems as the time goes by)
- stress level equals to 3; it means high stress level, a corrective intervention is required as soon as possible;
- stress level equals to 4; it means very high stress level, a corrective intervention is immediately required.

The OWAS analysis carried out for all the operators has highlighted only one problem for the third workstation (electrical circuits, control and security system assembly). The problem is due to position of electrical circuits located in the lower part of the heater main frame causing as consequence a continuous legs bending. The stress level is equals to 3, it means that a corrective intervention is required as soon as possible.

5 SYSTEM'S DESIGN MODIFICATIONS

The ergonomic analysis and related results impose system's design modifications for improving ergonomic efficiency.

The lifting tasks manually performed by the operator for moving components from warehouse to assembly line must be avoided. In particular the operator, in order to perform the required operation, must use a forklift or the overhead traveling crane.

In order to avoid legs bending (for operators working in the assembly line) the conveyor height has been increased. It's important to underline that increasing the conveyor height the problem highlighted by OWAS analysis is resolved but, a new problem, on the fourth workstation comes out. The greater conveyor height doesn't allow the assembly of heater superior protective coverings. This last problem has been fixed providing the operators of the last workstation with a step to be used during the previously mentioned operations.

Considering that the assembly line still doesn't exist the corrective interventions have been immediately proposed assuring money and time savings.

6 CONCLUSIONS

The paper focalizes on the effective design of assembly line workstations by means of integration between ergonomic analyses and Modeling & Simulation. The starting point is the plant lay-out of a production system still in the design phase.

The simulation model recreates all the assembly operations in a three-dimensional virtual environment giving the possibility to see, during the animation the human models performing the required operations. In such context the simulation has been used as cognitive tool. In fact the validation of the simulation model (in terms of times standard for each workstations evaluated by means of MTM-1) has required detailed discussions with system's experts as well as iterative integration of sequence motions.

The ergonomic analyses, carried out after the validation of the simulation model, have revealed different problems on lifting and transportation operations and on working postures. In particular problems related to Lift analysis have been fixed providing the operator with a forklift and avoiding to use manual operated dollies. The high stress level, due to legs bending, of the third workstation has been deleted modifying the conveyor height and adding a step for the workers of the last workstation (the step is required as consequence of the conveyor height change).

Further results regard the characterization of the operators performing lift operations in terms of Action Limit, Maximum Permissible Limit, Permissible Limit, and Energy Expenditure. At last we can conclude stressing, once again, that Modeling & simulation in combination with ergonomic analyses is a powerful tool for analyzing assembly line and providing effective design and optimal ergonomic solutions.

REFERENCES

Garg A. 1976. *A metabolic rate prediction for manual materials handling jobs*. Dissertation, University of Michigan.

Kharu O. et al 1977: Correcting working postures in industry: a practical method for analysis. In: *Applied Ergonomics 8*.

Kharu O. et al 1981: Observing working postures in industry: Examples of OWAS application. In: *Applied Ergonomics 12*

Longo F., Mirabelli G., Papoff E., 2005. Techiche di analisi avanzate per la progettazione efficiente delle postazioni di assemblaggio manuale, SdA – *Soluzioni di Assemblaggio, VNU Business Publications Italia*.

Longo F., Mirabelli G., Papoff E. 2005, Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System, *Proceedings of intelligent data acquisition and advanced computing systems*, September 5 – 7, Sofia (Bulgaria).

Longo F., Mirabelli G., Papoff E., 2003. Cape applications in special glass manufacturing, *Proceedings of intelligent data acquisition and advanced computing systems*, pp.385-389, September 8 – 10, Lviv, Ukraine.

Longo F., Mirabelli G., Papoff E., Grande A., 2003. Cape Application in special wood frames manufacturing, *Proceedings of international conference on the Modern and information technology in the innovation of the industrial enterprises*, September 4 – 6, Vol. 1, pp. 31-36, Saarbruecken, Germany.

Longo F., Mirabelli G., Papoff E., 2005. Modelli di Simulazione per la riconfigurazione strutturale delle postazioni di lavoro, *Proceedings of Associazione nazionale di impiantistica*, October 6 – 7, Rimini, Italy.

Maynard H. B., Stegemerten G. J., Schwab J. L., 1948. *Methods-time measurement*. McGraw Hill book company, New York.

Mirabelli G., Muzzupappa M., Papoff E., 2002. From the model to the digital factory: integration between planning and production process. *Proceedings of international conference on the Modern and information technology in the innovation of the industrial enterprises*, June 27 – 29, Savona, Italy.

Niosh Technical Report 81-122. National Institute for Occupational Safety and Health (Hrsg.): Work practices guide for manual lifting. (Center for Disease Control, U.S. Department of health and human services). Cincinnati, OH, USA: NTIS 1981.

Schultetus W., 1980. Daten, hinweise und beispiele zur ergonomischen arbeitsgestaltung. Montagegestaltung, Verlag TÜV Rheinland Gmbh, Köln.

Siemens AG, 1981. Daten und Hinweise zur Arbeitsgestaltung: Korperkrafte, Erlangen.

Waters T. R., Vern P. A., Garg A., 1994. Application Manuals for the Revised NIOSH Lifting Equation, U.S. Department of health and human services, National Institute for Occupational Safety and Health, Cincinnati, OH, USA.

Zandin K. B., 2001. *Maynard's Industrial Engineering Handbook* – Fifth Edition, McGraw-Hill.

Zandin K., 1990. *MOST Work Measurement Systems*, Marcel Dekker 1st and 2nd eds., New York.

AUTHOR BIOGRAPHIES

FRANCESCO LONGO was born in Crotone (Italy), on February the 08th, 1979. He took the degree in Mechanical Engineering from University of Calabria (2002). He received the PhD in Industrial Engineering (2005). He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard modeling & simulation of manufacturing systems and supply chain, DOE, ANOVA. His e-mail address is <f.longo@unical.it>.

GIOVANNI MIRABELLI was born in Rende (Italy), on January the 24th, 1963. He took the degree in Industrial Technology Engineering from University of Calabria. He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard work measurement and human reliability. His e-mail address is <g.mirabelli@unical.it>.

PAPOFF ENRICO was born in Naples (Italy) on February the 03rd, 1948. He took the degree in Mechanical Engineering from University of Napoli Federico II, in 1973. He is currently Associate Professor at the Mechanical Department (Industrial Engineering Section) of the University of Calabria. His research interests regard project management and business plans. His e-mail address is <e.papoff@unical.it>.