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Assembly line balancing to minimize balancing loss and system loss

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Abstract: Assembly Line production is one of the widely used basic principles in production system. The problem of Assembly Line Balancing deals with the distribution of activities among the workstations so that there will be maximum utilization of human resources and facilities without disturbing the work sequence. Research works reported in the literature mainly deals with minimization of idle time i.e. balancing, subject to precedence constraints. Lack of uniqueness in their optimum solutions has led to the present work where minimization of both balancing loss and system loss has been envisaged under the usual precedence constraints. The researchers suggest a generic approach for designing of an assembly line where, with a given number of workstations, one can efficiently arrive at the desired solution under different methods of search like simulation, heuristic etc. Thus, the main aim of this paper is to redefine the objective of the Assembly Line Balancing Problem and sequentially handle Balancing Loss and System Loss. A numerical example has been added to demonstrate the generic nature of the researcher's approach and improvement in the solution set when compared with different standard line balancing methods available so far in the literature.

Keywords: *Balancing loss; Idle time; System loss; Variance of idle time; Slackness; Simulation*

1. Introduction

1.1. Previous work

To meet the cost-reduction need of the era of mass production, the problem of assembly line balancing was addressed by Bryton (1954). Recently past, balancing of assembly line has again assumed importance under global strategy for standardization and cost reduction, and translation of core competence into competitive advantage (Keegan, 1995). Transnational companies have started re-thinking in terms of balanced flow lines to reduce the time and cost and increase the output.

For balancing an assembly line, one has to take into consideration the following issues such as number of products or models, deterministic or stochastic nature of task durations, line-layout, flow of work pieces, and level of automation. Accordingly, one can think of different classes of assembly line (Boyson *et al.*, 2007). For a detailed review of the related literature on generalized assembly line balancing, one may refer to Scholl (1999) and Becker and Scholl (2006). There are three ways of handling an optimization problem involved in assembly line balancing. These are heuristic approach (Boctor, 1995; Amen, 2001; Scholl and Becker, 2006), programming approach (Pinnoi and Wilhelm, 1998; Bukchin and Rabinowitch, 2006; Peeters, 2006) and simulation approach (Grabau *et al.*, 1997; McMullen and Frazier, 1998).

1.2. Problem description

The balancing problem studied in all the above-mentioned methods are oriented towards minimization of balancing loss and can be best used in transfer lines where work elements are preferably performed by machines/ robots. Assembly lines involving human elements have a different pressing problem. "The losses resulting from workers' variable operation times" is known as System loss (Wild, 2004) and losses resulting from the above-mentioned causes are more important than balancing loss. Increase in the cycle time is a crude solution to system loss; a better solution can be obtained through pacing. By adjusting the inter-work station distances and the speed of the conveyor belt, one can provide more time to workers in a work station. An alternative concept is to provide the work station with buffer stocks of semi-finished items. Optimum buffer stock capacity can be calculated using inventory cost, cost of idle facility, number of workstations, and extent of time variations in workstation (Wild, 2004).

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Our objective in this current work is to design an assembly line where dual objectives of minimization of balancing loss and system loss can be met. For this, the researcher's install our optimization method through multistage simulation approach. The procedure we propose herein will be generic in nature and can be used with different types of balancing methods so that the size of the balancing problem or the complexity of the same cannot act as hindrance. The researcher's present the proposed approach in Section 2. The concerned algorithm under simulation search is presented in the next section. Section 4 presents an worked out example.

2. Notation and methodology

2.1. Notation

K Number of jobs,

N Number of workstations,

T_i Task time or assembly time of i^{th} job,

L_j Idle time of j^{th} work station,

N_{min} Minimum number of workstation for a fixed cycle time,

C Cycle time,

C_t Trial cycle time,

C_{min} Minimum cycle time for a given K,

S_t Slackness for trial cycle time C_t, i.e., C - C_t,

V Variance of idle times, $L_1, L_2,.., L_K$,

B Balancing loss, i.e., $\{(NC - \sum T_i) / NC\}. 100\%$.

2.2. Methodology

To examine the efficiency of an assembly line, one uses the concept of balancing loss, B. The underlying objective is to minimize B subject to precedence constraints. Our proposed work is a multi-objective one where minimization of balancing loss is to be addressed along with system loss. As system loss arises out of workers' variable operation time, any configuration where one workstation has no idle time and another workstation has high idle time may result in high disruption in the system. Therefore, a measure for system loss may be considered as the variance of idle times (V). The stability of the total system will be maximum when this variance will be minimum. Thus, the underlying objective of a line-balancing problem should be minimization of B and V, subject to precedence constraints. The researchers propose to divide this multi-objective problem into two stages. Given a choice of cycle time C, one can arrive at the minimum number of workstations. Given this minimum number of workstation, they get a set of feasible solutions to line balancing problem, each optimizing the balancing loss. Within this set of feasible solutions, our objective is to minimize the system loss.

Given a choice of C, it may be noted that the theoretical minimum number of workstations, N_{min}, must satisfy the following constraints:

$$\sum_{i=1}^{K} T_i / C \le N_{min} \le \sum_{i=1}^{K} T_i / C + 1, \tag{1}$$

from where the researchers arrive at C_{min}, the minimum value of C, as:

$$C_{min} = \sum_{i=1}^{K} T_i / N_{min} + 1. \tag{2}$$

Thus, given a cycle time, C, one may conceptually start from a trial cycle time, C_t, satisfying the condition $C_{min} \le C_t \le C$, to arrive at the set of feasible workstation configurations and maintain the same cycle time C by uniformly adding to each workstation a slackness S_t to C_t. Thus, the generation of alternative solutions can be increased by manifolds. For each configuration, we get a value of the measure V. The configuration that gives minimum V is the trial optimal solution. Final optimal solution will be the one that has least V value across trial cycle times $C_{min} \le C_t \le C$. We next develop an algorithm based on simulation search method to make the suggested procedure computationally functional.

3. The algorithm

1. Set cycle time C, determine the minimum number of workstations N_{min} and calculate the C_{min} value.
2. Set the trial cycle time C_t at $C_{min.}$
3. Prepare the list of all unvisited tasks – call it List U.

4. Prepare List R from the tasks of List U with no immediate predecessor or whose immediate predecessors have been visited. The tasks of R are ready for selection.
5. Prepare List A from the tasks of List R having assembly time less than that of cycle time and is allowable for inclusion.
6. Randomly select a task from the List A and reset the cycle time as {C_t – assembly time}.
7. If cycle time is less than the assembly time, then open a new workstation. Reinitialize cycle time to its original value and repeat the above steps until all nodes are visited.
8. After getting the complete distribution of tasks to workstations, calculate the variance of idle times.
9. After each run, the new variance value is compared with the previous least variance value.

   If the new variance is less than the previous least variance, the new solution is stored as the basis for next comparison.
10. Increase the cycle time by one unit until it crosses C value. If C value is crossed, go to 12.
11. Repeat step 2 to 10.
12. Check whether all the work elements have been assigned to specified number of workstations. If not, increase the value of N_{min} by 1 and go to 2.
13. Print the best solution in terms of overall minimum variance.

The proposed algorithm has been converted in C language for numerical study.

4. Worked out example

To explain how the proposed algorithm works, we consider in Figure 1 an assembly line balancing problem from Ray Wild (2004). A figure within a circle represents task number and that close to a circle represents corresponding task time. Precedence constraints are represented by arrows.

Let us consider for our study a cycle time of 35(=C) time units. This results in N_{min} =5 and C_{min} = 29 and $29 \le C_t \le 35$ with S_t = 35 - C_t. For each trial cycle time we consider 20,000 runs.

Feasible solutions are obtained only for C_t=31, 32, 33, 34 and 35. The cycle time wise trial optimum solutions are presented in Table 1. Thus, from Table 1 we have obtained the optimum configuration for C_t=32, presented in Table 2.

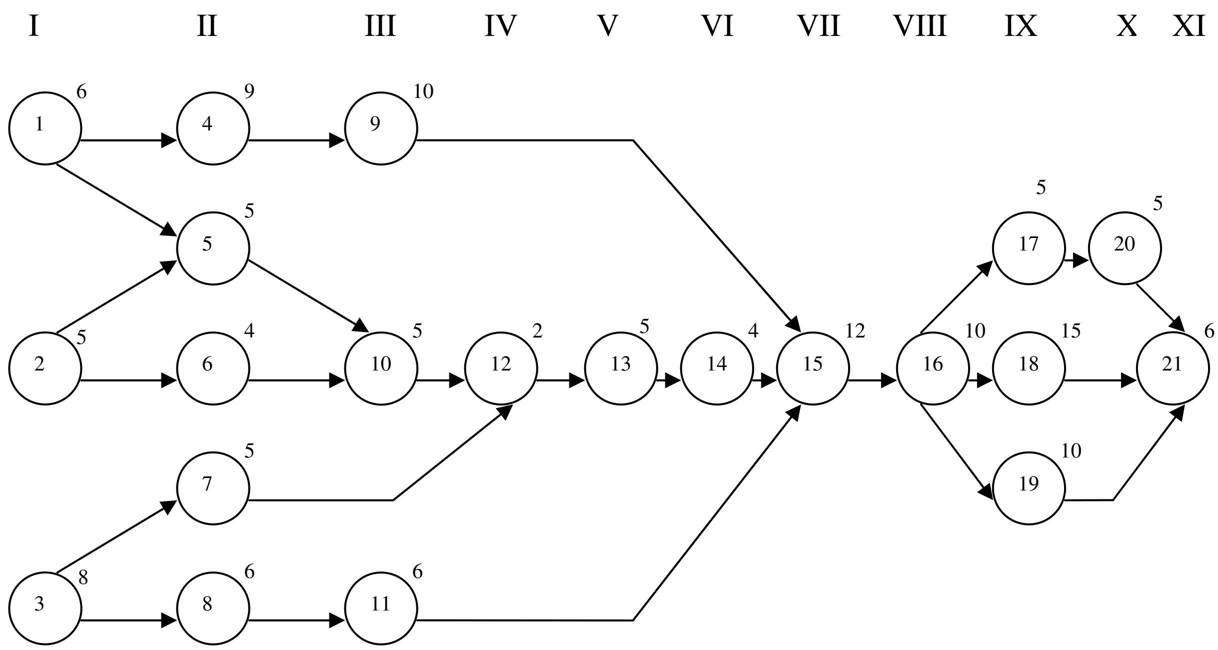

Figure 1: Precedence diagram of work stations along with the task times.

Table 1: Trial cycle time wise optimum solution including overall optima.

Trial cycle time	No. of opt. Sol^n	Work Station 1		Work Station 2		Work Station 3		Work Station 4		Work Station 5		Variance
		Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
31	01	1,3,2,5,8	01	6,4,10,11,7,12	00	13,9,14,15	00	16,19,17, 20	01	18,21	10	14.63999
	02	1,3,8,2,7	01	6,11,5,10,4,12	00	13,9,14,15	00	16,17,19, 20	01	18,21	10	14.63999
	03	2,3,7,8,1	01	11,6,4,5, 10,12	00	9,13,14,15	00	16,18,17	01	20,19, 21	10	14.63999
	04	2,3,1,7,8	01	5,11,6,10,12,13,14	00	4,9,15	00	16,18,17	01	20,19, 21	10	14.63999
	05	2,3,7,8,11	01	1,4,6,5,10,12	00	9,13,14,15	00	16,19,17, 20	01	18,21	10	14.63999
	06	3,1,7,8,11	00	2,6,5,10, 12,4	01	9,13,14,15	00	16,19,17, 20	01	18,21	10	14.63999
	07	3,7,8,1,2	01	5,6,10,12,13,14,11	00	4,9,15	00	16,19,17, 20	01	18,21	10	14.63999
	08	2,3,1,5,8	01	11,6,10,4,7,12	00	13,9,14,15	00	16,18,17	01	19,20 21	10	14.63999
	09	3,7,8,11,2	01	6,1,5,4,10,12	00	13,14,9,15	00	16,18,17	01	19,20, 21	10	14.63999
	10	1,2,3,8,11	00	4,6,7,5,10,12	01	13,14,9,15	00	16,17,18	01	20,19, 21	10	14.63999
32	01	2,1,5,6, 10	07	3,8,4,11	03	9,7,12, 13,14	06	15,16,17, 20	00	19,18, 21	01	7.44
33	01	2,1,6,5,4	04	9,3,10,8	04	7,12,13, 14,11	11	15,16,19	01	18,17, 20,21	02	12.24
	02	1,3,8,4	04	9,7,2,5,6	04	11,10,12, 13,14	11	15,16,17, 20	01	18,19, 21	02	12.24
	03	3,2,8,6,1	04	5,10,4,9	04	11,7,12, 13,14	11	15,16,19	01	18,17, 20,21	02	12.24
	04	3,2,8,1,6	04	4,5,7,9	04	11,10,12, 13,14	11	15,16,19	01	18,17, 20,21	02	12.24
	05	1,4,2,5,6,	04	9,10,3,8	04	7,12,11, 13,14	11	15,16,17, 20	01	19,18, 21	02	12.24
	06	3,1,4,8	04	2,5,9,7,6	04	10,12,13, 14,11	11	15,16,17, 20	01	18,19, 21	02	12.24
	07	1,2,6,4,5	04	9,3,8,7	04	10,12,11, 13,14	11	15,16,19	01	17,18, 20,21	02	12.24
34	01	3,7,8,1, 11	03	2,6,5,4, 10, 12	04	9,13,14, 15	03	16,19,17, 20	04	18,21	13	14.6399
	02	3,7,8,11,1	03	2,5,6,10,4, 12	04	13,9,14, 15	03	16,18,17	04	19,20, 21	13	14.6399
	03	3,2,8,1, 11	03	7,5,6,4, 10, 12	04	13,9,14, 15	03	16,18,17	04	19,20, 21	13	14.6399
	04	2,3,8,11,1	03	6,5,7,10, 12,13,14	04	4,9,15	03	16,17, 20, 19	04	18,21	13	14.6399
	05	3,2,8,11,1	03	7,5,4,6, 10, 12	04	13,9,14, 15	03	16,19,17, 20	04	18,21	13	14.6399
	06	3,1,8,11,2	03	6,7,5,10, 12,13,14	04	4,9,15	03	16,17,18	04	20,19, 21	13	14.6399
	07	3,8,11,1,7	03	2,5,6,10, 12,13,14	04	4,9,15	03	16,19,17, 20	04	18,21	13	14.6399
	08	3,7,8,1, 11	03	2,6,5,10, 12,13,14	04	4,9,15	03	16,18,17	04	20,19, 21	13	14.6399
35	01	2,1,6,4,3	03	7,9,8,11,5	03	10,12,13, 14,15	07	16,19,17, 20	05	18,21	14	16.64
	02	2,1,6,3,4	03	8,11,5,9, 10	03	7,12,13, 14,15	07	16,17,19, 20	05	18,21	14	16.64

Table 2: Final configuration.

Work Station 1		Work Station 2		Work Station 3		Work Station 4		Work Station 5		Variance
Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
2,1,5,6,10	10	3,8,4,11	06	9,7,12, 13,14	09	15,16,17, 20	03	19,18, 21	04	7.44

5. Conclusion

The researchers have presented a sequential approach for balancing an assembly line with twin objectives of minimization of balancing loss and system loss. Their approach is a generic one, which is capable of solving different line assembly problem with a reasonable computation time. From the solution set generated by simulation search, final choice is made based on optimum number of workstations and minimum variance.

In their algorithm first the researchers have taken into consideration balancing loss issue and generate a set of feasible solutions. Among those solutions the best solution is to be selected based on system loss criterion.

One may think of considering System loss first and then Balancing loss. But in that case the number of solutions will be very large. As a result, optimization task will be very difficult to handle. The same problem will arise if we want to simultaneously minimize System loss and Balancing loss.

This approach, according to numerical, study is giving a better set of configurations because we are using some amount of slackness (S_t) in each workstation with trial cycle time C_t varying from C_{min} to C.

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