

LINKING ERGONOMICS EVALUATION AND ASSEMBLY SYSTEM DESIGN PROBLEM IN EICHER TRACTOR LIMITED

Mahendra Singh¹, Atul Pandey² and Nikhalesh Soni³, * Mr. Padmakar Pachorkar

^{1,2,3}M. Teech(IEM) Student,BIST,RGPV,Bhopal(M.P)

*GUIDE M.Tech,Asst. Professor,Dept. Of ME,BIST,BHOPAL(M.P.).

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:-ergonomics, assembly system, design problem, integrated approach, simulation, framework.

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 Musculo-Skeletal Disorders (WMSDs= Work related Musculo-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. González 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. Usually ergonomics evaluations are performed by ergonomists, and workplace layouts are designed by planning engineers. 1 Such practices have been somewhat unsatisfactory both for results and productivity [1]. 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]. A number of papers aim to optimize a pre-existing system, without scrutinizing the workplace ergonomics or task times value feasibility and correctness. Experiences collected from the authors lead to recognize that task times analysis procedures are not sufficient in case of time losses due to workers disability.

Thus, a workplace solution that seems to provide the lowest cycle time value might not be able to 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 ergonomists), 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 easily accomplished with the optimization of both production time and operator load.

2. CONCEPTUAL FRAMEWORK

Figure 1 illustrates the conceptual framework to assess 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 integrated procedure presents a total of 14 steps. 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. As reported in the cross-matrix the Bucket Brigade balancing method might be considered in presence of high task time variability and high flexibility required when the number of operators is medium-low. "Bucket-brigades" are a way of organizing workers on an assembly line so that the line balances itself. Each worker carries a product towards completion; when the last worker finishes his product he walks back upstream to take over the work of his predecessor, who walks back and takes over the work of his predecessor and so on, until, after relinquishing his product, the first worker walks back to the start and begins with a new product. 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, OREG, Cube Model, etc.) and electromyography analysis (EMG). Following, incremental improvements in ergonomics condition at the workplace must be provided identifying:

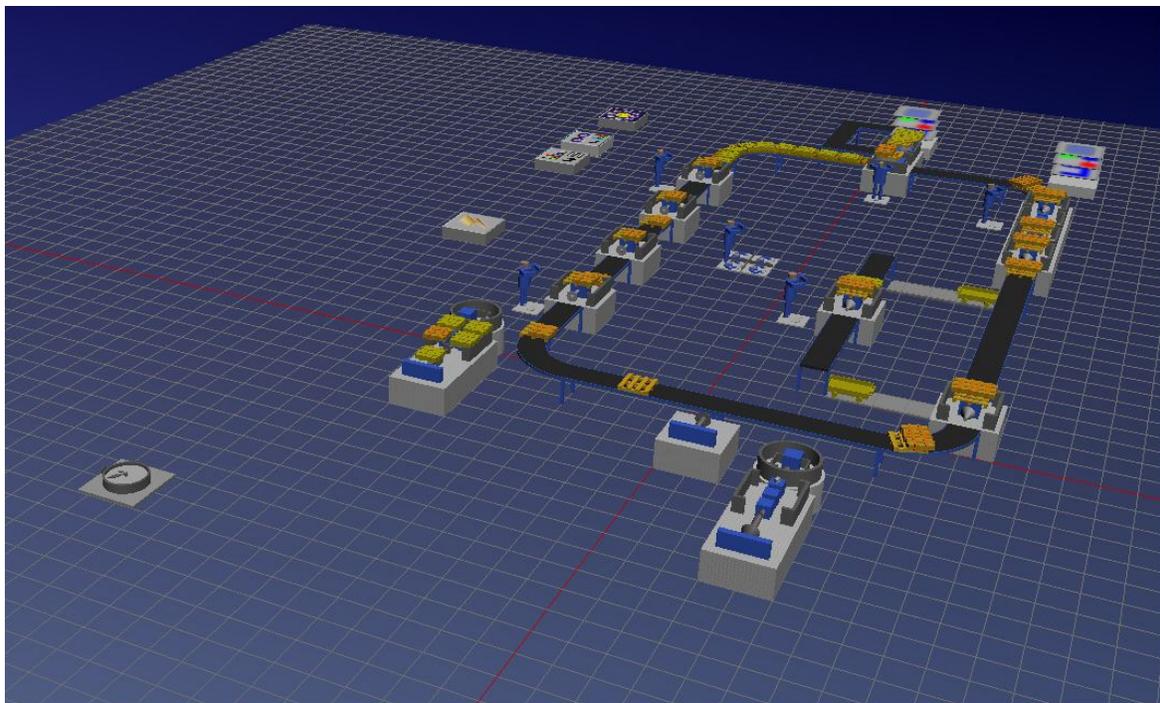


Fig.1 intergraded frame work of assembly line

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)

4. 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.

3 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

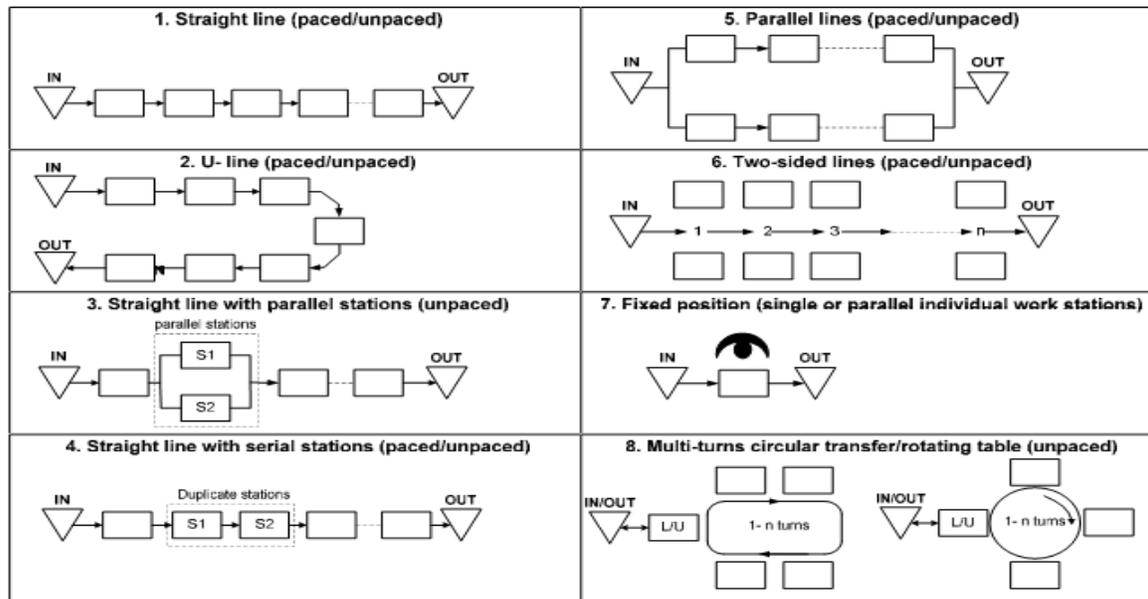


Figure 2. Alternative assembly layout configurations

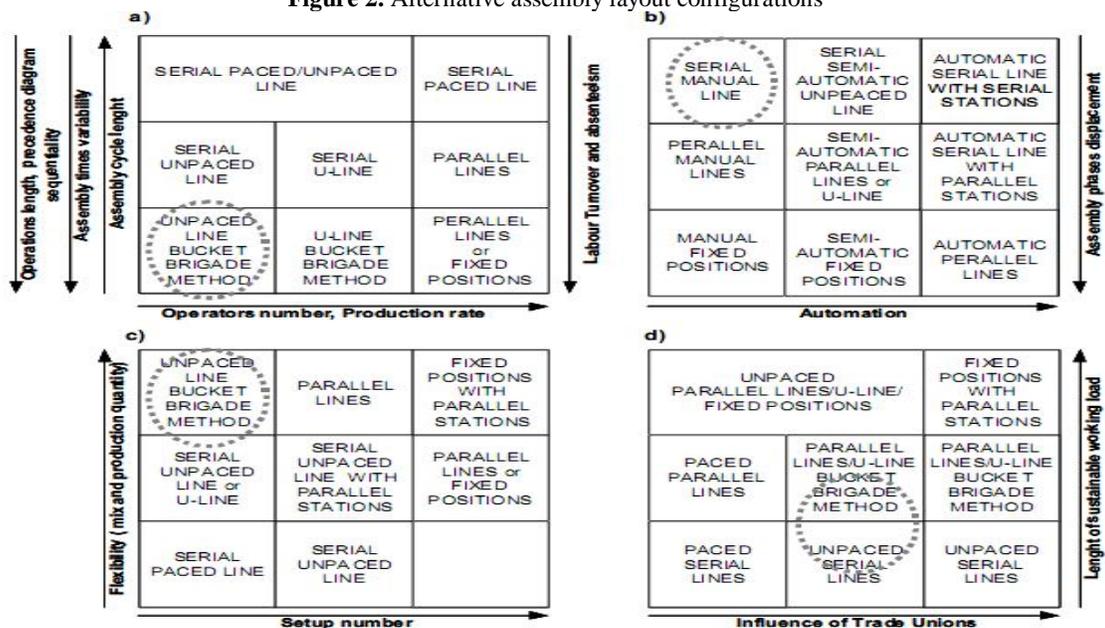


Figure 3. Qualitative cross-matrix examples to assess step 4 of the framework proposed

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, video recordings of existing 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.

to 3, which means they are evidently harmful action. Figure 5 reports results of the OWAS analysis conducted 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.

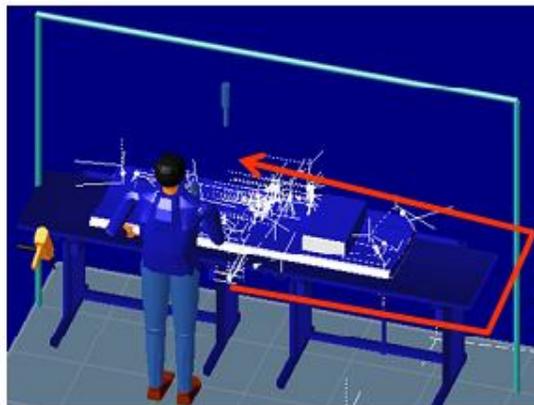


Figure 4. Solution 1: human model developed

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

4.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.

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