BALANCING MIXED ERGONOMICS -MODEL ASSEMBLY LINE TO REDUCE WORK OVERLOAD IN A MULTI-LEVEL PRODUCTION SYSTEM

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ABSTRACT

Several published case studies demonstrate that ergonomics considerations might lead to change the workstations layout and task time values. Traditional procedures take into account only task time analysis and precedence relations, while human postures evaluation is often not integrated in these techniques. Up to now many industrial fields require a systematic approach to allow assembly system design including ergonomics guidelines. The aim of this paper is to investigate how ergonomics and assembly system configurations are intimately related in practice, and to develop a conceptual framework for the assembly system design, in conjunction with ergonomics optimization of the work place. An industrial case to illustrate the procedure application is presented and advanced simulation software is used, as final step, to validate the procedure and support the theoretical framework.

Keywords :- Line Balancing, Process Mapping, Modeling & Simulation, Bucket Brigade Method

1.INTRODUCTION

Several work activities, in particular those associated with repetitive movements and with considerable level of stress or with extended assumption of uncomfortable posture, might be correlated to the insurgence of Muscolo-Skeletal Disorders (WMSDs= Work related Muscolo-Skeletal Disorders). It is known that these kinds of disorders involve high costs linked to absence, medical insurance, and rehabilitation. In addition to the overall increase of WMSDs, there is substantial evidence that ergonomics improvements result in financial gains for companies [1]. Ergonomics is defined as the applied science of equipment design, as for the workplace, intended to maximize productivity by reducing operator fatigue and discomfort. Benefits provided by ergonomics application in assembly systems design are first of all linked to the reduction in occupational injury risks and to the improvement of health condition and motivation of human resources. Secondly, ergonomics improvements permit to improve process quality and operators productivity. The link between ergonomics and process quality has been often investigated in published literature: Drury [2] analyzes the relationship between ergonomics and quality improvements of the production system and provides a guideline for a discipline that includes quality and ergonomics. Gonzàlez et al. [3] and Eklund [4] study the relationship between ergonomic performance and quality by empirical applications in industrial contexts. It is clear that attention to workplace ergonomics and reduction of Work-related musculo-skeletal disorders (WMSD) are worthwhile [1]. For these and other reasons, the links between assembly system design and balancing problems and ergonomics evaluation techniques achieve strategic importance in practice. Previous projects have demonstrated the extra value of combining assembly engineering with ergonomics [5,6]. De Looze et al. [6] apply an integrative approach bringing together assembly engineering and ergonomics disciplines in order to identify bottleneck and offer improvements. They need to be integrated. Computer aided workplace design and postural analysis software tools permit to simplify the analysis and create a virtual man-model [1],while traditional procedures are still time-consuming and often unfeasible in practice. Published literature on assembly systems design often focuses on balancing and sequencing procedures and addressing the mixed-model assembly line balancing problem (MALBP) in different layout configurations, developing exact, or heuristic methods [7]. Most methods address the balancing problem of traditional serial assembly systems and, in some cases; they allow the use of identical parallel workstations at each stage of the serial system. A considerable group of authors investigates the balancing problem in case of U-shaped layouts. A few studies address the fixed position layout and the two-sided layout in order to solve particular assembly cases [7]. respect the schedule at all time or might increase disability time for the operators. Anyway, the realization of ergonomic potential seems to depend on management culture, as well as on factors outside the company [8]. This work approaches assembly system design problems and task ergonomics evaluation in a new methodological framework, to assess times and methods analysis procedure in modern assembly systems. The framework considers not only technological aspects (normally considered in traditional procedures), but also variables linked to the industrial environment and with the work force (typically considered by ergonimists), in order to design an assembly system which will allow top productivity and motivation of the work force. The framework suggested in this paper is intended to be used by production engineers interested in ergonomics and involved in pre-production design, to help in the selection of the right assembly systems. The ideal situation presents room for changes in both assembly system layout and workplace design, as well as the desire to achieve high productivity and the realization that best results are easilyaccomplished with the optimization of both production time and operator load.

2.DETAILED PROBLEM DESCRIPTION

The final assembly line consists of numerous workbenches where assembly is done through manual labor, albeit not all workbenches are necessarily used for every product. Additionally, there is a pre-assembly line that can be seen as a sub-flow that enters the main line. After assembly, there are test stations that in parallel test the products to see whether they meet the quality specifications. If the product passes the test it is sent to final assembly and packaging, but if the test fails at one point the test is cancelled immediately and the product is sent to the troubleshoot line. . The test loop is thus very unpredictable due to the stochastic test times and the variation in yield. The test itself is automated but it requires an operator to move the product through the line and in to the test station. This assembly line setup results in a combination of a rather stable flow with an unstable stochastic flow. The Company has experienced several issues with this production setup, such as line congestion, unutilized test stations, line balancing problems which all results in longer lead times and not high enough throughput. An analysis of this flow is therefore needed to resolve these issues in order to shorten the lead times and increase the throughput.

3.OBJECTIVE

The objective of the master thesis is twofold. The first objective is to develop a simulation tool for production process analysis that is user-friendly, but still advanced enough to analyze several different scenarios. The second objective is to analyze the production setup and to purpose a feasible future production setup that increase throughput and flexibility. The questions that should be analyzed and answered are:

- Level of automations: What should be automated in the test stations?
- Flexibility: How generic should the line be, i.e. should all products be able to go through the same line?
- Rules: What production rules are suitable to achieve a smoother flow and an increased throughput?
- Buffer levels: What are reasonable buffer levels between assembly and test in order to have a high utilization in the test stations?

4.THE LIMITATIONS

The Company is currently working on a standardization program, which has driven the development of assembly lines towards a common design (MSP-lines), somewhat increasing flexibility through the use of new pallets that can cradle a wider range of products. Older, more static assembly lines that have become outdated will not be addressed in this work, as they, themselves, are phasing these assembly lines out. As manufacturing of circuit boards rapports to a different business unit and have come further in their improvement process, this process will not be taken into account. It has been assumed that material from this process will always be in stock. This quality improvement program is therefore not connected to the assembly process itself, rather an extension of product design and R&D. Lastly has the material handling part of the process been neglected as this too rapports to a different function and is thought to function well. Thus it has been assumed that all material needed for setups and continued production will be available at any given time at all workbenches.

5.DOCUMENTATION AND REPORTING

The model itself should be documented so that if the model will be used again, the user can understand how it works and how it was constructed. This gives the customer the opportunity to use the model after the project is done. The results of the simulation study should be well documented and reported. This will enable the customer to understand the different simulation scenarios and why some designs is better than others.

6. IMPLEMENTATION

During the implementation phase, the simulation analyst acts as a reporter rather than an advocate. If the client has been involved throughout the project and the simulation analyst has followed all of the previous steps, the likelihood for successful implementation is increased. Furthermore should the project plan include what time is required, which software to use and the output of the project.

7. MODEL CONCEPTUALIZATION

The real-world system under investigation is modeled into a conceptual model. The reality is described through series of mathematical and logical relationships concerning the different parts of the system. The modeling should start with a simple model and then grow until an appropriate level of complexity of the model is reached. By involving the client in the modeling, a higher quality in the model will be reached and the client's confidence in the model will be increased.

8. DATA COLLECTION

The data collection should be carried out by submitting requests of the data requirements to the customer. The data collection can be done at the same time as the model building. It is important to have proper data since the model will be based on historical data in order to describe the reality in best possible manner.

9.EXPERIMENTAL DESIGN

Decisions need to be made for how long to simulate each scenario and how many times each scenario should be simulated.

10.PRODUCTION RUNS AND ANALYSIS

Production runs and their subsequent analysis are used in order to estimate performance measurements for the scenarios being simulated.
iii. Analyzing the performance measures
iv. Evaluating alternative scenarios
Simulation mitigates the risk for sub optimization since continuous analysis is done after each run of the simulation. It also increases creativity of the design team. Another advantage is that the simulation model can capture system dynamics such as machine breakdown, defect products. This is done through random generators and probability distributions with set parameters. The software that is used for simulation also allows animation to visualize the product flow.

11. IMPLEMENTATION OF THE NEW PROCESS DESIGN

When selecting the process to be redesigned the implementation strategy is important. Criteria considering implementation are time, cost, likelihood to succeed and improvement potential. The implementation strategy can be seen as revolutionary, evolutionary or somewhere in between these two. A revolutionary implementation strategy includes rapid change with high costs. It requires high commitment from management that can force through the implementation. An evolutionary implementation strategy requires longer time and the changes will not result in quick improvements. The costs will be lower since mainly internal resources are needed and top management commitment is only needed to keep the vision alive.

12. PROBLEM FORMULATION

Every simulation is started with a statement of the problem. Either the customer or the simulation analyst could state the problem. It is important in this stage that both the customer and the analyst understands and agree with the problem formulation. Assumptions should be stated in this stage although the problem formulation may be changed further down the simulation process.

13.SETTING OF OBJECTIVES AND OVERALL PROJECT PLAN

The objectives indicate of what questions to be asked by the simulation study. The project plan is supposed to include the different scenarios to be investigated. 13 two questions to not get caught in the automation trap (Hammer and Champy, 1993):

How can technology be used to streamline, improve or enhance what we are currently doing? How can technology allow us to do new things that we are currently not doing?

14.ACQUIRING PROCESS UNDERSTANDING

Understanding the process is a key element of any process design effort. In order to acquire process understanding the design team needs to find the answers to the following questions:

- What does the existing process do?
- How well (or poorly) does the existing process perform?
- What are the critical issues that govern the process performance?

The goal for the design team is to understand the process and not to analyze it. By not analyzing the process and every detail of it, the understanding can be acquired at higher level. The analysis could also become an inhibitor of creativity when the new process should be designed since it is hard to think of new ways to produce the same output when the analysis is too deep, known as “analysis paralysis”.

Process modeling and simulation

The most powerful process modeling tool is simulation. There are many advantages for using quantitative models such as simulation. First of all, it is cheaper than a pilot project and much faster. The design team has greater freedom that stimulates creativity and the probability of a better design is increased. Simulation is a model of the reality and every aspect cannot be taken into the simulation model, especially behavioral issues such as attitude and resistance to change. Discrete event simulation is a computer-based model that allows simulating processes, people and technology. There are four basic steps for process modeling and simulation:

i. Building a simulation model of the process
ii. Running the simulation model
  a. A case for action statement: Shows where the Company is as an organization and why it can´t stay there.
  b. A vision statement: States where the organization needs to go and what objectives that needs to be fulfilled in order to get there.

Process identification and selection

The selection of process is critical for the success of the design project. All processes should initially be taken into consideration and especially the ones that is core to the organization. Generally the organization needs to prioritize which process to redesign since there are restrictions in budget and resources. Questions that help the selection of process are:

- Which process is currently in most trouble?
- Which process is most critical to accomplishing the firm´s business strategy and has the greatest impact on the customers?
- Which process is most likely to be designed and implemented successfully?

The implementation phase must be considered when selecting the process since a redesign could lead to high investments. Also, if the competence is available within the Company to perform the redesign or external competence is needed. Obtaining management commitment Research shows that if not top management is committed to the process change and implementation, the improvement effort will probably fail. The more strategic the redesign is, the more crucial top-management becomes.

Evaluation of design enablers

Technology and information technology (IT) is often seen as enablers for new process redesigns. Other enablers could be changes in legislature or changes in the market structure, in the supply or among the competition. Two principles should be followed when evaluating new technology for enabling the process redesign.

i. Do not equate technology with automation. It will prevent creative process design.
ii. Do not look for problems first and then seek technology solutions to fix them.

Breakthrough improvements are usually not done only with automation. Doing things the wrong way faster is not the solution. The team can ask themselves Transforming the data into visual representation in order to identify bottlenecks, waste, delays and duplication of efforts. The first level of process mapping (macro-level), usually describes the overall core process. To obtain more useful information, a more detailed map is needed. The detailed map (micro-level) is naturally more time consuming (Soliman, 1998). The visual information tends to isolate crucial information. Fewer levels of the map could result in greater abstraction. This means that if more details are needed, a higher level of mapping is required, although it exist a point where no additional information can be obtained from mapping. Okrent et al. (2004), argue that three steps is necessary when conducting a business process reengineering. The first step is to draw “As-is” model that describes the current processes. In this step should input be taken in from all key employees and the process map is easiest done with pencil and paper. The second step is to draw a “To be” model. Instigating this step is to conduct an evaluation to see which process has the biggest strategic impact and is most critical to the business. Furthermore should this process be customer oriented. The process can thereafter be modified to be more efficient. The third step relates to have to do the transition between the first and second step.

Simulation

One of the most powerful tools for modeling, analyzing and designing business processes is discrete event simulation (Laguna & Marklund, 2006). Supply chain simulation is a powerful method for analyzing the tradeoffs between product customization and supply chain efficiency and can support decision making in both product design and system design. Simulation models can be built for one-time projects or be used as continuous support in decision making (Hieta, 1998). Laguna & Marklund Model of Simulation A simulation-based framework for business process design projects has been developed by Laguna & Marklund (2004), with inspiration from Chase et al. (1998). The framework consists of eight steps and each step will be described in detail:

15.CASE FOR ACTION AND VISION STATEMENTS

Companies that are most successful in selling change to their employees are those that communicate the clearest message for change. Hammer and Champy (1993) states that this communication should include two key messages: The thesis has been carried out using a system approach with influence from the analytical approach. The system approach gives a holistic perspective and is suited for a combination of quantitative and qualitative research; this has mostly been associated with the qualitative data that has been obtained. While the analytical approach has been used to analyze more in detail, and deduct information from people involved in the process.

16.RESEARCH METHODS

Research methods relate to the data collection technique that refers to a specific research objects. The theoretical framework and research question affect which data needs to be captured and what measurements to use (Frankel et al., 2005). The object of research is production in general and how to improve flow in specific. Thus quantitative methods are the method of choice although qualitative aspects also have to be considered. This leads to research being done both in detail but also taking a holistic view and therefore a wide range of methods have to be covered.

17. PROCESS MAPPING

The foundation for any improvement project in organizations is to truly understand how the current state works. Routines and processes are factors that need to be understood, in addition to how tasks are organized (Jonsson et al., 2011). Process understanding is a fundamental element of all process reengineering (Soliman, 1998). Understanding why a process is designed in that particular way will permit the elimination of non-value added work (Okrent et al., 2004). Therefore is process mapping a great tool and starting point for any process reengineering project. It is essential that the correct process is chosen in order to maximize the business impact in relation to what resources is needed, to select the process that has the “biggest bang for buck”. The process map can be a map over the business process or the material flow (Jonson et al., 2011). The level of mapping varies from an overview map (macro-map) to a very detailed map (micro-map). Process mapping is usually done following three steps (Soliman, 1998): Identification of products and services and the related processes. The start and finish of the process is determined at this step. Data collection and preparation.

18.CONCEPTUAL FRAMEWORK

Figure 1 illustrates the conceptual framework to asses the assembly system design and optimization, linking productivity with ergonomics considerations: it shows all main variables and decision involved in a times and methods integrated procedure. The proposed procedure consist of three different sections:

- Technological variables
- Environmental variables

Integrated procedure: the flow chart illustrates the principal decisional steps required during the integrated design of an assembly system and their inter-correlation. The purpose of the whole design procedure is the maximization of both system productivity and work force motivation through a stage of careful analysis, and investigation of different assembly workplace solutions according to requirements in assembly times length and ergonomics conditions. The preliminary design stage focuses on product analysis and the creation of the assembly process scheme. This is the logical progression of operation following a pre-established sequence, which is necessary to the product transformation. The assembly cycle will be subdivided into principal tasks, a set of elementary tasks performed in sequence by the operator, the actuator or both; while elementary tasks are defined as a group of one or more indivisible primary movements that are assignable to a single operator. During the analysis, such subdivision permits to perform:

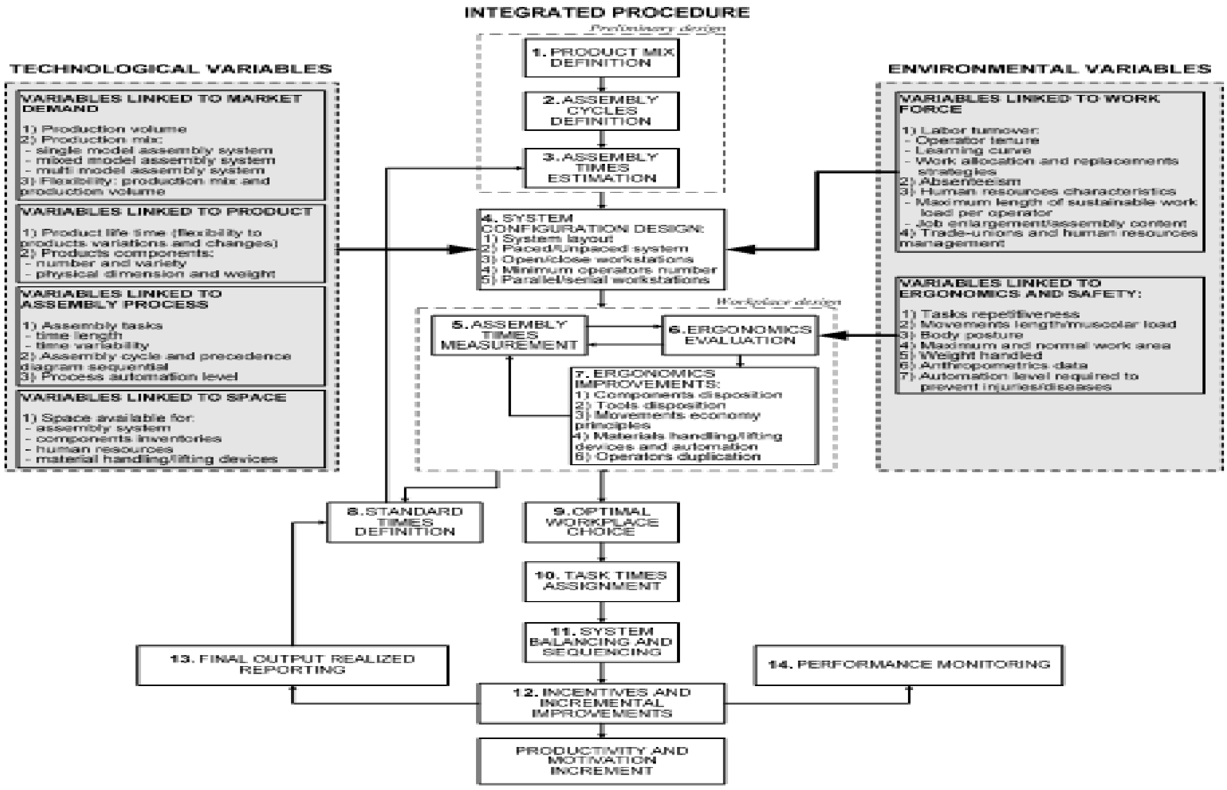
1. Accurate times measurement
2. Improvement assessments with identification of ergonomics solutions
3. Data base compilation to record and estimate company standard task times.

At the end of the third step, an assembly procedure including time requirements estimation is defined. The interdependence between technological and environmental variables is taken into account in the fourth step of the framework: considering all the variables it is possible to define the best assembly system solution, one that can provide the higher efficiency. To this purpose, a layout of the assembly system and the involvement of people must be determined defining:

1. The assembly system layout configuration (serial line, U-line, serial line with parallel stations, parallel lines, fixed positions, two-sided lines, four-sided lines, etc.): figure 2 shows the most important alternatives of layout configuration that will be considered (the transport systems between stations will be realized by using rollers or conveyor belts, electric conveyor rails, automated-guided vehicles or hand trucks).
2. The classification concerning cycle time , which indicates the time between the exits of two consequent units. Generally, in a paced line , the handling system is periodically moving (when a unit arrives at a station, it remains there for a time called cycle time and is then moved to the following station); while an un-paced line is equipped with buffers located between stations (the decoupling buffer can be realized between groups of stations or between single stations).
3. The workstations type: open or closed stations, automatic, semi-automatic or manual station.
4. The minimum number of operators required to reach the desired the production rate.One of the major mistakes in the system design phase (fourth step) is that to make decisions based only on few variables that seem relevant, without taking into account the repercussions. For this reason, figure 3 reports four examples of qualitative cross-matrix that might be considered in choosing the best assembly configuration. These maps provide a link between technological and environmental variables by a qualitative point of view. Matrix a) classifies assembly layout configurations according to three variables linked to the assembly process (on the left), level of turnover and absenteeism tolerated by the system (on the right) and production rate and number of operators required to reach the desired production volume. The set of variables considered on the two vertical sides of the matrix influence the system balance and might lead to differences between the achieved productivity and the forecasted productivity. "Bucket-brigades" are a way of organizing workers on an assembly line so that the line balances itself. Workers are sequenced from slow to fast; they will spontaneously gravitate to the optimal division of work so that throughput is maximized [9]. In the workplace design stage task time measurement is useful to identify bottlenecks and time losses due to material flow and ergonomics. Times measurement and ergonomics evaluation must be jointly performed for each workplace tested: it is a multistage iterative procedure that integrates different tools such as times measurement techniques, ergonomics evaluation methods and Visual Interactive Simulation (using software tools to test different assembly solutions and human models according to ergonomics considerations).

Following are the main task times measurement techniques:

1. Direct times measurements (i.e. Bedaux method): consisting of the direct survey of each elementary task time with contextual record of the operator's efficiency level (working rhythm).
2. Predetermined motion time system (PMTS), the most commonly used are MTM and BasicMOST.
3. Work sampling procedure. Tools and techniques for the measurement of task times and for the efficiency evaluation of human operators are well known and improved, while the definition of rest time coefficients is usually subjective and experimental. The percentage varies between 10% and 30%. Considered the difference between the numerous tables used in practice, many perplexities still exist about their use. For this reason ergonomics evaluation of the workplace in detailed stage of the framework is preferable. Ergonomics evaluation techniques are numerous and might be summed-up in three main approaches: self assessment evaluation techniques, observational methods by the use of video recording or software tools to compute ergonomics indexes (RULA, REBA, OCRA, JSI, OWAS, OREGE, Cube Model, etc.) and electromyography analysis (EMG). Following, incremental improvements in ergonomics condition at the workplace must be provided identifying:



1.Changes in material and tools disposition
2. Application of movement economy principles
3. Introduction of lifting and handling devices and automated equipments (in order to implement a zero lift policy)

19.OPERATORS DUPLICATION AND TRAINING

The outcome of the iterative workplace design procedure is the kind and number of workplaces, the available space, the location of tools, equipments and components and the task times to be assigned considering ergonomics and physiological aspects. Finally, balancing and sequencing problem linked to the specific layout examined must be performed to reduce idles times and improve system efficiency.

20. INDUSTRIAL CASE

The present paragraph describes the application of this approach in an industrial reality, leader in the production and distribution of multifunctional shower enclosures. The questions investigated were which layout configuration

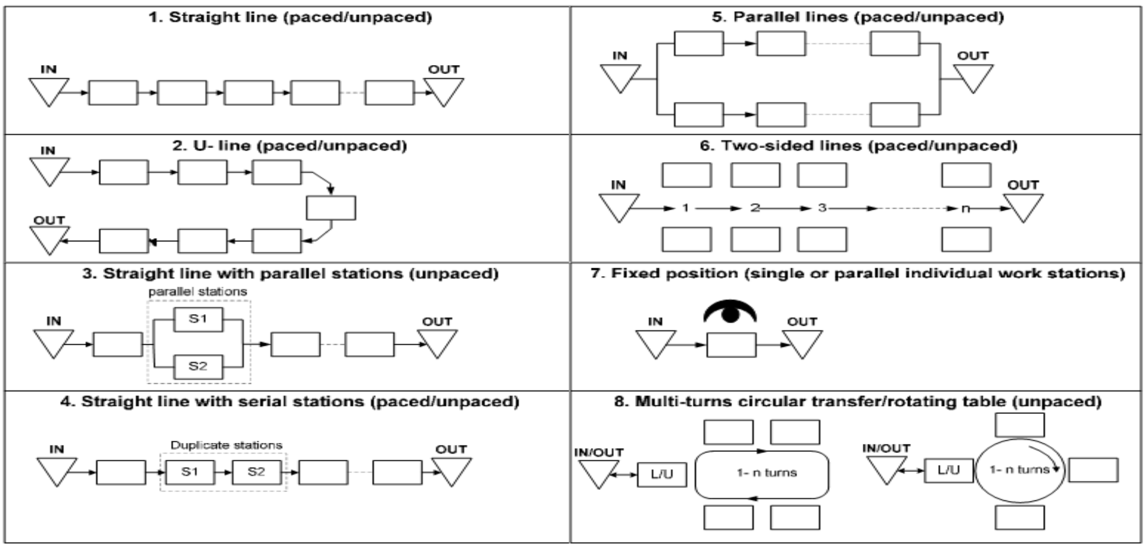


Figure 2. Alternative assembly layout configurations

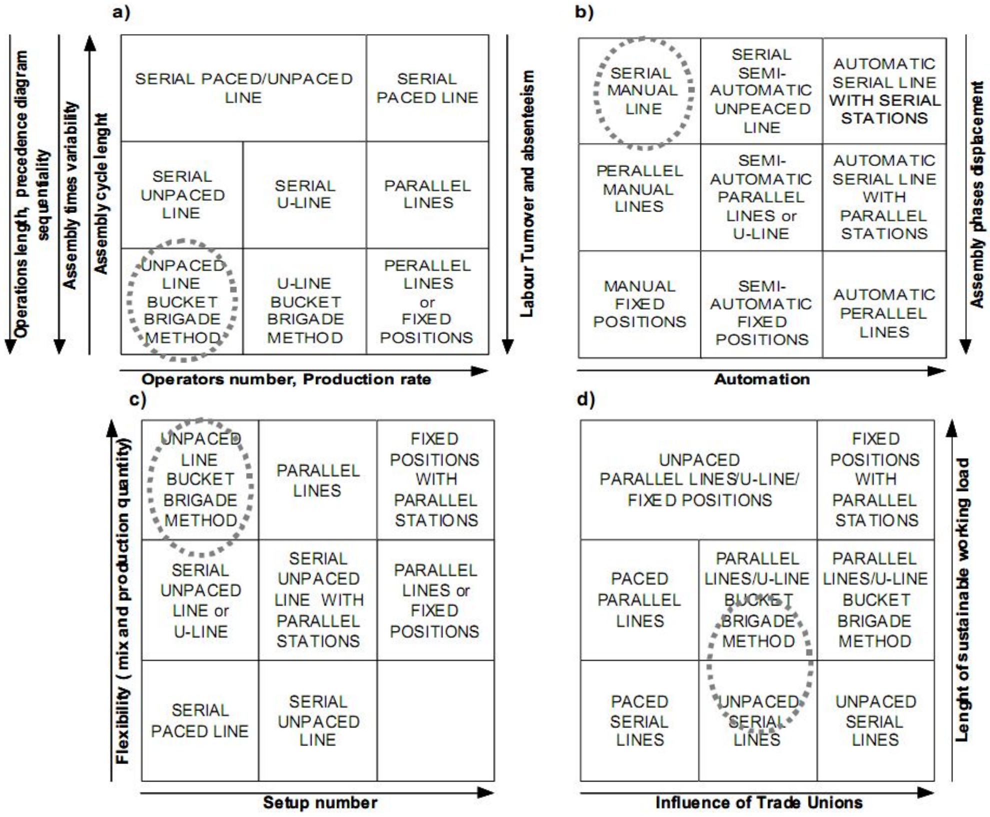


Figure 3. Qualitative cross-matrix examples to asses step 4 of the framework proposed

could be defined and which workplace solutions could maximize the productivity of a new product family and the motivation in the work force with respect to the ergonomics of the whole system. First, Eicher data of existing setup similar workstations were made, in order to determine assembly process scheme and assembly task times. The demand of products per year is about 15,000 pieces (with an assembly process equal to 28 minutes per pieces), the presence of product variety and high labour turnover revealed the necessity of a flexible unpaced line configuration with parallel workstations balanced with the Bucket Brigade method. Moreover, old assembly lines presents operations length of about 5 minutes, with more than 30 different elementary tasks (figure 3a). Grey circles in the cross-matrix b), c) and d) [figure 3] confirm the configuration choice considering the very low level of automation, a low displacement in assembly phases, a low number of setups and necessary high flexibility, which is a normal requirement of trade unions, resulting in a medium/low work content assignable to the same operator. After it was decided that the new assembly system would be an un-paced line subdivided in 5 workstations groups with 2 parallel workstations each, five different workplace solutions have been selected and investigated:

1) Assembly on workbench in horizontal position
2) Assembly in vertical position up-ended on a truck
3) Assembly in vertical position overturned on a truck
4) Assembly in vertical position with enclosure in up-side-down position
5) Assembly in vertical position up-ended on a lift platform.

Using EM-Plant, as software tool to simulate and evaluate current and future assembly process, a virtual model of each of the five solutions was developed. The software tools enables the times measurement of each elementary task applying an MTM module and a contextual work posture evaluation. In considering the risk of WMSD the software applies the OWAS method (Ovako Working-postures Analysis System) which allows to attribute a specific class of risk to the postures assumed during the job and to calculate the relevant index of risk on the bases of the time frequency (by a multi-moment time study). The simulation analysis conducted for solution 1 clearly shows that the operator must turn around the table to be able to perform all tasks (figure 4). This implies time losses and process inefficiency. The OWAS evaluation of the work posture of solution 1 reveals that this solution does not create ergonomics problems or physical fatigue. The OWAS analysis of workplace solution 2 shows the presence of two main critical phases, characterized by a value of action category (according to OWAS scale) equal to 3, which means they are evidently harmful action .

21.RESULT AND CONCLUSION

for solution 3: the scheme reports the Action Category values of the elementary task called cabin drilling as a function of the task duration (in seconds). The figure shows that during the drilling activity, the operator assumes positions that are not only uncomfortable, but also extremely harmful. These operations cause fatigue and efficiency reduction of the operator, who is forced to frequent breaks during the workday. Because workplace solutions with vertical position of the cabin present critical ergonomics issues, the possibility to perform the assembly process using an automated platform to turn the enclosure upside-down has been considered. Three rotations of the platform became necessary in order to minimize fatigue and reduce cycle time. However, this solution presents space problems and assembly times slowdown because each rotation causes the already assembled components to change orientation. Moreover, due to the evident big dimension of the product, the rotation of the cabin is quite slow penalizing the assembly times. In conclusion, solution 2, 3 and 4 with a vertical position of the shower column do not reach acceptable balance between effort and ergonomics, even if some of them reach low task times. In fact, as explained before, there are critical actions that stress the lumbar region whenever the operator is required to assume an unnatural position in order to achieve better visibility during the assembly. A better option is presented in solution 5 with the shower column positioned in vertical up-ended on a lift platform programmed to perform 2 consecutives lifting in order to increase performances of the workplace, illustrated in figure 6. The two lifting (of 40 cm and 110 cm for a man high 180 cm) allows the operator to work in the optimal working area at all times (in accordance with standard ergonomics principles), eliminating harmful actions and obtaining low OWAS index value. Table 1 shows that in reference to the critical elementary task cabin drilling , solution 5 matches the minimization of task time with the minimization of work fatigue resulting in an overall increment in productivity of the 15%, in comparison to solution 1. In conclusion, even if solution 2 seems to provide, an increase in productivity, it implies also a high level of fatigue and high compensation time of the operator during the day, while the application of conceptual integratedprocedure results in the creation of an optimal workplace solution. This mammoth product development initiative for the entire Pro series range, from 5 to 49 tonnes, involved an investment of three million hours of engineering efort, 7.7 million kilometres of testing and 50,000 hours of engine development. The Pro range ensures a level of quality and innovation that will continue to set standards in the commercial transportation industry in India and the developing world. The year also saw revamping and modernisation of the truck plant with a new paint shop and assembly lines.

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