WORKFORCE ADJUSTMENT TO ABSORB CHANGES IN PRODUCTION RATE IN CONTINUOUS PRODUCTION SYSTEMS

تفعيل القوى العامله لأحتواء التغيرات في معدلات الانتاج في النظم الانتاجية المستمرة

Naseem M. Sawaqed
Mechanical Engineering Department, Mut'ah University, Mu'tah, Jordan

ملخص:
يقدم هذا البحث بعض النماذج الرياضيه لتخطيط متطلبات القوى العامله للانتاج في خطوط الانتاج المستمرة وذلك للتفاعل مع تغيرات معدلات الانتاج المترتبه عن تغيرات مفاجئه في طلب المنتج. يتم عادة تحديد المعايير الاساسيه لاوقات التشغيل للعمليات الانتاجيه وكذلك معدلات الانتاج للعمال من قبل الاداره وحسب القدرة التصميمية لخط الانتاج. النماذج المقدمة في هذا البحث يمكن ان تساعد الادارة في تقييم القوى العاملة اللازمة للتعامل مع تغيرات الانتاج المطلوبة على حجم الانتاج العادي لتغطية أي تغيرات مفاجئه في طلب المنتج، وخاصة في التخطيط على المدى القصير. وتم اعتبار تحليلات التكاليف لتشمل التاثير الناتج عن برمجة القوى العامله على الربحيه حسب خطة الانتاج الجديده. تزود هذه النماذج ادارة الانتاج بوسائل قادرة على التقليل من التأثير السلبي الناتج عن التغير المفاجئ في خطط الانتاج وبالتالي تعظيم الربحيه.

ABSTRACT:

This paper presents some mathematical models that deal with the planning of the workforce requirement on continuous production lines to react with changes in production rates in order to meet sudden changes in product's demand. Norms for operation times and workers production rates are normally set by management based on the design capacity of the production line. The models presented in this paper can assist management in evaluating the workforce needed to react to the changes in production required over the normal production volume in order to satisfy any sudden changes in product demand, especially for short term planning. Cost aspects and analysis are also considered to include the profitability impact of workforce scheduling according to any adopted new production plan. It is expected that these models will provide management with powerful tools to alleviate the effect of any disturbances that may occur due to sudden changes in production plans, and thereby maximizing profitability.

KEYWORDS:
Workforce – Production Systems – Assembly Lines – Production Rate

1- INTRODUCTION:

Assembly processes play a central role in the manufacturing of most products and systems which people use. The final products resulted from assembling individual parts must function properly as intended, and the entire assembly process has to be performed efficiently and effectively. The economic importance of assembly production lines in manufacturing has led to extensive efforts for improving the efficiency and cost effectiveness of assembly operations. Assembly production lines can be manually operated, automated, or both. Manual assembly is characterized by high labor costs, while automated assembly requires very high investment in dedicated equipment, tooling and feeding devices. A

Accepted March 31, 2005.

common way to achieve efficiency in an assembly process, is to perform it on an assembly line. An assembly line consists of multiple workstations, in which part of the assembly task is accomplished as the product is moved from station to station. A key advantage of using manual assembly lines is the specialization of labor. By giving each worker a limited set of tasks which are performed repeatedly the worker is able to perform the tasks at a faster rate and higher consistently. For both types of systems to be efficient, the line must be balanced, which means that the individual processes must be allocated to workstations in such a way that the total assembly time required at each assembly station is approximately the same. If such balance cannot be achieved, inefficiencies in the form of idle time at stations, or temporary blocking or starving of stations will result.

The traditional assembly line balancing problem considers the manufacturing process of a single product as a sequence of tasks which need to be assigned to different workstations. The distribution of tasks among the workstations is based on the required time units to complete each task as well as the precedence constraints that exist among these tasks [2]. Historically, the traditional assembly line balancing problem scenario leads to two groups of optimization problems: simple Assembly line balancing and general assembly line balancing [3], [4], [22], [24]. The first group determines the tasks assigned to a set of workstations with the same cycle time; each task has a deterministic duration and must be performed in only one of the workstations, either by human operators or by robots. Two goals can be considered in addition to the precedence relations between the tasks; which are the minimization of the number of workstations for a given cycle time and the minimization of the cycle time for a given number of workstations. Any other variation of the problem is included in the second group. The simple assembly line balancing problem is known to be NP-hard (not solvable by polynomial time algorithms) [17]. If there are m tasks and r ordering constraints then there are $m!/2^r$ possible tasks sequences [4]. With such vast space it is nearly impossible to obtain an efficient solution using a deterministic algorithm. However, for the high dimension examples found in industry, heuristic procedures are accepted [9] for the simple assembly line balancing problem [5], [28].

Many attempts have been made to solve the assembly line balancing problem [2], [6], [8], [10], [11], [16], [19], [20], [21], [29], [31], however none of these methods have been proved to be of practical use for large problems due to their computational inefficiency. Several heuristic-based methods for the traditional assembly line balancing, have been developed. Abdullah et al [1], Baybars [3], and Mastor [23], review and evaluate these different approaches. Erel et al [9] critically examined, evaluated and summarized heuristic procedures for the single-model deterministic version of the assembly line balancing problem in sufficient detail to provide a state-of-the-art survey. They concluded that heuristic procedures appear to be more promising than the optimum-seeking algorithms due to the complexity of the problem.

Another proposed solution considers a five-phase method using task elimination, decomposition and heuristics [4]. Also, a genetic algorithm was used to obtain near optimal solutions to the traditional assembly line balancing problem in combination with heuristic-based methods [22]. Miltenburg and Wijngaard [24] adapted heuristics developed for the traditional assembly line and applied it to the U-shaped line balancing problem. They tested their algorithm using previously studied examples and test cases found throughout the assembly line literature. Also, a dynamic programming procedure has been devised. However, results were reported for small problems (11 tasks) because of the computational costs of the dynamic programming technique. Other exact and optimal procedures such as branch and bound algorithms that are only useful for low dimension examples have also been applied to the simple assembly line balancing problem [12], [14], [15], [18], [25], [26], [27], [29].

As mentioned earlier, the conventional line balancing techniques deal with balancing the workstations in the assembly line by distributing tasks to them to minimize the cycle time for a given number of the workstations, or their number for a given cycle time. This balancing is done without regard to workforce requirement when production rate is changed to meet customer demand. In this paper the problem of determining the manpower required to adapt to new production plans caused by fluctuating product demand in a continuous production line is considered. Furthermore, a set of models are suggested to balance out the fractional manpower resulting from a decrease or increase in production in order to meet fluctuations in product demand.

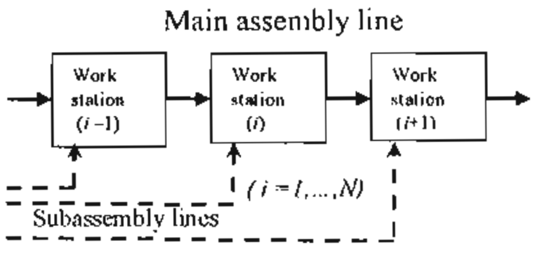
2- MODEL CONSTRUCTION:

In continuous production, products flow continuously through the workstations. Although varying number of workers may be required at different workstations, workers are not allowed to transfer between these workstations. Also, any interchange of workers along the line could cause an interruption in the line production rate unlike the case in batch production where workers may be permitted to move from one place to another. Therefore, if production rate in a continuous production line is to be changed to meet new customer demand, additional workers should be obtained from other sources. Thus a workforce planning system becomes technically and economically essential to provide sufficient manpower in the system to meet any unexpected change in production. Several factors in a production setting cause crucial problems for both management and workers and present limiting constraints that require sophisticated solutions especially for short term production and workforce planning in continuous production lines. Such factors are related to: 1) variability of operations times, 2) multiple products, 3) type of production and facility layout, 4) production rate, 5) social factors and workforce constraints, 6) positioning constraints; when the product is too large for one worker to perform work on both sides, operators are located on both sides of the flow line and, 7) zoning constraints; may be either positive or negative. According to positive zoning constraint, certain work elements should be placed near each other A negative zoning constraint indicates that work elements should not be located in close proximity since they might interfere with one another.

Because of the technical and human factors constraints. as mentioned above, unlike the normal manpower planning, workforce required can not be determined based on exact linear relationship between production rate and workforce. If workforce size is so determined then fractional workforce may result and this is impossible to implement. Instead, the computed theoretical value for the workforce size required is approximated to the smallest higher integer value; e.g. if the work content at workstation i requires 1.5 mandays and that of workstation j is 2.5 mandays then the theoretical number of workers needed to do the work in one day is 1.5 and 2.5 workers for workstations i and j, respectively. But since this can not be achieved the number of workers is rounded up to the next integer values of 2 and 3 for workstations i and j, respectively. Thus, the theoretical and actual total number of workers needed for both workstations is 4 and 5, respectively. Therefore, an idle time is created which is equal to (5-4)=1 mandays. Based on this illustration and as observed in some local manufacturing companies producing kitchen cabinets, components, home and office furniture the following assumptions are considered:

1) Movement of workers between workstations create disturbance in production and lead to lower production rate and therefore is not permitted.
2) Workforce sizes with fractions at main assembly line workstations are not additive and are rounded up to the next higher integer.

The production system considered, shown in Figure 1, is a continuous production line consisting of N workstations.



parts/components/subassemblies are fed from subassembly lines with batch production

Figure1.Continuous production line.

An operation (task or work element) is performed by one or more worker of a certain class at each workstation. There are J classes (grades) of workers available to carry out the line operations. Products flow continuously from one workstation to another along the main assembly line. Subassemblies (or components) used in the main line are produced and fed to the main line workstations by other subassembly lines operating under batch production settings.

Consider a working day (shift) of 8-hours from which the effective production time expressed in hours is denoted by T_{eff}. If the normal production rate in units per day (shift) per worker of class j at workstation i, ($i=1,...N$; $j=1,..,J$), as set by management is denoted by R_{ij} then, the time T_{ij} in hours required to complete an operation (task or one unit) by a worker of class j at workstation i is given by:

$$T_{ij} = \frac{T_{eff}}{R_{ij}} \qquad (1)$$

In practice, more than one worker may be required to perform an operation. If the minimum number of workers of class j required to complete one unit at workstation i is MNW_{ij} , then the time spent by each worker to complete the task becomes

$$\textit{The time spent per worker} = T_{ij} / MNW_{ij} = \frac{T_{eff}}{(MNW_{ij})\,(R_{ij})} \qquad (2)$$

Now, let P be the number of units of output per day (or shift) of the i^{th} operation (work element) at workstation i which is set by management as the normal production rate, then the theoretical value of the workforce (number of workers) of class j required to produce P units at workstation i, denoted by WF_{ij}^{Th}, is given by:

$$WF_{ij}^{Th} = (P / R_{ij}) MNW_{ij} \qquad (3)$$

This theoretical value of the workforce may contain a fraction of worker and thus becomes impossible to provide such a number of workers to workstation i.

Therefore, an actual value must be determined by rounding up the theoretical value to the next higher integer. Defining an operator $\lceil X \rceil$ that rounds off the value of X to the next higher integer value, then the actual workforce as an integer value, WF_{ij}^{Ac}, needed is

$$WF_{ij}^{Ac} = \lceil WF_{ij}^{Th} \rceil = \lceil (P / R_{ij}) MNW_{ij} \rceil \qquad (4)$$

and hence,

$$WF_{ij}^{Ac} \geq WF_{ij}^{Th} \geq (WF_{ij}^{Ac} - 1) \qquad (5)$$

Moreover, suppose that management intends to change the daily production P by an amount of $\pm p$ units per day such that $0 \leq p/P \leq 1$ (or expressed as a %age of P) in order to respond to a change in the market daily demand for the product, then a new production plan should be formulated for the production of $P \pm p$ units per day (or shift). The theoretical workforce size of workers of class j required at workstation i for the new production is given as a function in p as follows:

$$WF_{ij}^{Th}(p) = \left(\frac{P \pm p}{R_{ij}} \right) MNW_{ij} \qquad (6)$$

and can be written as

$$WF_{ij}^{Th}(p) = \frac{P}{P} \left(\frac{P \pm p}{R_{ij}} \right) MNW_{ij} = \left[\left(\frac{P}{R_{ij}} \right) MNW_{ij} \right] \left(\frac{P \pm p}{P} \right) \qquad (7)$$

which shows that the theoretical mandays is the multiplication of the theoretical mandays for the normal production (i.e. first term in the right hand side) and the ratio of the new planned production to the normal production (i.e. second term in the right hand side). The corresponding actual workforce size is

$$WF_{ij}^{Ac}(p) = \lceil WF_{ij}^{Th} \rceil = \left\lceil \left(\frac{P \pm p}{R_{ij}} \right) MNW_{ij} \right\rceil \qquad (8)$$

It can be seen that the difference between the theoretical and the actual workforce expressed in mandays is just the idle time expressed in mandays created by the rounding off operator applied to the theoretical workforce value required at that workstation. Denoting this idle time for workers of class j at workstation i by $I_{ij}(p)$, then we have:

$$WF_{ij}^{Ac}(p) \geq WF_{ij}^{Th}(p)$$

or,

$$WF_{ij}^{Ac}(p) = WF_{ij}^{Th}(p) + I_{ij}(p) \qquad (9)$$

The total idle time (mandays) of class j workers over all workstations in the production line, $I_{.j}(p)$, can be written as

$$I_{j}(p) = \sum_{i=1}^{N} \left\{ \left\lceil \left(\frac{P \pm p}{R_{ij}} \right) MNW_{ij} \right\rceil - \left(\frac{P \pm p}{R_{ij}} \right) MNW_{ij} \right\} \qquad (10)$$

Summing up the actual workforce for class j workers over all workstations in the production line we obtain the total actual workforce (mandays) of class j workers, $WF_{.j}^{Ac}(p)$, required for the whole production line.

$$WF_{.j}^{Ac}(p) = \sum_{i=1}^{N}[WF_{ij}^{Th}(p) + I_{ij}(p)]$$

$$= \sum_{i=1}^{N} WF_{ij}^{Th}(p) + I_{.j}(p) \qquad (11)$$

Note that because of the rounding off to the next higher integer done in Eq. (10) for the total idle time, the total workforce $WF_{.j}^{Ac}(p)$, presented in Eq. (11), is a step function with respect to p.

Assuming all workers on the line of the same class j, then the total actual workforce required for the whole production line, $WF_{..}^{Ac}(p)$, and the total workforce idle time, $I_{..}$, can be expressed as follows:

$$WF_{..}^{Ac}(p) = \sum_{i=1}^{N}\sum_{j=1}^{J} WF_{ij}^{Ac}(p) \qquad (12)$$

$$I_{..}(p) = \sum_{i=1}^{N}\sum_{j=1}^{J} I_{ij}(p) \qquad (13)$$

3- COST ASPECTS AND ANALYSIS:

In a general sense, the objectives of the production function are (1) to produce the desired product, (2) to achieve the desired rate, and (3) to minimize cost. Different types of costs are involved in the production process. These costs include direct labor cost, inventory cost, administrative cost, maintenance cost, setup cost,..etc. Since the models derived above are pertinent to workforce adjustment to balance changes in production, the labor cost is considered as the major cost in this analysis and other costs are assumed to be of minimal effect and therefore are considered constant regardless of the production output.

Obviously, increasing the size of the workforce to absorb any changes in the production volume will increase the direct labor cost. Therefore, it is more effective to consider the impact on profit achieved by setting up a new production plan to respond to changes in product demand rather than just considering the costs accrued by the new plan. The surplus or profit, defined as the difference between revenues generated and labor cost for the new production plan will be considered in this analysis as the criterion upon which management decision should be based to adopt any new production plan due to changes in production volume.

Let the wage rate for a class j worker be c_j dollars per day (shift), then the total labor cost per day accrued by the j^{th} class of workers for the new plan with a change of p units in production (or can be expressed as a %age of P), denoted by $TLC_j(p)$, is given by

$$TLC_j(p) = WF_{.j}^{Ac}(p)\, c_j \qquad (14)$$

but since $WF_{.j}^{Ac}(p)$ is a step function with respect to p, as mentioned earlier, then $TLC_j(p)$ is a step function as well with respect to p. Therefore, to simplify the application of the model the total actual workforce function $WF_{.j}^{Ac}(p)$ is simplified to a linear function as follows. From Eq. (11) and Eq. (6) we have

$$WF_{j}^{Ac}(p) = \sum_{i=1}^{N} WF_{ij}^{Th}(p) + I_{.j}(p)$$

$$= \sum_{i=1}^{N}\left(\frac{P \pm p}{R_{ij}}\right) MNW_{ij} + I_{.j}(p)$$

or,

$$WF_{.j}^{Ac}(p) = \sum_{i=1}^{N}\left(\frac{MNW_{ij}}{R_{ij}}\right)P \pm \sum_{i=1}^{N}\left(\frac{MNW_{ij}}{R_{ij}}\right)p + I_{.j}(p) \quad (15)$$

The quantity $\sum_{i=1}^{N}\left(\frac{MNW_{ij}}{R_{ij}}\right)P$ is assumed to be a constant value and $I_{.j}(p)$, in real life situations, could be approximated by a constant for large number of workstations and work elements in the production line. Denoting the sum of these two values by a constant $A_{.j}$, then Eq.(15) is approximated by

$$WF_{.j}^{Ac}(p) \cong A_{.j} \pm \sum_{i=1}^{N}\left(\frac{MNW_{ij}}{R_{ij}}\right)p$$

or,

$$WF_{.j}^{Ac}(p) \cong A_{.j} \pm B_{.j}p \quad (16)$$

$$where,\ B_{.j} = \sum_{i=1}^{N}\left(\frac{MNW_{ij}}{R_{ij}}\right)$$

Substituting in Eq. (14), the approximated total cost becomes

$$TLC_{j}(p) \cong A_{.j}c_{j} \pm (B_{.j}c_{j})p$$

The approximated total labor cost for the whole production line, $TLC(p)$, is given by

$$TLC(p) = \sum_{j=1}^{J} TLC_{j}(p)$$

$$\cong \sum_{j=1}^{J} A_{.j}c_{j} \pm \sum_{j=1}^{J}(B_{.j}c_{j})p$$

or,

$$TLC(p) \cong K_1 \pm K_2 p \quad (17)$$

$$where,\ K_1 = \sum_{j=1}^{J} A_{.j}c_{j}$$

$$K_2 = \sum_{j=1}^{J}(B_{.j}c_{j})$$

Thus, the total labor cost function is approximated by a linear function.

Usually, workers are paid according to their skills and job characteristics and therefore, different wage rates are paid to different classes (grades) of workers. Let worker wage rates, dollars per day (or shift), paid to different J classes of workers be c_j, $j = 1,\dots,J$ such that $c_1 \le c_2 \dots \le c_J$. Because of the behavior of the step function $TLC(p)$ the total labor cost does not increase linearly with the changes in production, $\pm p$, and therefore, if having two changes in production, say p_1 and p_2 such that p_2 is greater than p_1 by a very small amount, then the total labor cost for these two changes may remain the same and not necessarily greater for p_2. This can be generalized for n values of $p_i, i = 1,\dots,n$, in the neighborhood of the required p by

$$TLC(p_1) \le TLC(p_2) \le \dots \le TLC(p_n)$$

Based on this argument, management should determine the required actual workforce for the new production plan to absorb the change of p units in production by searching for the optimal or near optimal value p^*, in the neighborhood of p, that optimizes the generated profit from the new plan. To do so, a step-by-step neighborhood search procedure is outlined below:

Step 1: For a given p units change (increase/decrease) over the daily normal production of P units, select a set of p_i, $i = 1,\dots,n$ in the neighborhood of p such that p is included in the set. Thus, n production levels are selected (i.e. $(P \pm p_i)$, $i = 1,\ldots,n$).

Step 2: Establish an estimated revenues $R(p_i), i = 1,\ldots,n$ corresponding to each of the selected production levels.

Step 3: Calculate the total labor cost $TLC(p_i)$, $i = 1,\ldots,n$ accrued for each of the selected production levels using Eq. (17).

Step 4: Calculate the surplus (i.e. profit) $S(p_i)$, $i = 1,\ldots,n$ resulted from each of the selected production levels using

$$S(p_i) = R(p_i) - TLC(p_i) \quad \text{for } i = 1,\ldots,n$$

Step 5: Set the best change as $p^* = p_i$ such that:

$$S(p^*) = \max_i \left(R(p_i) - TLC(p_i)\right)$$
$$\text{for } i = 1,\ldots,n$$

This is the maximum surplus achieved amongst the selected production levels, and the best production level to be considered is $(P \pm p^*)$ for either an increase or a decrease in normal production.

Step 6: Calculate the corresponding actual workforce $WF_j^{Ac}(p^*), j = 1,\ldots,j$ required for the new production plan using Eq. (16).

4- CONCLUSIONS:

Productivity is one of the main elements of success for any organization, as well as profitability. Therefore, for any production plan adopted by management to be profitable, a surplus must be generated as a result of implementing such a plan. A set of mathematical models are constructed and presented in this paper to help management in selecting the most profitable production plan by smoothing the workforce requirement to absorb unexpected fluctuations in production volume due to changes in product demand in continuous production lines. Surplus (or profit) is defined as the difference between generated total revenue and total actual workforce cost accrued, and hence the most advantageous outcome of the application of these models is the optimal or near optimal scheduling and assignment of different classes of workers at different workstations on the production line to maximize profit (surplus) generated by the production operations.

5- REFERENCES:

[1] Abdullah T. A., Popplewell , K., and Page, C. J., 2003, A review of the support tools for the process of assembly method selection and assembly planning, *International Journal of Production Research*, Vol 41, pp. 2391-2410.

[2] Balakrishnan, A., and F. Vanderbeck, 1999, A tactical planningmodel for mixed-model electronics assembly operations, *Operations Research*, Vol 47, pp. 395-409.

[3] Baybars, I.,1986. A survey of exact algorithms for the simple assembly line balancing problem, *Management Science*, Vol. 32, pp. 909-932.

[4] Baybars, I, 1986, An Efficient Heuristic Method for the Simple Assembly Line Balancing Problem, *International Journal of Production Research*, Vol. 24, pp. 235-243.

[5] Boctor, F.F.,1995, A Multiple-rule Heuristic for Assembly Line Balancing, *Journal of the Operational Research Society*, Vol. 46, pp. 62-69.

[6] Dar-El, E. M. and Rubinovitch,Y., 1979, Must- A Multiple Solutions Technique for Balancing Single Model Assembly Lines, *Management Science*, Vol.25, pp. 1105-1114.

[7] De Looze, M P , Van Rhijn , J. W., Van Deursen , J., Tuinzaad , G. H.,

Reijneveld, C. N., 2003, A participatory and integrative approach to improve productivity and ergonomics in assembly, *Production Planning & Control*, Vol. 14, pp. 174 – 181.

[8] Dikos, A., Nelson P.C., Tirpak, T.M. and Wang, W., 1997, Optimization of high-mix printed circuit card assembly using genetic algorithms, *Annals of Operations Research* Vol.75, pp. 303-324.

[9] Erel, E. and Sarin, S. C., 1998, A survey of the assembly line balancing procedures, *Production Planning and Control*, Vol. 9, pp. 414-434.

[10] Steiner, G., Yeomans, J.S., 1996, Optimal Level Schedules in Mixed-Model, Multi-Level JIT Assembly Systems with Pegging, *European Journal of Operational Research*, Vol. 95, pp. 38-52.

[11] Held, M., Karp, R.M., and Sharesian, R., 1963, Assembly line balancing-Dynamic programming with precedence constraint, *Operations Research*, Vol. 6, pp. 113-119.

[12] Hoffmann, T.R., 1992, Eureka. A hybrid system for assembly line balancing, *Management Science*, Vol. 38, pp. 39-47.

[13] Hutchinson, S. T., Villalobos, J. R., and Beruvides, M. G., 1997, Effects of high labour turnover in a serial assembly environment, *International Journal of Production Research*, Vol 35, pp. 3201-3224.

[14] Johnson, R. V., 1988, Optimally Balancing Large Assembly Lines With FABLE, *Management Science*, Vol. 34, pp.240-253.

[15] Johnson, R. V., 1981, Assembly Line Balancing: A Branch and Bound Algorithm and Comparisons, *International Journal of Production Research*, Vol. 19, pp. 277-287.

[16] Jackson, J.R., 1956, A computing procedure for a line balancing problem, *Management Science*, Vol. 2, pp. 261-272.

[17] Karp, R. M., 1972, *Reducibility among combinatorial problems: Complexity of Computer Applications*, New York: Plenum.

[18] Klein, R.; Scholl, A.,1996, Maximizing the production rate in simple assembly line balancing – a branch and bound procedure, *European Journal of Operational Research* Vol 91, pp. 367-385.

[19] Kurashige, K., Yanagawa, Y., Miyazaki, S., Kameyama, Y., 2002, Time-based goal chasing method for mixed-model assembly line problem with multiple work stations, *Production Planning & Control*, Vol 13, pp. 735-745.

[20] Klincewicz, J.G., and Rajan, A., 1994, Using GRASP to solve the component grouping problem, *Naval Research Logistics*, Vol 41, pp. 893-912.

[21] Leon, V.J., and Peters, B.A., 1996, Replanning and analysis of partial setup strategies in printed circuit board assembly systems, *International Journal of Flexible Manufacturing Systems*, Vol. 8, pp. 389-412.

[22] Leu ,Y., Matheson, L. and Rees, L., 1995, Assembly Line Balancing Using Genetic Algorithms with Heuristic-Generated Initial Populations and Multiple Evaluation Criteria, *Decision Sciences*, Vol. 25, pp. 314-321

[23] Mastor, A. A., 1970, An Experimental Investigation and Comparative Evaluation of Production Line Balancing Techniques, *Management Science*, Vol. 29, pp. 728-746.

[24] Miltenburg, G.J.and Wijngaard, J.,1994, The U-line Line Balancing Problem. *Management Science*, Vol. 40, pp. 445-456.

[25]. Nevins, A. J., 1972, Assembly Line Balancing Using Best Bud Search, *Management Science*, 18, 9, pp.530-539.

[26] Sprecher, A., 1998, A competitive branch-and-bound algorithm for the simple assembly line balancing problem, *Production Planning & Control*, Vol 9, pp. 414-434.

[27] Talbot, F.B. Patterson, J. H., 1984, An Integer Programming Algorithm with Network Cuts Solving the Assembly Line Balancing Problem, *Management Science*, V. 30, pp. 85-99.

[28] Ugurdag, H.F., Rachamadugu, R., Papachristou, C.A., 1997, Designing paced assembly lines with fixed number of stations, *European Journal of Operational Research*, Vol. 102, pp. 488-501.

[29] Van Assche, F. and Herryen, W.S, 1979, An Optimal Procedure for the Single Model Deterministic Assembly Line Balancing Problem, *European Journal of Operational Research*, Vol. 3, pp. 142-151.

[30] Ventura, J. A., and Radhakrishnan, S., 2002, Sequencing mixed model assembly lines for a Just-In-Time production system, *Production Planning & Control*, Vol 13, pp. 199-210.

[31] Wee, T.S. and Magazine, M.J.,1981, *An effecient branch and bound algorithm for assembly line balancing- Part I: minimize number of workstations*, University of Waterloo, Waterloo, Ontario, Working Paper 151.

[32] Zeramdini, W., Aigbedo, H., and Monden, Y., 2000, Bicriteria sequencing for just-in-time mixed-model assembly line, *International Journal of Production Research*, Vol. 38, pp 3451-3470.