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Improving Efficiency and Job Sequence of a Solar Panel Assembly Line in Virtual Environment

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ABSTRACT

Background: The design of an assembly line necessarily includes minimizing the number of workstations, fairly balancing workload among workstations, etc., which leads to better utilization of facilities and produce desired number of finished units to meet the market demand. This paper aims to inspect a mixed model assembly line and analyze the current system in relation to production volumes, line efficiency and task assignments. The optimization-based simulation (OBS) is applied to evaluate the mathematical results and helps to find the optimum job sequence. By using these stages, the minimum number of required workers are found and line efficiency is improved by 12.4% while workload is fairly distributed among all workstations.

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INTRODUCTION

Combining components of a system in a specific order and sequence is called assembly. Assembly starts with parts that completely independent of each other and ends with combination of these parts to form a whole system (Keskintürk, T. and B. Küçük, 2006). The system, which requires that stations, that are formed by transferring with the advantage of hardware or labor force through material flow line and unifying operations on component with taking into consideration of constraints such as cycle time and primary relations between them, is arranged in a line, is named as "assembly line". One of the main issues concerning the development of an assembly line is how to arrange the tasks to be performed. This arrangement may be somewhat subjective, but has to be dictated by implied rules set forth by the production sequence (Kao, E., 1976). For the manufacturing of any item, there are some sequences of tasks that must be followed. The Assembly Line Balancing Problem (ALBP) originated with the invention of the assembly line. The assembly line balancing problem consists of assigning tasks to an ordered sequence of stations such that the precedence relations among the tasks are satisfied and some performance measure is optimized (Erel, E. and S. Sarin, 1998). Helgeson *et al*. (1961) were the first to propose the ALBP, and Salveson (1955) was the first to publish the problem in its mathematical form. However, during the first forty years of the assembly line's existence, only trial-and-error methods were used to balance the lines (Erel, E. and S. Sarin, 1998).

Solving real life ALBP is a very difficult task for decision makers and practitioners since even a simple case is NP-hard by nature and an exact mathematical solution with exact result cannot be expected. For this reason, most assembly line balancing problems involve only a few aspects of the real systems (Becker, C. and A. Scholl, 2006). It means routine solutions need to simplify the problem assumption or ignore some of constraints to be able to handle complicated scenarios and it undesirably affects the final results.

In order to deal with the complexity of industrial problems, a great variety of problem definitions have arisen, which consider other restrictions apart from the technological ones. Most common, these include mixed models, multiple products, different line layouts, parallel workstations and multiple objectives which requires tackling many of those generalizations simultaneously (Falkenauer, E., 2005).

Although ALBPs are NP-hard and might be multi-objective, the stochastic factors must be taken into account as they can affect balancing of mixed-model assembly lines. For instance, according to the nature of task times, they can be considered constants or random variables. In a realistic manufacturing

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environment, however, the task time may be random due to worker fatigue, low skill levels, job dissatisfaction, poorly maintained equipment, defects in raw materials, etc. and being considered as a stochastic parameter (Shin, D., 1990). Simulation has become one of the most reliable methodologies or tools of Operations Research. Initially, its use was very restricted as it required a great knowledge of computational programming to simulate a model, in addition to the required effort of modelling and corresponding knowledge of the problem in question. The first level computer languages were used at the begining. The application of the methodology increased singnificantly as these languages were developed to facilitate the simulation (i.e., GPSS-H). Currently, the utilization of simulators such as ProModel, Witness and others have facilitated enormously the application of simulation to the design, improvement and validation of systems in a wide variety of areas of knowledge (Bowersox, D.J., 1972; Weigle, K., 1998; Park, Y.H., 1998; Lee, Y., 2004).

The application of simulation to the problem of designing manufacturing cells is recommended to integrate the uncertainty and interdependency inherent in their operation. Ruiz-Torres, *et al*. 2008 utilize simulation to analyse and measure the performance of a number of multi-cell configurations gained by altering cell size, worker flexibility and shop type. Cochran, *et al*. 1998 apply it to verify the feasibility of operating a cellular system in an enterprize of the automotive industry. The purpose of the change was the reduction of the product manufacturing flow time. To achieve this the authors developed a simulation model for each alternative of the cellular system using Witness, a discrete event simulation software. The focus of the analysis was micro, that is, at the cell level detail. It is neccessary to clarify that when designing a system, the alternatives created about its fundamental could be numerous. These depend upon the number of variables of interest that could be controlled, and that are essential to define the structure. The zone of possible solutions could be very cast. So, applying simulation to search for the best design, requires using an investigate strategy for finding the values of the relevant variables associated with it. Carson, *et al*. 1997 give a general review of the methods used to obtain such goal. This process has been called simulation optimization in which the result of the simulation model is used in the optimization strategy to provide feedback about the progress made towards the optimum solution, that in turn is used as an input for the simulation model.

Case studied in this paper is a mixed model assembly line which adopts its arrival sequence of models to the line based on customer orders. The company must be able to produce the desired product at any time with any amount. Based on Research and Development (R&D) department reports, the line efficiency is 75% while it must exceed 80% or even higher. Occurring bottleneck and starvation in some workstations are the other reported issues which need to be eliminated or reduced. Bottleneck and starvation can cause unfair workload distribution among all workstations. Also the current number of workers assigned to perform tasks are 8 persons that based on managers long-term policies, the number of workstations or workers needs to be reduced as much as possible. These evidences indicate that the assembly line must be balanced. For the assembly lines, balancing the problem must be done by assigning the tasks to the workstation while optimizing one or more objectives without violating restrictions imposed on the line. Mathematical solutions like heuristic methods, mostly propose solution approaches to solve single-objective ALBPs. However, there are no realistic design tasks that are single objective problems. Design, planning, scheduling projects usually involve trade-offs among different incompatible goals (Askin, R.G. and M. Zhou, 1997). In fact, because of NP-hard nature of ALBPs, being multi-objective and also including stochastic factors, developing a simulation modeling is necessary to tackle all problems simultaneously.

The objectives of this project are: (i) To observe existing production line and collect timing and precedence data of each task and machine for line efficiency calculation, and (ii) To develop a simulation model in virtual environment (VE) through Simio software for finding optimal job sequence. The production line and reported issues needs to be observed and exact amount of time wasted in each workstation must be recorded. Also the precedence of each task should be identified as an important required factor for modeling and calculation of line efficiency and workload. The exact efficiency of the current line must be calculated. At the end, a simulation can be done to find the better and more reliable solutions for balancing of this assembly line.

MATERIALS AND METHODS

A lot of assumptions are considered in assembly line balancing. One of these is, accepting operation times deterministic unless otherwise stated. Operation times in the content of the problem are evaluated as deterministic.

In the assembly line considered, there are some constraints which may affect workload distribution. These are priority relations, cycle time restriction, works desired to be assigned to the same station and works not desired to be assigned to the same activities.

The methodology used in this paper is shown in figure 1.

RESULTS AND DISCUSSION

A solar panel manufacturer which has been chosen as a case study produces variety of solar panels and categories them based on number of solar cells used and amount of electricity output. Two production line of AS-M120 and AS-M200 panels are studied. These panels are made up of 48 and 72 solar cells and their electricity out up of them are 120 and 200 watts.

The production line of AS-M120 and AS-M200 panels is formally U-type but functionally straight and included to the operation extend of the enterprise and mixed-model products are produced in this line. Type 1 of mixed-model assembly line balancing studies (MMALB-1) must be implemented to the application.

So, minimizing the number of stations will be aimed when the cycle time is given. This is because cycle time cannot be changed in order to meet amount of the desired product demand.

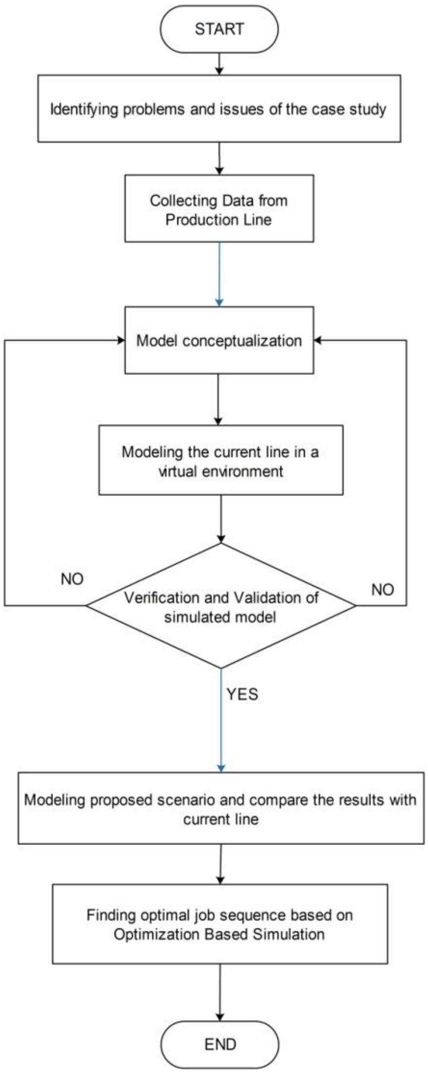

Fig. 1: Methodology flowchart.

For evaluating the current assembly line production, both models which are produced in this assembly line, are considered and joint precedence diagram is created.

Manufactured products in this line are mixed model and have a fixed cycle time. This cycle time is calculated in a way to meet customer demand and not to cause idle time or bottleneck during shipment. According to identified criteria, assignments of tasks to stations are made.

Current Line Analysis:

In the current assembly line, 20 tasks are assigned to 8 stations in total. Assignment of tasks to stations is as follows;

Station1= {4, 5}, Station2= {1, 2}, Station3= {6, 7}, Station4= {3, 15}, Station5= {8, 9, 10, 11}, Station6= {12, 13, 14}, Station7= {16, 17, 18, 19}, Station8= {20}.

When the line efficiency is calculated according to determined cycle time and defined workstations, the value of 76.2% is obtained.

Line Efficiency **=** 100* (Sum of total required time for each element of all models/ (Number of stations*largest time among all stations)).

Current Line Efficiency **=** 100* (334.75/ (8*54.87)) = 76.2%

The current situation is modeled in Simio 7.114 simulation software. After verification and validation of the model, optimization based simulation is used for finding the optimal job sequence in the assembly line.

A block diagram including all stations and position of each worker must be modeled which makes it easier to find out workers' assigned tasks.

Optimization-Based Simulation (OBS) Scenario:

Based on calculations, the minimum theoretical number of workers is seven. To find the optimum arrangement of machines in workstations, the precedence, zoning and time constraints must be taken into account. It means different scenarios should be examined and some control elements in Simio need to be applied to check whether the results are acceptable or not. For example the time length of simulation has a great influence on final results. If the simulation takes longer than expected planned time, it means the cycle time will pass allowed margins and the production rate will not meet the desired amount.

After changing the machines sequences and worker assigning to workstations, the best results achieved. 20 machines arranged in 7 stations in total while assigning of tasks is as follows:

Station1= {4, 5, 1}, Station2= {2, 3}, Station3= {6, 7}, Station4= {8, 9, 10, 11}, Station5= {12, 13, 14}, Station6= {15, 16, 17, 18, 19}, Station7= {20}.

The block diagram of stations in proposed scenario is shown in figure 3.

The results achieved from the simulation is used to calculate the efficiency of proposed scenario as follow:

Line Efficiency for OBS scenario = 100* (334.65/ (7*54.1)) = 88.36%

Comparing with current line, OBS scenario improved the line balancing efficiency more than 12.4%. The efficiency of current line and OBS line is illustrated in figure 4.

The other parameter improved in this study is worker utilization. The utilization of workers in both scenarios are compared in figure 5.

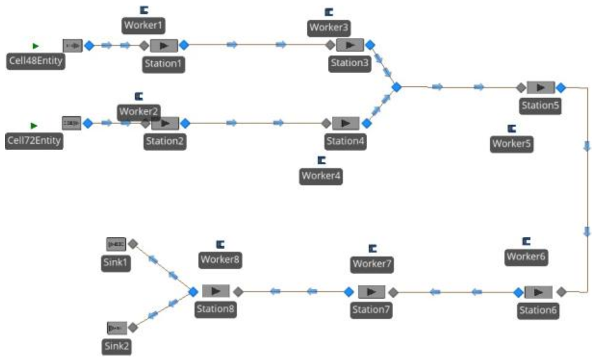

Fig. 2: Block diagram of Stations in current line.

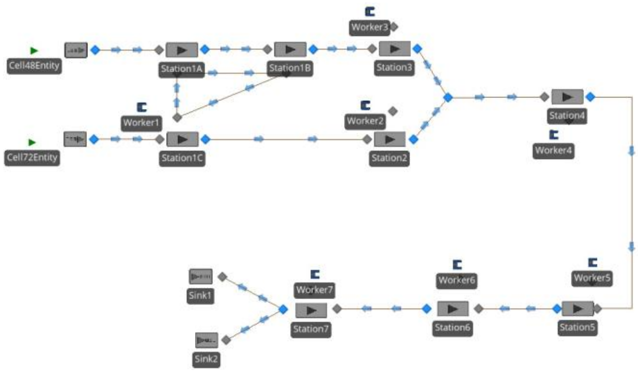

Fig. 3: Stations in OBS scenario.

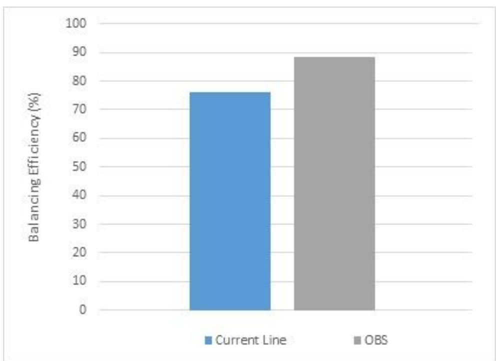

Fig. 4: Efficiency of current and OBS line.

Conclusion:

In this study, mixed model assembly line balancing subject is discussed. The case is a company working on solar modules manufacturing that its production is completely carried out as customer oriented. In the line, different models are produced depending on customer demand. Firstly, the current situation was evaluated for each model. According to the production amount in the determined planning period, the cycle time was determined for the current situation which can be used in the assembly line balancing calculations. The main objective of the study is maximizing line efficiency while balancing the line. To overcome the situation in current line, a new task assignment is presented.

Then, U-shaped assembly line with parallel stations are modeled in Simio simulation software. When results obtained from this study are evaluated, the improvement in the proposed scenario became clearly visible comparing with the current situation. An optimization-based simulation was applied for finding the best efficiency and workload distribution. Different scenarios are examined and some control elements are applied in Simio in order to find the minimum number of workers required for accomplishing assigned tasks and improve line efficiency.

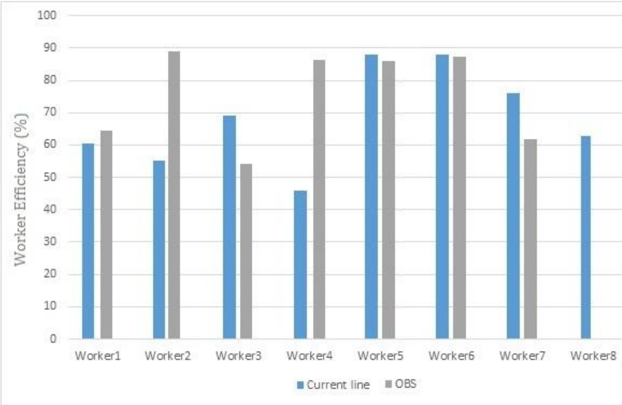

Fig. 5: Comparing worker utilization of Current and OBS scenario.

Discrete event simulation is a powerful tool in production engineering which reduces the wastes in terms of time and monetary when the current state and suggested state are compared.

In addition, even if there is no real process, it is still possible to use discrete event simulation in order to establish a process with the best possible conditions. For instance; it is not necessary to re-design a process in case of low efficiency, move workers or robots to another place, change the numbers of workers directly in a real system and so on. Furthermore, the support of computer systems is increasing with 3D features which make it possible to illustrate the simulation models with virtual machines, lines and workers to observe and verify each process and find any possible issue or defect.

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