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RISK ANALYSIS IN ASSEMBLY LINE BALANCING: A STUDY

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ABSTRACT

The traditional assembly line balancing problem considers the manufacturing process of a product where production is specified in terms of a sequence of tasks that need to be assigned to workstations. Each task takes a known number of time units to complete. Most research works assume deterministic task times and the methods developed is not practical in a realistic environment. However, task times may vary from cycle to cycle and relatively less work is focused on stochastic assembly line balancing. In a single model assembly line, product flows through series of workstations arranged in a sequential manner. Each workstation has a finite number of tasks and each task has stochastic nature of task time, the task times can exceed the expected standard task time at some instance. If a series of tasks exceeds in a particular station, then there is risk that the product may exceed the cycle time. The larger the variability of task time, the higher the risk associated with that station. Risk is defined as potential loss caused when product fails to complete within the specified station time. For line balancing, in addition to cycle time balancing, the risk should be balanced in order to improve performance of assembly line. In this paper method has been developed to balance risk among workstations in order to make assembly line work smoothly and efficiently.

Keywords: Line *balancing, workstations, environment, assembly, performance*

INTRODUCTION

The basic assembly line consists of a set of workstations arranged in a sequential manner, with each station connected by a material handling device. A station is considered any point on the assembly line in which a task is performed on the part (Grzecha W. (2008))[7]. These tasks can be performed by machinery, robots, and/or human operators. The time it takes to complete a task at each operation is known as the process time (Sury, 1971). The cycle time of an assembly line is predetermined by a desired production rate. This production rate is set so that the desired amount of end product is produced within a certain time period (Baybars I. (1986)) [1]. In order for the assembly line to maintain a certain production rate, the sum of the processing times at each station must not exceed the stations' cycle time. If the sum of

A heavily studied problem is the problem of balancing an assembly line by assigning the operations required by a single model to a number of stations. When there is only one model of a product that is being assembled on the line, the resulting problem is called the simple assembly line balancing problem (SALBP).The SALBP problems are divided into two categories, one for minimizing the number of workstations for given cycle time (SALBP-1) and another for minimizing cycle time for given no. of workstations (SALBP-2) (Karabatı, and Sayın 2004) [8].

Most research works assume deterministic task times and the methods developed are not practical for application in a realistic environment. In manufacturing of products such as aircraft, there is high variability in task times. This is because most tasks involve manual activities and as a result, task

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times vary from one unit to next and relatively less work is focused on stochastic ALBP. Moodie and Young (1965) [10] proposed a two-step heuristic procedure aimed at assigning tasks among workstations so to obtain minimum number of workstations for a given cycle time and also to reduce the probability of workstations not exceeding the cycle time in amoving line. If a series of tasks exceeds in a particular station, then there is a risk that the product may exceed the cycle time. Risk is defined as potential loss caused when the product fails to complete within the specified cycle time (Modarres (2006)) [9].The objective of this work is to develop a methodology to balance risk among workstations in order to improve performance of assembly line. For this purpose, a heuristic method has been proposed to minimize the maximum difference in risk among workstations.

LITERATURE REVIEW

Assembly line balancing problem (ALBP) is one of the important problems in manufacturing industries. ALBP involves optimally distributing the work among the workstations without violating assignment restrictions based on an objective such as minimizing the total cost, number of workstations, cycle time, maximizing the throughput, and efficiency. Baybars (1986) [1] has developed a single pass heuristic for single model deterministic line balancing, for different priority rules. Shin D. (1990) [12] developed a heuristic procedure for solving stochastic SALBP by considering normally distributed task times. This methodology finds an optimal task allocation to workstations by minimizing the total expected cost. Scholl and Vob (1996) [11] solved assembly line balancing problem (SALBP-1) based on minimizing no. of stations along the line for a given cycle time. The next version, SALBP-2 is based on minimizing the cycle time for given number of workstations Ugurdag et al. (1997) [13]. If both cycle time and number of workstations can be minimized considering their interrelationship, SALBP-E maximizes line efficiency. Generally, line efficiency is defined as the ratio of total task time to the product of cycle time and no. of stations (BoysenFliedner and scholl 2007) [3].Gokcen (1997) [6]has proposed a nonlinear integer program as a model for mixed model line balancing problems with parallel workstations. Fleszer and Hindi (2003) [5] have proposed a bidirectional heuristic for assembly line balancing problem with a reduction technique..Karabatı S.S. and Sayın S.(2003) [8] have considered the assembly line balancing problem in a mixed-model line which is operated under a cyclic sequencing approach. Authors specifically studied the problem in an assembly line environment with synchronous transfer of parts between the stations. The assembly line balancing problem with the objective of minimizing total cycle time by incorporating the cyclic sequencing information has been formulated. It has been shown that the solution of a mathematical model that combines multiple models into a single one by adding up operation times constitutes a lower bound for this formulation. As an approximate solution to the original problem, authors proposed an alternative formulation that suggests minimizing the maximum sub cycle time. A survey has been done on SALBP. The survey shows that assembly line balancing research which traditionally was focused upon simple problems (SALBP) has recently evolved towards formulating and solving generalized problems (GALBP) with different additional characteristics such as cost functions, equipment selection, paralleling, U-shaped line layout and mixed model production Becker C. and Scholl A(2004) [2].

METHODOLOGY

RISK ESTIMATION PROCEDURE

The objective of this work is to balance the risk among all the workstations. For each task risk is calculated by newly developed risk index method. This method computes risk by multiplying two ratios, which are delay index and contribution ratio. These two ratios address the two components of risk. Delay index addresses the frequency and contribution ratio addresses the task time. So, risk is estimated in terms of Risk index. The two ratios are explained in detail as:

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Delay Index

This ratio can be defined as the no. of data points exceed the standard task time divided by the total no. of data points. This ratio addresses the frequency that the task exceeds allotted task time.

$$\text{Delay Index (D)} = \frac{E}{l}$$

Where, E is the no. of times task exceeds standard task time

l is the total available no. of data points

The value of D ranges from 0 to 1. If the value of D is low, then the task exceeds less frequently which in turn reduces the risk index and thereby, shows that the task is at low risk. Similarly, if the value of D is high, then the task exceeds more frequently and contributes for an increase in RI.

Contribution Ratio

Contribution ratio is the ratio of standard task time and total cycle time of the product. This ratio illustrates the contribution of each task to its total cycle time.

$$\text{Contribution Ratio (C)} = \frac{t}{Cp}$$

Where, t is the standard task time

C_p is total cycle time of the product

The value of C ranges from 0 to 1. When C is low, the task has a less processing time and the contribution to risk is also low. On the other hand, when C is high, the task has a high processing time and the contribution to risk is high.

Risk Index Number

Risk index number is calculated by multiplying the above two ratios.

$$RI = D\times C\times 1000$$

Risk Balancing Method

In this section, we will discuss about the method, that, we have used to balance the risk among workstations. For this purpose, we have used a heuristic method to reassign tasks among workstations in order to balance the risk without violating precedence relationship. This method aims to minimize the maximum difference in RI for all workstations.

Heuristic Method

Heuristic method is developed to balance the risk (minimizes the maximum difference in RI) between workstations without violating assignment restrictions (precedence constraint and cycle time constraint).

Algorithm:

Step 1: Draw precedence and follower matrix, and calculate no. of followers for each task.

Step 2: Open a suitable station with cycle time $t_{max} \leq T \leq \sum_{i=1}^{m} ti$ and set Sj = 0.

Step 3: Determine set of available tasks, if set is empty, then terminate else go to step 4.

Step 4: Determine set of assignable tasks and select a task with maximum no. of followers.

Step 5: If $t_i + S_j \geq T$, then open a new station else assign that task to station j.

Step 6: Update $S_j = S_j + t_i$ and remove task from set, and Go to step 3.

DATA COLLECTION AND NUMERICAL EXAMPLE

DATA REQUIREMENT

To do risk analysis for an assembly line, data such as set of tasks, standard task time (i.e. the specified processing time of any task) of all tasks, precedence constraints and a set of actual task times (i.e. the variable time due to stochastic nature of task). They are represented as follows:

$I = \{I_1, I_2, \ldots\ldots I_m\}$, where I is set of tasks

$t = \{t_1, t_2, \ldots\ldots\ldots t_m\}$, where t is set of standard task time

Precedence constraints are represented by precedence table P_{ij} as task i should be completed before task j.

P_{ij} Binary precedence table: 1, task i is precedent to task j; 0, otherwise

Where, $i, j \in I$

Actual task times have been obtained from a 'c' program, which has been written to distribute task times randomly.

l = no. of data points for each task.

T = Cycle Time

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DATA COLLECTION

To illustrate the problem of risk oriented assembly line balancing, we present an example from literature with 12 tasks and cycle time is 15 minutes. Figure 1 shows the precedence relationship among tasks and table 1 shows the standard task times of all tasks:

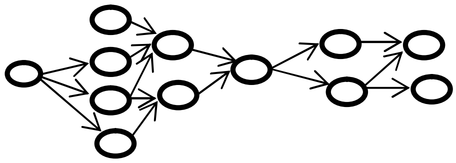

Fig.1 Precedence Relationship

Table 1 Standard task times of all tasks

Task	1	2	3	4	5	6	7	8	9	10	11	12
Time	9	4	2	3	2	5	2	7	8	4	4	3

Due to stochastic nature of task, task times vary and these variable task times are represented as actual task times. A ‘C Program’ is written to obtain these actual task times for the above problem. These are shown in the table 2, given below:

Table 2 Actual task times of all tasks for 10 no. of data points

Task no.										
1	8.590	9.220	9.830	8.500	9.080	9.460	8.950	9.02	8.22	8.55
2	4.140	4.210	4.270	4.100	3.910	4.010	4.090	4.11	3.93	3.87
3	2.090	1.820	1.980	1.940	1.870	1.850	2.010	2.14	1.900	1.970
4	3.180	3.170	2.730	3.030	3.190	3.150	3.020	2.94	3.13	2.96
5	2.020	2.110	1.970	1.910	2.040	2.110	2.060	1.92	2.09	2.080
6	5.080	5.020	5.250	4.790	4.840	4.680	5.040	5.330	4.890	4.540
7	1.990	1.930	1.840	2.160	2.130	2.010	2.000	2.010	2.200	2.000
8	6.790	7.250	7.000	7.660	6.490	7.360	7.080	6.470	7.690	6.72
9	8.350	7.370	8.480	8.110	8.440	7.330	7.50	8.18	7.220	8.69
10	4.270	3.980	4.000	3.760	3.700	3.930	3.76	4.200	4.240	3.910
11	4.310	4.33	4.240	3.740	3.830	3.830	3.72	3.93	3.96	4.32
12	2.980	2.790	2.740	3.170	3.270	2.970	2.750	2.92	3.19	3.28

ESTIMATION OF RISK:

Risk index of each task can be calculated by the collected data such as, standard task time (t), total cycle time of the product (c_p), available no. of data points (l) and no. of times task exceeds the standard task time (E). First, we calculate delay index (D) and contribution ratio (C) (two components of risk), then risk index by risk index method given in section 3.1.3. Table 3 shows the risk index of all 12 tasks:

Table 3 Risk index of all 12 tasks

Task No.	Delay index (D)	Contribution ratio (C)	Risk index (RI)
1	0.5	0.169	84.5
2	0.7	0.075	52.5
3	0.3	0.037	11.1
4	0.7	0.056	39.2
5	0.7	0.037	25.9
6	0.5	0.094	47
7	0.5	0.0376	18.5

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8	0.5	0.132	66
9	0.6	0.150	90
10	0.3	0.075	22.5
11	0.4	0.075	30
12	0.4	0.056	22.4

BALANCING RISK BY PROPOSED HEURISTIC:

The given problem is balanced in terms of cycle time and initial allocation of tasks without violating precedence relationship is shown in table 4. Heuristic method is applied to the problem and the same table 4 shows the task allocation, value of risk and station time before and after reallocation.

Table 4 Task order before and after reallocation

Workstations	J_1	J_2	J_3	J_4
Before Reallocation				
Tasks	1,2,3	4,6,5,7	8,9	10,11,12
Station time	15	12	15	11
Risk index	148.1	130.6	156	74.9
After Reallocation				
Tasks	1,4,3	2,5,6,7	8,10,12	9,11
Station time	14	13	14	12
Risk index	134.8	143.9	110.9	120

RESULTS AND DISCUSSIONS:

The present work concentrates on risk analysis in assembly line balancing and objective of this work is to balance the risk among workstations by an efficient heuristic method.

For this analysis, we took a problem from literature and estimated risk of each task by risk index method.

All the tasks are assigned to workstations without violating precedence relationship and cycle time. After allocation of tasks to workstations, it is found that, there is a huge variation of risk among workstations. To minimize this maximum difference, tasks were reallocated by proposed heuristic method in order to improve performance of assembly line.

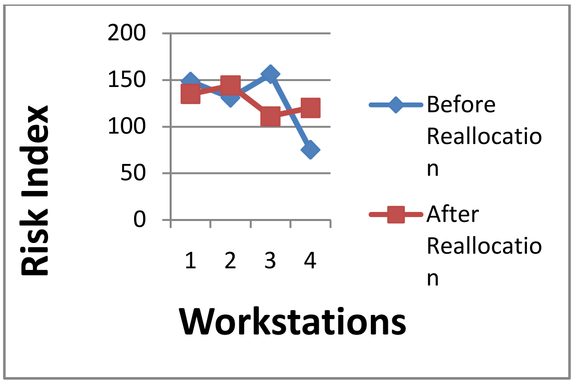

Fig. 2 Risk balance chart

It can be seen from figure 2 above, that the variation in risk among workstations has been reduced by proposed heuristic method. It can also be seen, that the risk is distributed somewhat equally and the maximum difference in risk among work stations is minimized.

CONCLUSIONS

A heuristic method to balance risk among workstations was proposed, which gives better results and somewhat balances the risk. A numerical example from literature was taken and above method was applied to balance risk.A risk estimation procedure was given to estimate risk. The two components of risk, Delay index and contribution ratio were calculated to compute risk of each task. Following concluding remarks have been drawn from the study:

- Maximum difference in risk among workstations has been minimized after reallocation of tasks to workstations.

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