ASSEMBLY LINE BALANCING WITH PARALLEL-OPERATOR STATIONS AND TWO-OPERATOR TASKS: A CASE

Şükrü Özen (*)

SUMMARY

In this article, we define a real deterministic assembly line balancing problem with parallel-operator stations and two-operator tasks, and, in the light of the production policies adopted by the company, we propose a number of alternative line designs obtained by applying the Modified Ranked Positional Weights Technique to the problem.

INTRODUCTION

Assembly Line Balancing (ALB) problem deals with minimizing **total idle time (TIT)** along an assembly line, or equivalently, **balance delay ratio (d)** of the line by grouping a set of tasks into a set of work stations while satisfying **the cycle time (T)** and **precedence constraints.**

ALB problems are classified into two categories depending on whether the process times of tasks are deterministic or stochastic. The ALB promlems in which the process times are given and fixed are called **deterministic ALB problems.** When the process times are assumed to be random variables having a known probability distribution, the problem becomes a **stochastic ALB problem.**

Furthermore, when a deterministic or a stochastic ALB problem satisfies the following requirements as stated by Baybars (1985a;5), it becomes a deterministic or a stochastic **Simple Assembly Line Balancing (SALB) problem:**

a) all stations involved are identically equipped and manned,

b) the process times are independent of the station at which they are performed and of preceding and following tasks,

---

(*) Araş. Gör, Erciyes Ü. İ.İ.B.F. İşletme Bölümü

c) anytask can be processed at any station.

d) the total line is considered to be serial with no feeder or subas sembly lines,

e) the assembly system is assumed to be designed for a unique model of a single product.

There are two versions of the deterministic SALB problems that have two different optimization criteria, namely, **SALBP-1 and SALBP-2** (Baybars,1985a;6). SALBP-1 aims at minimizing number of stations (**n**) for a given T while SALBP-2 aims at minimizing T for a given n. Both versions attempt to achieve the same goal, the minimum TIT or d.

The stochastic SALB problems are designed to optimize a number of criteria as well as minimizing n or T (Kao, 1976; 1097). For instance, Reeve and Thomas (1973) attempt to minimize the probability that one or more stations exceed a given cycle time (Buffa, 1976; 388) while Kottas and Lau (1981; 177) try to minimize the total system cost consisting of the labor cost and the cost of incompletion.

Except for the first requirement above, relaxing one or any combination of the requirements results in **General Assembly Line Balancing (GALB)** problem, whether the goal is to minimi. e n or T (Baybars, 1985a; 6). Relaxing the first requirement, we define a different problem, called **Assembly Line Design (ALD)** problem, that has two optimization criteria, line design cost and TIT (Baybars,1985a. 7-8).

In this paper,we identify an actual deterministic ALB problem violating the fourth simplicity requirement as well as having specific features, and solve the problem for a series of cycle times by employing the Modified Ranket Positional Weight Technique (HEMAXRPW)

I.DESCRIPTION OF THE PROBLEM

The study reported in this paper was conducted in a company manufacturing presently single model of aqricultural tractor,6610. The line chosen for the study assembles the engine of the 6610 model tractor.

The engine assembly line is equipped with a rail on which an assembly car goes along the stations located serially. As depicted in Figure 1 below, the engine line has 4 stations with 8 operators: two operators (A and B) at each station. Here two operators perform the same set of tasks assigned to the station, and therefore, it is a **parallel-operator stations**

assembly line (Vrat and Virani, 1976; 446). Furthermore, some tasks are performed by both operators, called **two-operator tasks**. The numbers at the stations in Figure 1 refer to the tasks assigned to A or B, or both, at that stations. Along the line, 31 individual tasks are performed.
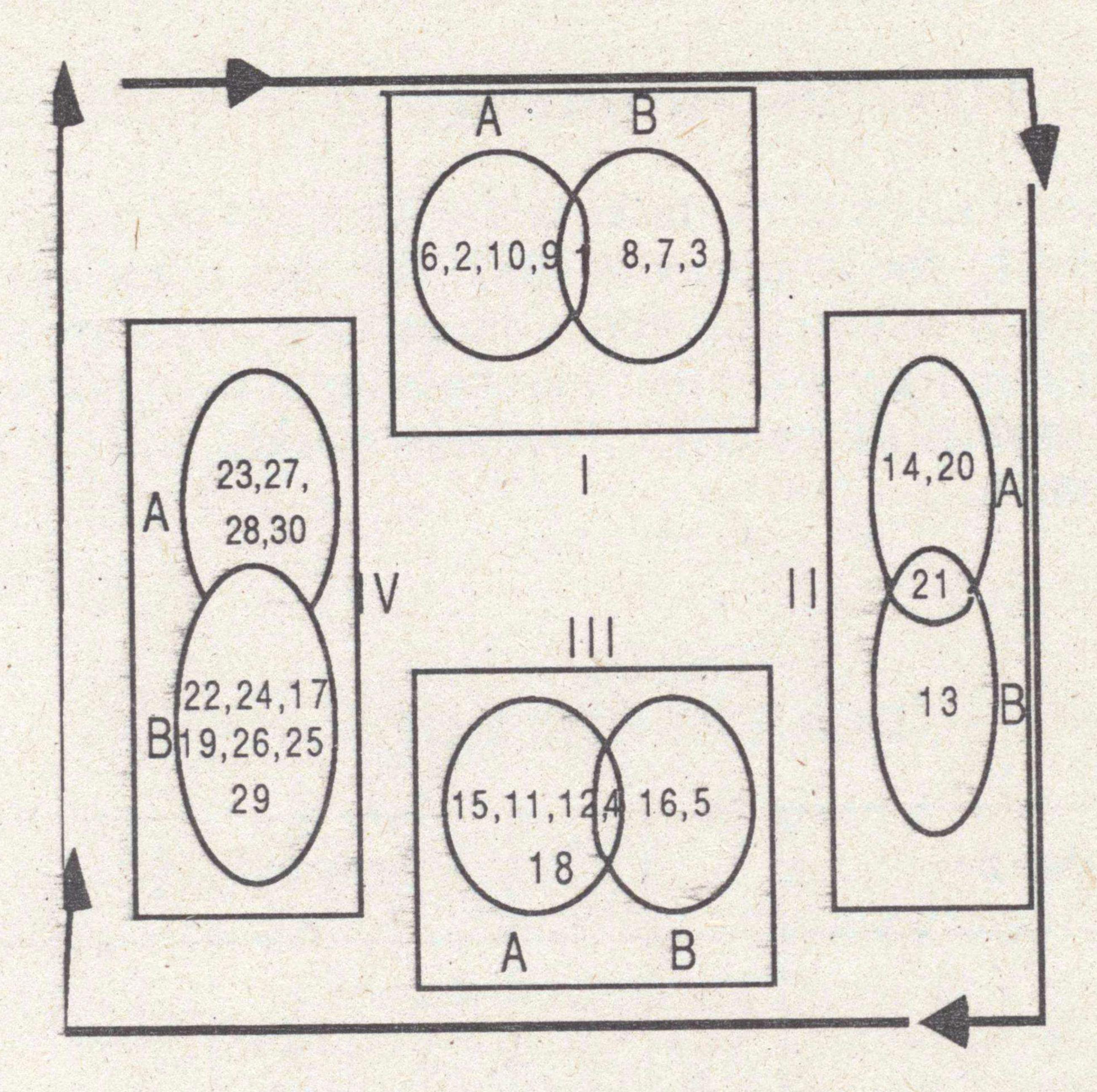

Figure 1. Layout and Task Assignme nt of the Existing Engine Assembly Line

In the production of the 6610 model engine, the management implements two different policies, namely **traditional policy** and **labor-shifting policy**. The former contains the use of a line designed for the cycle time of 20 minutes which enables the company to produce 24 engines within an 8-hour workday. When a production rate greater than 24 eng is required, the later policy is put into practice. This policy is characterized by the reduction of the cycle time of 20 minutes to abouth 15 minutes in such a way that the operators with excessive idle times are shifted to the parallel tasks in the bottleneck station. The number of operators to be shifted from one station to another is based on the supervisor's own judgement.

The problems stated by the management are two-fold. First, the cur-

rent line design practiced in the traditional policy has an unfavorably high balance delay,41.875 %.Therefore,the management intends to adopt,in the traditional policy,a balanced line design yielding the minimum d.Since the use of a balanced line in the traditional policy will leave no room for the practice of the labor-shifting policy, the management also intends to determine a number of alternative line designs to attain the increasing daily production rates by shifting not operators but the tasks between the stations.

II.DATA FOR THE PROBLEM

The process times of the tasks were estimated by a stop watch time study conducted by the company in 1987. The means and variances were computed for each task.In this study, the process times are fixed at their mean values.Table 1 gives the mean process times in minutes (t) and precedence relationships of the tasks. The tasks marked with "*"refer to the two-operator tasks.

TABLE I
DATA FOR THE PROBLEM

task no.	preceded by	$\overline{t}$	task no.	preceded by	$\overline{t}$
1*	-	3.1	17	4	1.0
2	1	1.4	18	12	4.2
3	1	1.4	19	5,13	1.0
4*	1	9.6	20	7,14	2.1
5	1	1.2	21*	15	4.1
6	1	1.8	22	18	2.7
7	1	1.4	23	22	5.1
8	1	1.5	24	22	1.1
9	1	0.3	25	23	1.0
10	1	1.0	26	23	3.0
11	1	0.5	27	27	4.3
12	4	0.5	28	27	4.3
13	6	4.8	29	28	2.0
14	8	2.0	30		4.3
15	4	2.0	31*	2,3,9,10,11,16,17,19,20,21,24,25,26,29,30	1.2
16	4	1.5			

* two-operator task

III-IDENTIFICATION OF THE PROBLEM

The problem involved is a deterministic ALB problem in the sense that a set of tasks with the deterministic process times is to be assigned to the work stations such that TIT or d is minimized while satisfying the cycle time and precedence constraints.

The problem satisfies all requirements of SALB problems except the fourth one requiring that the total line be serial with no feeder or subassembly lines. The implication of this requirement is that the process times are additive at any station. In spite of the fact that the engine line has no feeder or subassembly line, the process times are **not** additive due to the parallel-operator stations assembly. Therefore, the problem **implicitly violates** the fourth requirement of SALBP.

Moreover, a special requirement of the problem is the two-operator tasks referring to the tasks that must be processed by two operators.

Consequently, the problem can be defined as a single-model deterministic ALB problem characterized by the parallel-operator stations and two-operator tasks. In general sense, the problem can also be referred to as a GALB problem since it satisfies the first requirement of SALBP.

IV. PROPOSED METHODOLOGY FOR THE PROBLEM

This study aims at specifying a number of line designs that are to be alternative to the current line designs being practiced in the 6610 model engine assembly line. The alternative line designs are selected on the basis of their balance delays from among those obtained for all cycle times ranging from 12 to 30 minutes. This cycle time range is specified by considering the demands of the company.

The solution method to be applied to the problem is first selected by considering the solution methods proposed for solving the deterministic SALBP-1 and then modified according to the special requirements of the problem in question.

a) Selection of the Solution Method

The solution methods for solving the deterministic SALBP-1 are divided into two categories; **exact** and **inexact methods**. The exact methods consist of two subcategories; Integer and Dynamic Programming methods. These methods do guarantee the finding of the optimal solution to the problem (Baybars, 1985b; 16).

The inexact methods are grouped into four categories;Single-Pass, Composite, Bactracking and Optimal-Seeking methods (Talbot and others, 1986;432). The inexact methods employ a heuristic rule or a combination of heuristic rules and they do not guarantee the finding of the optimal solution (Baybars, 1985b;16).

Evaluating the performances of the exact methods, Baybars (1985a;35) argues that "when the problem size (number of the tasks) is large,all exact algorithms fail due to the excessive computational requirements".This problem is also true for our 31-task problem; although our problem size is by no means unmanageable, computational requirements would still render an application in this case rather cumbersome. As a matter of fact, the inexact methods have an absolute advantage over the exact methods in terms of the required computations. Hence, we are concerned with the inexact methods to select the so ution method for the problem at the expense of the guarantee for finding the optimal solution.

The inexact method to be adopted or the problem should be modified to satisfy the special requirements of the problem. In this sence, the Single-Pass methods seem to have an advantage over the other inexact methods because of their simple solution procedures.Additionally, as reported by Mastor (1970), for the 40-task and 0.25 order strength problems the performances of Single-Pass methods overlap with those of the overall most efficient inexact methods (Buffa and Miller,1979; 469).Therefore, we can expect that Single-Pass methods will yield the same results for our 31-task and 0.24 order strength problem.

The most prominent methods in this category are MAXDUR and MAXRPW methods. The only sound way of selecting one of these methods is first modify them and then to coi ipare their results on the real problem . Both methods are modified, but only the procedure of the modified MAXRPW is presented in the following section.The lowest balance delay found by the modified MAXRPW, 1 064% ,is considerably lower than that obtained by the modified MAXDUR,26.77 %. Thus, we choose the modified MAXRPW as the solution method to be applied to the problem in the study.

b)Modification on the Selected Method.

In MAXRPW method, tasks are assigned to stations on the basis of the size of their weigths defined as the sum of the process times for a task plus all of the tasks which follow it; the task with the largest weigth is assigned first.The procedure is terminated whenever a feasible solution is found.

In MAXRPW, it is assumed that each station is manned with one operator resulted in "the principle of one task at a time", and each task is performed by one operator. In our problem, one or two tasks can be performed at a time due to the parallel-operator stations and some tasks must be processed by two operators. Therefore, the MAXRPW method is modified so that these requirements of the problem are satisfied; this version of MAXRPW is called **HEMAXRPW**. The computerized program of HE-MAXRPW incorporates the following steps in its solution procedure;

I. Read the cycle time for which the problem is to be solved.

II. Form the available list. Available list is the list of tasks that can be assigned next while satisfying the cycle time and precedence constraints.

III. Rank the tasks in the available list in descending order of their positional weights*.

IV. Starting with the first task in the thus constructed, assign the tasks to the operators A and B in the present station, by checking the following conditions;

    1. If the task considered for assignment is a one-operator task;

        a. Assign it to A if both operators are idle, and consider thenext available one-operator task for assigning it to B.

        i. Keep B idle until A completes his task if there is no available task for assignment to B, otherwise assign the available task to B.

        b. Assign it to the idle operator if there is an idle operator.

    2. If the task considered for assinment is a two-operator task,

        a. Assign it to both operators if there are two idle operator.

        b. Consider the next available one-operator task for assignment to the idle operator if one operator is idle.

        i. Keep the operator idle until the busy one completes his task if there is no available task for assignment to the idle operator, otherwise assign the available task to the idle one.

V. Update the available list after the assignment.

VI. When both operators have no enough time to process any task in the list, print the task assignments, idle times of operators and station idle time, and establish a new station.

VII. Repeat Steps II through VI unless the condition in Step VIII is satisfied.

VIII. If there is no task in the available list, terminate the solu-

---

*In the modified MAXDUR, tasks are listed in descending order of their process times; this is the unique difference between the modified MAXRPW and MAXDUR.
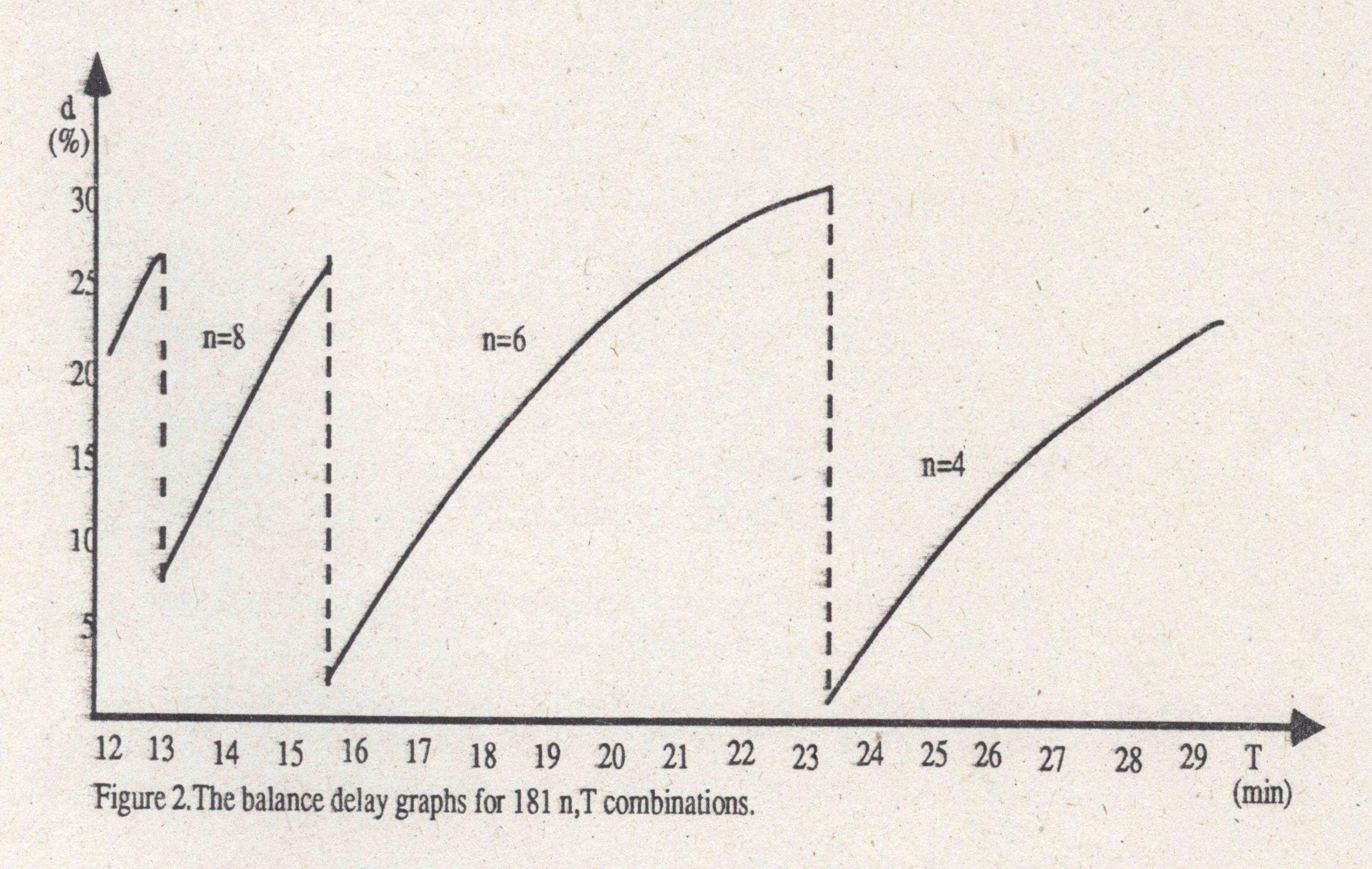
tion procedure, and print the number of operators, total idle time and balance delay of the line.

The flow chart of HEMAXRPW is presented in the appendix.

V. APPLICATION AND FINDINGS

Given the mean process times, the problem is solved repeatedly by executing the program of HEMAXRPW, for a series of cycle times starting with 12 minutes and incremented by 0.1 up to 30 minutes. This process is terminated when the solutions of 181 cycle times are obtained. Then, the line designs yielding the best results in terms of balance delay are specified as the alternative line designs.

The balance delays corresponding to 181 solutions are plotted in Figure 2 below.

Figure 2. The balance delay graphs for 181 n,T combinations.

As seen in the graph, the three line designs yielding the three lowest balance delays within the range are obtained at the cycle times of **12.7, 15.7** and **23.5** minutes. The associated balance delays are **8.464%, 1.274%** and **1.064%**. These line designs are called "**alternative line designs**" and are denoted by LD_1, LD_2 and LD_3 respectively. The total required numbers of operators, tasks assigned to A and B at each station, idle time of each operator, station idle times and total idle times of LD_1, LD_2 and LD_3 are also indicated in Table II, III and IV.

TABLE II
ALTERNATIVE LINE DESIGN LD $_1$, T= 12.7 minutes

St.	Opr.	Tasks assigned	Idle time of operator (min)	Station idle time (min)
I	A	1,4	0.00	
	B	1,4	0.00	0.00
II	A	9,11,12,14,18,23	0.00	
	B	5,6,7,8,13,15	0.10	0.10
III	A	3,10,16,27,28	0.20	
	B	2,20,22,24,26,29	0.80	1.00
IV	A	21,30,31	3.10	
	B	17,19,21,25,31	4,40	7.50
n=8		d=8.464 %	TIT=8.60	

TABLE III
ALTERNATIVE LINE DESIGN LD $_2$, T= 15.7 minutes

St.	Opr.	Tasks assigned	Idle time of operator (min)	Station idle time (min)
I	A	1,4,12,8,10	0.00	
	B	1,4,6,5	0.00	0.00
II	A	18,23,27,20	0.00	
	B	13,15,14,7,22,26	0.20	0.20
III	A	28,30,25,9,21,31	0.50	
	B	29,16,2,3,24,17,19,11,21,31	0.50	1.00
n=6		d = 1.274 %	TIT = 1.20	

TABLE I V
ALTERNATIVE LINE DESIGN LD_3 , T= 23.5 minutes

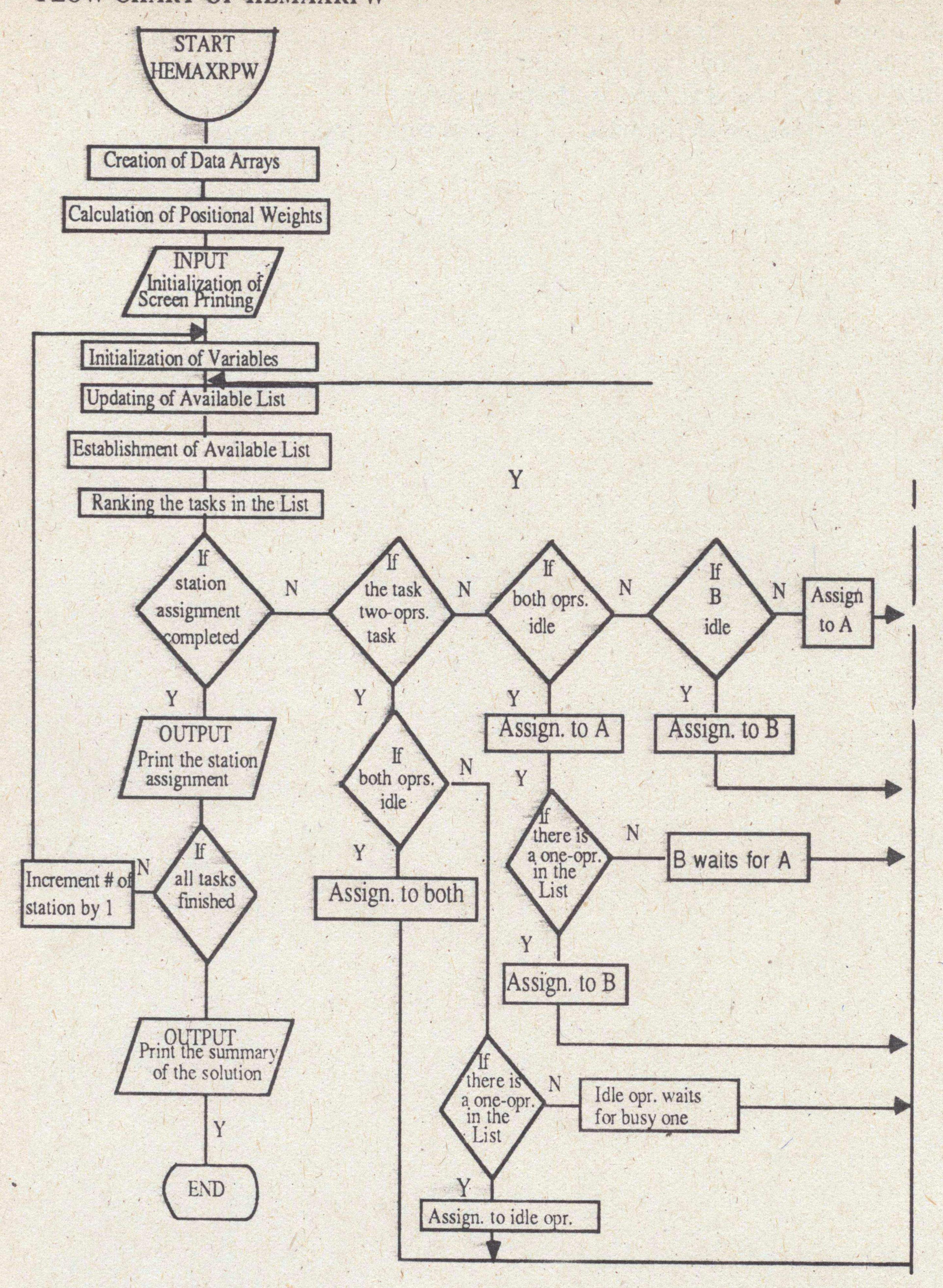| St.	Opr.	Tasks assigned	Idle time of operator (min)	Station idle time (min)
I	A	1,4,10,12,18,23	0.00	
	B	1,4,6,8,11,13,15	0.20	0.20
II	A	3,16,17,21,25,27,27,28,30,31	0.40	
	B	2,5,7,9,14,19,20,21,22,24,26,29,31	0.40	0.80
n= 4		d= 1.064 %		TIT= 1.00

CONCLUSIONS

The lines design obtained for the cycle time of 20 minutes practiced in the traditional policy yields a balance delay of 22.5% with 6 operators; this is the minimum possible balance delay with HEMAXRPW for 20 minutes. Regarding the current situation with 8 operators and the balance delay of 41.875% for the same cycle time, we can definitely argue that the currently practiced line design is an **illbalanced line.** Moreover, as compared to the balance delays of all alternartive line designs, the balance delay of 22.5% implies that the cycle time of 20 minutes, itself, is not the best cycle time to keep for the line.

The best line design to implement within the traditional policy is the alternative line design yielding the overall lowest balance delay, LD_3. LD_3 requires 4 operators and the total idle time of 1 minute. The achievement of a "balanced" line in the traditional policy will leave no room for the implementation of the labor-shifting policy that presumes the existence of an "illbalanced" line design. Therefore, the line designs LD_1 and LD_2 should be implemented to meet the increasing daily production rates. LD_3 yields a daily production rate of 20.43 tractors within an 8 hour workday while LD_1 and LD_2 enable the company to produce 37.8 and 30.57 tractors in a workday, respectively. The balance delays of the proposed designs increase as the daily production rates increase. Eventhough the highest balance delay, 8.464%, is considerably lower than the current balance delay, 41.875%.

Consequently, we suggest the company should adopt LD_3 within the traditional policy and LD_1 or LD_2 for the increasing daily production rates.

In addition, we should note that the process times in the problem are given and fixed. In fact, the process times would be more realistically assumed to be random variables which result in variable cycle times. The assumption of the stochastic process times will require the measurement of the variability of the cycle times by simulating the alternative line designs. Thus, we propose a future study to be devoted to the reliability of the proposed line designs in the case of process time stochasticity.

PARALEL İŞÇİLİ İSTASYON VE İKİ İŞÇİLİ İŞ DURUMUNDA MONTAJ HATTI DENGELEMESİ

Bu makalede, paralel işçili istasyonlar ve iki işçili işler içeren gerçek bir deterministik montaj hattı dengeleme problemi tanımlanmakta ve tadil edilen Sıralandırılmış Pozisyon Ağırlıkları Yöntemi yardımı ile, işletmenin üretim politikaları da dikkate alınarak, belirli sayıda alternatif hat dizaynı önerilmektedir.

BIBLIOGRAPHY

Baybars, İ. (1985 a), "A Survey of Exact Algorithms for the Simple Assembly Line Balancing Problem", GSIA. WP-84- 82-83, Carnegie-Mellon University, Pittsburgh, P.A.

(1985b), "A Survey of Inexact Algorithms for the Simple Assembly Line Balancing Problem", GSIA. WP-86- 82-83, Carnegie-Mellon University, Pittsburgh, P.A.

Buffa, E.S. (1976), **Operations Management: The Management of Productive Systems**, John Wiley and Sons, Inc., Santa Barbara, New York.

Buffa, E.S., and Miller, J.G. (1979) , **Production-Inventory Systems:Planning and Control**, Richard D.Irwin, Inc., Home wood, Illinois.

Kao, E., 1976, "A Preference Order Dynamic Program for Stochastic Assembly Line Balancing Procedure", **Management Science**. No.10, pp. 1097-1104.

Kottas, J.F ., and Lau, H.S.(1981),"A Stochastic Line Balancing Procedure",**International Journal of Production Research**. No.19, pp. 177-198.

Mastor, A.A. (1970), "An Experimental Investigation and Comparative Evaluation of Production Line Balancing Tech niques", **Management Science**. No.16, pp.728-746.

Reeve, N.R., and Thomas, W.H. (1973), "Balancing Stochastic Assembly Lines ",**AIIE Transactions**. No.5, pp.223-229

Talbot, F.B., and others (1986), "A Comparative Evaluation of Heuristic Line Balancing Techniques ", **Management Science**.No.4 pp. 430-454.

Vrat, P., and Virani, A. (1976),"A Cost Model for Optimal Mix of Balanced Stochastic Assembly Line and the Modular Assembly System for a Customer Oriented Production System", **International Journal of Production Research**. No.4 pp.445- 463.