# Human factors in efficiency measurement of manufacturing production processes

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Despite a wide literature about benefits of ergonomic design of job processes and work environment, ergonomic interventions in manufacturing industries are commonly aimed to the simple and generic fulfillment of law constraints or, on the opposite, they are meant as single overcoming of a specific trouble. In this framework, the availability of protocols for monitoring practical effects of ergonomic interventions in short and medium period cold be crucial, in order to advise industrial management about social and financial benefits of ergonomics implementation.
This paper illustrates an experimental research in which a method for the efficiency assessment of production process in a white-goods industry has been developed in order to observe the effects on production system coming from ergonomic improvements of some working positions. A detailed description of the EMeHF methodological approach, steps and the results of its experimental application in one of the Indesit Company factories in Southern Italy are provided.

## INTRODUCTION

### Ergonomic interventions and organization expectation

Nowadays, the interest of companies towards ergonomics shows a general increasing trend but, if in product and service design there is a flourishing of studies aimed to demonstrate the return of investments in ergonomics, not the same it seems to be in manufacturing. In a manufacturing process, efficiency is the actual extent and accuracy of work tasks achievement in relation to spent resources. It has also to be considered that competitiveness is based on the optimal employment of available resources, of tangible or intangible nature; ergonomic approach to industrial process analysis can easily demonstrate that ergonomic doesn't represent a resources waste, rather it can be a long term benefit driver.

In general terms, the efficiency is the extent of whatever nature resources exploitation so that, obviously, the efficiency level is inversely related to resources consumption. Then, in a manufacturing process, efficiency is the actual extent and accuracy of work tasks achievement in relation to spent resources. Under the ergonomics perspective, efficacy and resources indicators should comprise not-financial aspects, in order to take account of personal resources employment by workers, so that one of most important step for process efficiency assessment is the definition of indicators and metrics for efficacy and resources description including human factors.

### The EIP project

This paper illustrates an experimental research in which a method for the efficiency assessment of production process in a white-goods industry has been developed in order to observe the effects on production system coming from ergonomic improvements of some working positions.

The EIP - Ergonomic Implementation Process is an applied research program, funded by INAIL Campania and Indesit Company, aimed to ergonomic and bio-mechanical risks analysis by an experimental study developed in the production plant of Teverola-Carinaro (Southern Italy). It has been conducted with a research and development approach, since after having defined a survey protocol for risk investigation, some specific solution have been designed, realized and assessed with the scope to validate the entire implemented ergonomic intervention process and drawing general recommendations for a wider application of the Ergonomic Implementation Process Protocol.

Within the validation phase of the EIP program, a protocol for assessing impact of ergonomic intervention on working conditions has been formalized, so that repeated measures of ergonomic working condition are allowed and impact of work environment transformations on production process become traceable, as described in following paragraphs.

## PROCESSES EFFICIENCY IN THE ERGONOMIC PERSPECTIVE

### EIP protocol for ergonomic working conditions survey

According to the overall scope of the project, that is the availability of a practical tool which is applicable in multiple contexts trigging effective technical decisions, a codified protocol for investigation of ergonomic conditions in manufacturing work environment was defined, also converted in an interactive tool (ERA Ergonomic Risk Assessment software).

In that way, an assessment tool integrating heterogeneous aspects and multiple specific methods from literature was created, in order to obtain a method for repeatable and reliable ergonomic evaluations of any type of working positions in mechanic manufacturing.

EIP protocol for ergonomic working conditions survey is based on the joined execution of hierarchical task analysis, layout analysis, literature methods for MSD risk assessment, providing also a qualitative evaluation of ergonomic features of workstation and related tasks.

In detail, proposed task analysis is based on a task breakdown structure of job cycles, where each task is observed indicating:

- brief description of task goal, movements, postures and handled devices and/or materials
- picture
- detailed description of required actions and related body part involved
- graphic, schematic, identification in plan or front view of point where task is accomplished in the workstation
- displacement in the workstation space required to accomplish the task
- description of used devices and tools
- actual duration of single task, excluding waiting and recovery time
- physical characteristics of work environment and handled objects, with indication of their possible impact on whole ergonomic risks conditions.

Layout analysis is conducted in order to find out possible constraints for operators coming from workspace specific shapes or organizations. It is carried out combining all displacements among the workstation points where single actions are accomplished in order to complete job cycle, so that plan depiction will show starting and ending points of job cycle, path reiterations and crossings as well as rotations.

Task and layout analysis accomplishment gives evidence of possible ergonomic risks related to strength exertion, repetitive movements, postures, so that risk assessment will be developed applying most appropriate among following standard methods: OCRA, NIOSH, Strain Index, Liberty Mutual Material Handling Tables, RULA, HAL.

At the end of these survey phases, the EIP method allow to express a qualitative assessment of ergonomic conditions for the whole workstation and each single task accomplished in it, comparing working conditions described in task and layout analysis with a set of ergonomic conditions indicators, defined for: physical ergonomics of workstations and devices, organizational ergonomic aspects, psycho-social ergonomic aspects. The adequacy of ergonomic conditions can be expressed by a rating showing percentage of fulfilled ergonomic conditions on their total set, highlighting those critical factors in working positions much needing ergonomic improvements.

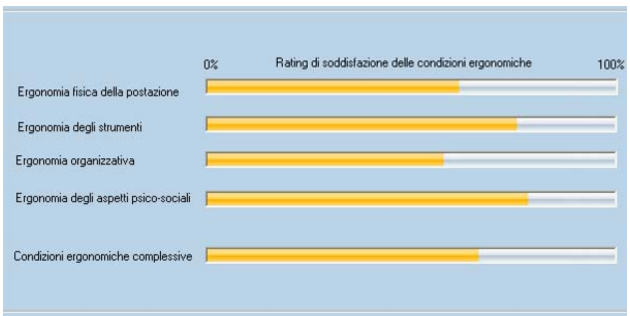


Figure 1: Sample of rating display of ergonomic conditions of a workstation assessed with ERA software and EIP protocol for ergonomic working conditions survey

**Closing the circle: measuring organization benefits from ergonomic intervention**

The effectiveness of any transformation design in job processes requires the management of many factors which often are broader than the single working position or production line. A possible strategy to control uncertainties and unexpected effects of ergonomic interventions in manufacturing industries, from either workers either organizations wellbeing side, is recurring to a standardized practice for ergonomic conditions monitoring over than analysis. Furthermore, it has to be considered that effectiveness of ergonomic interventions, meant as overcoming of detected critical points, isn't measurable in a short time view, since workers habits and self confidence in job execution often cause some resistance to changes, even if ameliorative. Moreover, attention should be paid in case of short time running of new workstation settings, as perception of immediate benefits and contingent appreciation of transformations wouldn't allow to find out possible new situations which, even less critical than first ones, would need further adjustments in a continuous improvement perspective. Thus, effects of organizational or technical implementations, on both workers and company, should be forecasted and monitored with a methodology which:

- finds design requirements coming from physical and organizational constraints most affecting health and comfort
- considers more alternative solutions before actual implementation
- foreshadows new possible risks for proposed changes with a preventive task analysis
- considers the permanent or temporary nature of the ergonomic intervention
- involves workers or their representatives in transformations design
- takes into account impact of changes on workers mood and motivation
- considers the effect of ergonomic intervention on process efficiency
- takes into consideration any kind of material and immaterial resources when estimating process efficiency
- provides operators with information and education about new job procedures and equipment
- involves all concerned corporate functions in intervention design.

Once the ergonomic improvement intervention is implemented, it is suggested to activate a monitoring program in order to do some little adjustment for transformation optimization grasping possible, not predictable, side effects. Then, it is suggested to:

- measure compliance of gained results respect intervention goals
- repeat task analysis after six and/or twelve months, also with the scope to understand self-adjustments realized by workers
- encourage suggestions and opinions by involved operators.

In this framework, the necessity of applied methods for process efficiency assessment including ergonomic factors is not just a theoretical ambition rather than a practical need for successful driving of ergonomics in industrial contexts.

## THE EMeHF PROTOCOL

### Combining peoples goals and process goals

The experimental research here presented propose a method for efficiency assessment of production process in a white-good industry in order to observe the effects on production system coming from ergonomic improvements of some working positions.

The consideration of ergonomic aspects in production process requires to include human factors among process inputs, which are not commonly included in traditional models for productivity analysis. In fact, in the ergonomics perspective, efficacy and resources indicators should comprise not-financial aspects able to represent personal resources employment by workers. The identification of effectiveness indicators proposed in the EMeHF (Efficiency Measurement through Human Factors) protocol is based on the assumption that activities goals are explicit and implicit; the achievement of production results compliant with quality management specifications can be considered as the process explicit goal, while among implicit purposes it can be taken into account the mandatory rules respect, the environment safeguard, workers health and well-being. Having assumed that, the method EMeHF found the effectiveness measurement on both production pieces and workers safety, considering as production cycle effectiveness of a white-goods industry standard parameters such numbers of pieces correctly treated, but also ergonomic parameter as number of work accident, MSD or injuries, in relation to the work plant and industrial sector statistics. Once determined efficacy indicators, it has been possible to define resources needed to achieve them. In this case, some of ergonomic factors considered are: time needed by operator for task accomplishment at starting and ending displacements, number and length of displacements, required skills, strength exertion, posture comfort, accuracy required by task, etc.

The aim to build a protocol for comparing different efficiency levels coming from different transformation hypotheses entails the necessity to convert in homogeneous value the efficiency measures, therefore, the EMeHF protocol provides a conversion table to turn into numerical ratings the heterogeneous markers considered.

### Effectiveness indicators in EMeHF

In order to identify effectiveness indicators we can consider that the scope of an activity is defined by implicit and explicit goals. An explicit goal is the one fixed for the system function and then, in manufacturing, it can be intended as a final product consistent with production process requirements. Among the implicit goals of an activity we can identify other types of productive process finalities, such the observance of the mandatory norms, psycho-physical well-being protection of workers, environment protection, etc. In a manufacturing workstation, for example, we can refer efficacy indicators both to production measures both to operators safety, defined as follows:

- number of consistent pieces in the a given time compared with the available time;
- number of work injuries occurred in the workstation compared with the number of operators working to that workstation;
- number of workstation operators affected by MSD in the last two or three years compared with the number of operators working to that workstation;
- number of operators got injured acting to the workstation compared with the number of operators working to that workstation;
- …

### Resources consumption indicators in EMeHF

After having identified indicators for work activity goals measuring, we can define necessary resources to achieve them. In case of mechanic manufacturing workstations we need to put a particular attention to ergonomic aspects identifying time, physical force and worker involvement components (mental effort, motivation, etc.) as factors representing exploited resources. Therefore efficiency indicators of job cycle can be indicate as follows:

- neat time spent by the worker to carry out his assigned job cycle, in different conditions (in rest condition, at the beginning of the work shift and in fatigue condition, at the end for the work shift);
- number of displacements in work space for job cycle;
- total length of displacements in work space for job cycle;
- number of work days lost for health leaves compared with plant average;
- number of discomfort complains even without registered disorders;
- required labor specialization for job tasks;
- demanded strength exertion for job tasks;
- demanded accuracy for job tasks;
- demanded attention for job tasks in relation to the shape of pieces to manipulate;
- demanded attention for job tasks in relation to the constraints deriving from conformation of work place;
- postural comfort;
- risk exposure level to work related MSD, assessed by standard methods (NIOSH, OCRA, SI, etc.)
- …

In order to produce an efficiency assessment protocol of a workstation different shapes and layout, we need to make efficacy levels obtained by different evaluations comparable; also make scores representing to the efficacy and spent resources to be compared have to be homogeneous. Consequently, identification of measuring parameters, accordingly with each indicator, has to be completed with gathered measures in score conversion. This operation have to be preliminarily executed considering each analyzing plant specificities.

## A CASE STUDY FOR EMeHF PROTOCOL APPLICATION IN A WHITE GOODS INDUSTRY

The case study relates the efficiency measurement of new working conditions in a workstation devoted to the front counterbalance mounting in production lines of washing machines, after its ergonomic improvements. Measured parameter and corresponding score for assessment of effectiveness and efficiency in this specific case study are specified below.

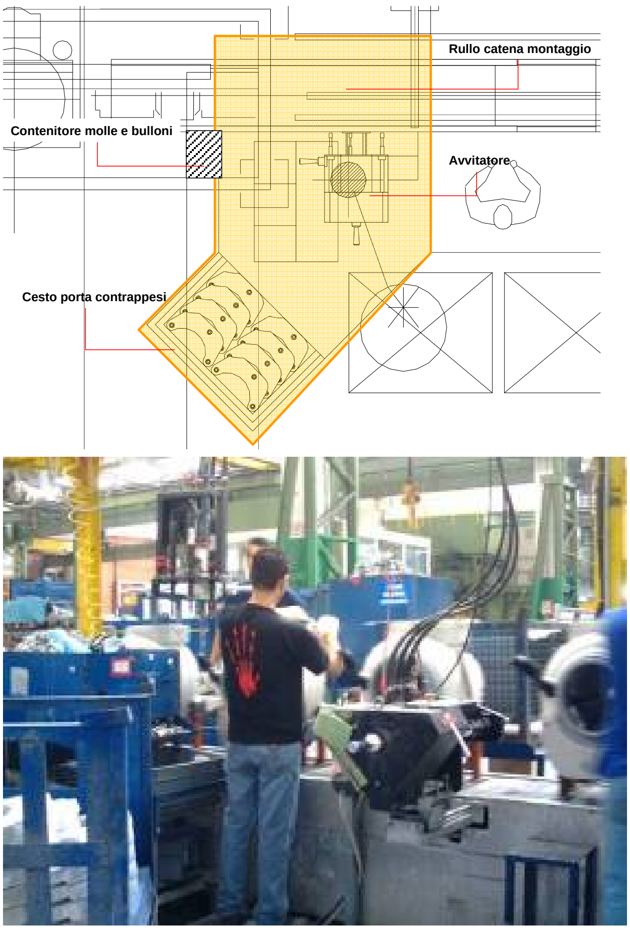


Figure 2: Analyzed workstation for counterbalance mounting

### Effectiveness indicators

Compliant pieces

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Faulty pieces/ produced pieces | - >0,00006 = 1 point<br>- 0,00006 - 0,00003 = 2 points<br>- 0,00003 - 0,000015 = 3 points<br>- <0.000015 = 4 points |

Work injuries happened at specific workstation

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Number of work injuries at workstation in last 3 years / Number of workers shifting at workstation | - < 0,05 = 3 point<br>- 0,05 – 0,1 = 2 points<br>- 0,1 – 0,2 = 1 points<br>- > 0,2 = 0.5 points |

Work related MSD disorders

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Number of MSD diagnosed at workstation in last 3 years / Number of workers shifting at workstation | - 0 = 3 points<br>- 0,01 – 0,1 = 2 points<br>- >0.1 = 0,5 points |

Number of workers got injured ad workstation compared with national statistic data for the same industrial sector

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Difference between number of injuries happened at workstation and average number of injuries happened in the industrial sector* (expressed as number of injuries / 1.000.000 worked hours)<br>*for mechanic manufacturing number of ingjuries/1.000.000 worked hours = 19,32 | - Number of injured workers at workstation > national average + 5 = 1 point<br>- Number of injured workers between national average + 5 and national average – 5 = 2 points<br>- Number of injured workers at workstation > national average - 5 = 3 points |

### Exploited resources indicators

Time

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Net seconds spent by worker / available seconds | - 0.7 = 2 points<br>- 0.7 - 0.9 = 1 point*<br>- 0.9 – 1.0 = 2 points<br>- > 1 = 3 points. |

Number of displacements in workspace for job cycle

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Number of displacements/ job cycle duration in seconds | - <0.03 = 2 points<br>- 0.03 - 0.05 = 1 points *<br>- >0.05 = 3 points<br>*On the ergonomics point of view it is preferable to avoid fixed postures, therefore short displacements are considered as positive aspects for human resources protection |

Total length of displacements in workspace for job cycle

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Meters/ job cycle duration in seconds | - <0.03 = 2 points*<br>- 0.03 -0.05 = 1 points<br>- >0.05 = 3 points<br>*On the ergonomics point of view it is preferable to avoid fixed postures, therefore short |

| Measured parameter | Corresponding effectiveness score |
|---|---|
| | displacements are considered as positive aspects for human resources protection |

Number of work days lost for health leaves compared with plant average

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Difference between number of work days lost by workstation operators and plant average | - Number of work days lost by workstation operators < plant average – 0.5 = 1 point<br>- Number of work days lost by workstation operators between plant average – 0.5 and plant average + 0.5 = 2 points<br>- Number of work days lost by workstation operators > plant average + 0.5 = 3 points |

Number of discomfort complaints, even without registered disorders

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Number of complaints in last 3 years / total number of workers shifting at specific | - Number of complaints > 0.30 = 4 points<br>- Number of complaints between 0.3 and 0.15 = 3 points<br>- Number of complaints between 0.15 e 0.05 = 2 points<br>- Number of complaints <0.05 = 1 point |

Required labour specialization for job tasks

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Professional skills of operators | - Level 1 of collective labour agreement in mechanic manufacturing industry = 1 point<br>- Level 2 of collective labour agreement in sector = 2 points<br>- Level 3 of collective labour agreement in sector = 3 points<br>- Level 4 of collective labour agreement in sector = 4 points<br>- Level 5 of collective labour agreement in sector = 5 points |

Demanded strength exertion

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Perceived intensity of requested effort | - Barely noticeable or relaxed effort = 1 point<br>- Noticeable or definite effort = 2 points<br>- Obvious effort; unchanged facial expression = 3 points<br>- Substantial effort; changes facial expression = 5 points<br>- Uses shoulder or trunk to generate force = 5 points |

Demanded accuracy for job task

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Importance of damages in case of non-accuracy | - Non-accuracy causes irreversible damages of worked piece or of some of its parts = 4 points<br>- Non-accuracy causes requires to work again the piece = 3 points<br>- Non-accuracy requires to repeat done actions or tasks without consequences for worked piece = 2 points<br>- Non-accuracy hasn't effects because it is impossible to happen = 1 point |

Demanded attention for job tasks in relation to pieces to manipulate

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Risk of likely errors | - Parts to be manipulated or assembled have constraints impeding their improper use = 1 point<br>- Parts to be manipulated or assembled could be used improperly = 2 points<br>- Parts to be manipulated or assembled often are misused (e.g. a screw badly slotted and then appropriately replaced) = 3 points |

Constraints deriving from workspace shape

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Risk of likely injuries | - Workstation has edges or protruding parts with which it is likely to bung = 2 points<br>- Workstation has drop where it is likely to slip or fall = 2 points |

| Measured parameter | Corresponding effectiveness score |
|---|---|
| | - Worker is allowed to trim in a not controlled way its workstation = 2 points |

Posture comfort

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Comfort level offered by the workstation according NASA definition of neutral posture | - Operator's body posture has no deviation from the NBP defined by NASA = 1 point<br>- Operator's body posture has some mid-range deviation from the NBP defined by NASA = 2 points<br>- Operator's body posture has some wide-range deviation from the NBP defined by NASA = 4 points |

Risk exposure level to work related MSD

| Measured parameter | Corresponding effectiveness score |
|---|---|
| Risk exposure level to work related MSD according Revised NIOSH Lifting Equation | - Lifting index < 0,75 = 1 point<br>- Lifting index 0,75 = 2 points<br>- Lifting index >1 = 4 points |
| Risk exposure level to work related MSD according OCRA check-list method | - OCRA index < 7,5 = 1 point<br>- OCRA index between 7,6 and 11 = 2 points<br>- OCRA index between 11,1 - 14.0 = 3 points<br>- OCRA index between 14,1 – 22,5 = 4 points<br>- OCRA index between > 22,6 = 5 points |
| Risk exposure level to work related MSD according Strain Index method | - Strain Index < 3 = 1 point<br>- Strain Index between 3 and 5 = 2 points<br>- Strain Index between 5 and7 = 3 points<br>- Strain Index between > 7 = 5 points |

From above criteria application, the efficiency level measured before ergonomic intervention is:

$$\text{Efficiency}_{\text{before}} = \frac{\text{Efficacy}_{\text{before}}}{\text{Exploited resources}_{\text{before}}}$$

$$\text{Efficiency}_{\text{before}} = \frac{8{,}5}{38} = 0{,}22$$

**RESULTS AND CONCLUSIONS**

The study evidences that work cycle efficiency level assessed after workstation ergonomic improvements cannot be calculated in quantitative terms, i.e. giving a particular number, as in the case of the efficiency level evaluated before the interventions.

In fact, shortness of improvement application time would give partial results about efficiency and spent resources not significant in statistic term, and therefore numerically identified. Anyway, we can singularly compare spent resources and efficacy levels scores matching values assessed before and after ergonomic implementations of workstation, verifying how these scores have increased or decreased with the consequent improvement of the global efficiency level.

From comparison we can see that global efficiency level will be grater after ergonomic interventions. In fact our experimental study demonstrates that the number of MSD decreases, with a consequent efficacy score increasing from 2 to 3 points, other indicators are unchanged, while the score relating to injured operators is insignificant considering the shortness of time for follow up, even if it surely expected to not decrease if compared with the 3 points score of this parameter in the efficiency assessment conducted prior ergonomic interventions.

However we can deduce that:

$$\text{single efficacy measured parameter}_{\text{after}} > \text{single efficacy measured parameter}_{\text{before}}$$

For what concerns resources consumption, the scores comparison shows that the value of global spent resources will be probably lower after ergonomic improvement interventions. In fact the study demonstrates that, excluding an increasing number of displacements per work cycle inside work station derived by a manipulator introduction, all remaining resources decrease considerably with ergonomic improvements. We can see, for example, the improvement in resources consumption to maintain comfortable postures during work tasks (from 4 to 2 points of score), or the significant decreasing of exposure to the MSD risk (from 4 to 1 point of score).

$$\text{single exploited resources measured parameter}_{\text{after}} < \text{single exploited resources measured parameter}_{\text{before}}$$

Even if partial, these results show it will be very probable that spent resources global values will be lower after ergonomic interventions on workstation, with a consequent increasing of total efficiency level of production process.

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