Mansoura Engineering Journal. (MEJ), Vol. 24, No. 1. March 1999. M. 14

Stochastic Methodology for Designing Assembly Lines

طريقة احتمالية لتصميم خطوط التجميع

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ملخص

هذا البحث يستعرض طريقة مبتكرة تستخدم الحاسب في جدولة خطوط التجميع ذات العمليات التى لها أزمنة إنجاز عشوائية و ذلك من خلال أسلوب يوازن و يقيم مثل هذه الخطوط فى ظل ظروف العمليات غير محددة التوزيع العشوائى، إمكانيةاتمام العمليات الناقصة فى نهاية الخط، ميكنة المحطات التى تبدى إحتمالية عالية لتخطى الزمن الدورى الذى تم الإتزان على أساسه. وأيضا لغرض التقييم قدمت دالة تكلفة متكاملة عشوائية ذات ثلاث مركبات أدمجت مع أسلوب الإتزان. هذا الإجراء يُمكن من تسيير الخط بتكلفة كلية منخفضة وعند ظروف عمل مُتوقعة. وتم تقدير إحتمالات عدم إتمام العمل بالمحطات بإستخدام أسلوب مُبسط يعتمد على طريقة مونت كارلو وذلك باختبار الأحداث العشوائية لأزمنة العمليات بعد توزيعها؛ وهذا يسهل تقدير إحتمالية إنهاء العمل على ذات الخط. وأيضا وُضع فى الإعتبار حالة العمليات ذات التوزيع الطبيعى.

Abstract This paper presents a "Computerized Methodology" for solving the problem of scheduling assembly lines having tasks of stochastic performance times. An approach is introduced for balancing and evaluating such lines under the conditions of unspecified task time distributions, off-line repair of incompleted tasks, and automating the stations which exhibit potentially significant probability of incompletion. Also, for evaluation purpose, a three-component comprehensive stochastic cost function is integrated into the balancing algorithm. The procedure making it possible to pace the line at low cost and keep the work at predictable conditions. A simple **Monte-Carlo** mechanism is merged to approximate the probability of incompletion of stations, hence the probability of line completion can be found by simple computations; that by examining the occurrence of random events when the assignments are completed. On the other hand, the case of normally distributed task times is addressed.

1. Literature Review

Moodie and Young [29] have developed a two-phase heuristic technique, they suggested that task times can be represented by independent normally distributed random variables Ignall [19] has reported the industrial approach by assigning extra labor. Mansoor and Tuvia [26] have described an incentive system to avoid making incompletion. Ramsing and Downing [31] have incorporated *ranked positional weight* criterion of Helgeson and Birnie [15], and the work made by Moodie and Young [29] in a FORTRAN computer program to solve the problem under different significance levels. Kottas and Lau [23] have introduced a cost oriented approach to stochastic line balancing with normally distributed task times. Labor and incompletion costs, and off-line repairs are explicitly considered in grouping tasks into work assignments in a manner may achieve a near minimum cost layout. Reeve and Thomas [33] have

Accepted July 15, 1998

evaluated four procedures assuming that task times are normally distributed and the repairs are made by stoppage. Sphicas and Silverman [38] have reduced the stochastic format to deterministic. Kottas and Lau [24] have presented a two-component stochastic cost function. Task times were assumed normally distributed with off-line repairs are made off-line. Kao [20] has developed a preference order dynamic programming method for balancing assembly lines with independent stochastic task times with known arbitrary identical distribution functions. He formulated and solved the problem following previous work which had been proposed by Held et al. [14], Gutjahr and Nemhauser [13], and Mitten [28]. Vrat and virani [39] have used the model proposed by Kottas and Lau [23] with very slight modification to suit mixed model and parallel stations. Kao [21] incorporated, in a computer programming policy, his old work with computational experience, and two new issues, in solving the stochastic line balancing problem.

Maani and Hogg [25] have proposed a stochastic network model to simulate and analyze the assembly system. They used "GNS" as a modelling vehicle. The GNS is an 'activity-on-node'queue network which replaces the precedence diagram. Namely, Generalized Network Simulator. Rauf and [32] have tried Chebyshev's inequality and the confidence level approach of Moodie and Young in a heuristic. Shtub [35] has used the work proposed by Kottas and Lau [23], for both balancing and evaluating the assembly lines with normally distributed task times, and each station is manned by a variable crew size; and parallel work stations were considered. Carter and Silverman [7] have described, by integrating the work proposed by Moodie and Young [29] and Arcus [2] into a stochastic cost function with two components, a methodology for designing a near less cost layout, under conditions of normally distributed task times and off-line repair. Silverman and Carter [36] have extended their work, in Carter and Silverman [7], by developing a two-component stochastic cost function with on-line stoppage repair. Akagi et al. [1] have proposed a balancing method, in which tasks are assigned to work stations varying the upper time limit according to its performance rate. Henig [16] handled the problem by integrating Moodie and Young [29] criterion into the dynamic programming model of Gutjahr and Nemhauser [13]. He has dealt with a family of distributions. Carraway [6] has offered two dynamic programming algorithms, the approach is based on the formulation proposed by Held et al. [14]. Thus represents a modification of previous work made by Kao [20] and Kao [21]. Shin [34] has investigated the problem of assigning tasks to stations in balanced stochastic assembly lines.

Recently, Nkasu and Leung [30] adopts the methodology of stochastic modeling whereby various probability distributions are integrated within a modified COMSOAL algorithm , in their methodology for balancing assembly lines. They incorporate four objective criteria options. However, the work does not represent a salient departure from the similar algorithms. Our proposed approach avoids the limitation to a specific probability distribution.

2. Proposed Approach

This section presents a new heuristic manipulates the single model paced stochastic assembly lines. It consists of two phases. First allocates tasks to a series of work stations with a given cycle time and technological precedence restrictions. Second evaluates the probability of incompletion of each station and the whole line and the total operating cost of each unit by using stochastic cost function considers off-line repair. The main objective is minimizing the total operating cost by minimizing the chance of incompletion of all tasks. It can solve the problem without having information about task time distributions, which represents a departure from the literature heuristics. It represents a complete stochastic process during assignments and decision points constitute a statistical series.

2.1 FORMULATION OF THE PROBLEM

2.1.1 Assumptions and Restrictions

The central objective is to minimize the total variable operating cost by minimizing stochastic cost function comprising three components include the most effective component, incompletion cost. Subject to

1. The assembly line operates at a constant production rate.
2. Units produced are identical (single model assembly line.)
3. Operators have similar ability and paid the same rate regardless of their assignments.
4. Each station is manned by only one operator.
5. Each task can be assigned to one and only one station.
6. The precedence restrictions are specified and must be not violated.
7. The cumulative station time is limited by the cycle time.
8. Task times are independent random variables with estimable means and variances.
9. Task time distributions are unknown and may be different. This assumption is very important because it generalizes the heuristic applications.
10. The repair action can be taken when all tasks are not completed on the line assembly, is to allow the product to complete the assembly line operation without regard to the uncompleted tasks. At the end of the line all units are inspected and all unfinished tasks are completed at end of the line on the modular assembly. The cost to repair a task is not a function of the lost work done on this task.

Some of these assumptions and restrictions are similar to those made in the literature; see Kottas and Lau [23], Carter and Silverman [7], and Soltan [37]. In the majority of stochastic line balancing approaches, task times are assumed to be normally distributed; Soltan [37] has reviewed the studies and the work depends on this assumption. The developed approach relaxes this assumption which needs extensive studies before making a balance. Also, this assumption must be made at a significance level may not be well imposed; this may lead to incorrect results and confused layout. Thus making the proposed approach applicable in many different working conditions.

2.1.2 Mathematical Model

A job comprises a finite set of tasks $E=E_i$ compared with a set of times $T=T_i$ having general independent density functions $G(T_i)=G_i(\mu_i, \sigma_i)\backslash\ \mu_i, \sigma_i>0$; $i=1,2,...,N$ A partial order pr (precedence) and a limiting time C (cycle time) are imposed on E. The problem is to define a finite family $S=S_k$: $\bigcup_{k=1}^{K} S_k = E$ such that

Minimum $T.C. = L.C. + I.C. + A.C.$	subject to	objective function
$S_i \cap S_j = \phi,\ i \neq j$		no station sharing
If $(E_n \in E)pr(E_m \in E) \Rightarrow (E_n \in S_i)pr(E_m \in S_j)$ $and\ i \leq j$		precedence restrictions
$\{T_k = \sum_{i \in S_k} T_i\} \leq \rho C$		maximum station time

Given that all stations are independent, a joint density function $\psi = \prod_{k=1}^{K} \psi_k(T_k)$ defines line reliability and failure. Where

N : total number of tasks in the assembly job,
K : total number of work stations in the line,
ρ : cycle time utilization,
μ_i : mean time of task i,

σ_i . time standard deviation of task i,
$T.C.$: expected total operating cost of a unit,
$L.C.$: normal operating cost of a unit,
$I.C.$: expected incompletion cost of a unit,
$A.C.$: expected automation cost of a unit,
S_k : set of tasks assigned to station k,
T_k : random variable represents the time of station k with density function ψ_k.

This formulation modifies those found in the literatur; Moodie and Young, Kottas and Lau, Reeve and Thomas, Ignall, Johnson and Brennecke; reviewed by Carraway. The departures are salient in the generally distributed task times and the three component stochastic cost function which will be explained later.

2.2 INPUT DATA AND COMPUTATIONAL PARAMETERS

2.2.1 Data Required

Product data include the task time observations and the precedence relationship represented in a square matrix. Assembly line data include the cycle time, on-line normal labor rate, off-line labor rate, and automatic rate.

2.2.2 Assignment Parameters

The task parameters which are used to carry out the balancing process Included are mean and variance, coefficients of skewness, kurtosis, and variation number of immediate followers and predecessors, and incompletion cost.

2.3 BALANCING PROCEDURE

The procedure successively carries out assignments to a series of work stations until the line is designed as next steps.

1) Input data: The data must satisfy the mathematical model. Go to step (2).

2) Compute fixed assignment parameters: Those are computational quantities cited in section (2 2.2) which are necessary to form the stochastic lists and to make the assignment decision. Go to step (3).

3) Begin with a new cycle time: After a layout has been completed, a new design can be begun. Go to step (4).

4) Open a new station: When a station capacity became not able to accommodate more tasks, it should be closed and a new one is opened for the current design. Go to step (5).

5) Form available list: Available list is the list of tasks are currently do not violate the precedence restrictions, they can be assigned next. In other words it comprises the tasks with no unassigned immediate predecessors (NIP =0). This list is updated each time a task is assigned.

6) Check if available list is empty: If it is empty, the line design is finished, and, the output of the balancing phase can be obtained; go to step (18). If it is not empty, go to step (7).

7)Form fit list: Fit list includes the available list tasks which will fit into the current station such that

$$\sum_{i\in S_k} \mu_i \le \rho C \tag{2.3-1}$$

8)Check if fit list is empty: If it is empty, the station is closed, return to step (4). If it is not empty, go to step (9).

9)Check if the tasks are highly skewed: The task time distribution is called highly skewed if the moment coefficient of skewness much deviates from zero, this means that the distribution is highly asymmetrical. A specific number is suggested, 75% or more one sided area of the total area of the task time distribution; it is the area left or right to the mode value. If the skewness is positive, the small values of task time observations are found with larger frequencies, therefore, such a task can be assigned to last part of the station at which the probability of incompletion is high. On the other hand, if the skewness is negative, the large values of task time observations are found with larger frequencies, therefore, such a task can be assigned to first part of the station at which the probability of incompletion is low By the computer experimentation, it is found that the probability of station completion reaches its extreme improvement at about 75% to 80% utilization. Thus the cycle time, in sense, can be divided into two parts, about 75% first and 25% second and assigned by two different ways. If the group of tasks in the fit list is highly skewed, go to step (10); otherwise, go to (11).

10)Test the remain time: If it is greater than or equal to 0.25C, assign the fit list task of minimum skewed time distribution; otherwise, assign the fit list task of maximum skewed time distribution. Return to step (5).

11)Check if the tasks are highly kurtic: The task time distribution is called highly kurtic if the moment coefficient of kurtosis is very large, this means that the distribution is highly peaked (has at least one mode with very large frequency). A specific number is suggested, 30 (ten times normal distribution) or more. The mode value may be corresponding to an observation has a value more than mean time, this situation increases the chance of exceeding the allocated time at the high kurtosis. Therefore, such a task can be assigned to first part of the station at which the probability of incompletion is low. If the fit list tasks are highly kurtic, go to step (12); otherwise go to step (13).

12)Test the remain time: If it is greater than or equal to 0.25C, assign the fit list task of maximum kurtic time distribution; otherwise assign the fit list task of minimum kurtic time distribution Return to step (5)

13)Check if the current station is empty: If the current station is just opened and no tasks were assigned, assign the fit list task of largest number of immediate followers to increase the size of available list; in turn this increases chance of better next assignment; return to step (5).Otherwise, if the station is not empty, go to step (14).

14)Compute task-station coefficient of variation: This parameter is computed for each task in the fit list each time the procedure reaches this step because it depends on the tasks assigned before in the current station *k*. For each candidate task *j*, it is a function of time means and variances of the set of tasks, S_k ,which assigned before in addition to such task. Nevertheless this parameter is a very simple statistic, it has an important indication to the load of variation

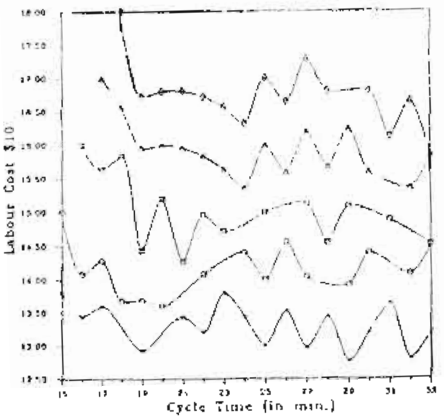

Fig. (3-2) Change of labor cost.

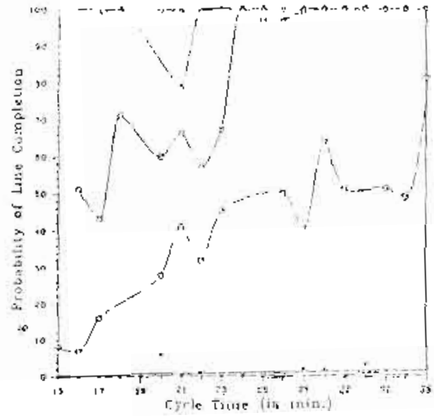

Fig. (3-3) Change of probability of line completion.

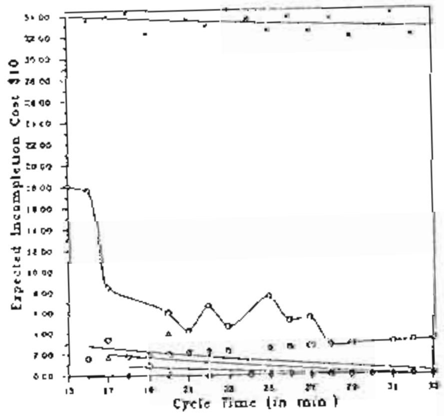

Fig. (3-4) Change of expected incompletion cost.

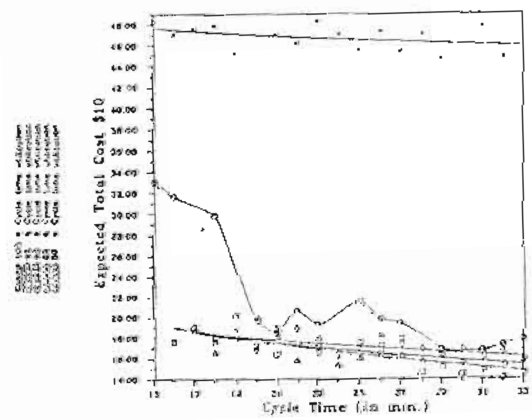

Fig. (3-5) Change of expected total cost.

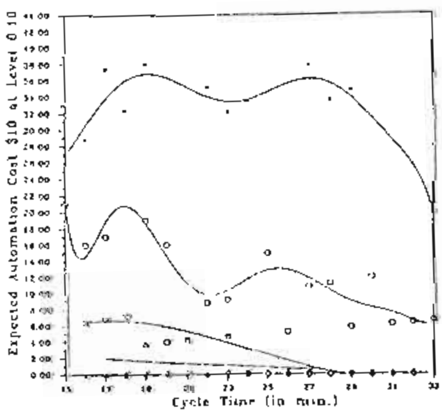

Fig. (3-6) Change of expected automation cost at 10% level.

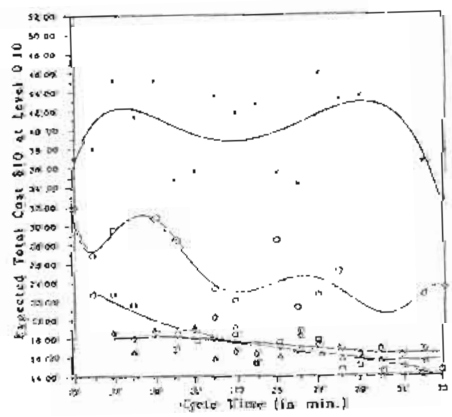

Fig. (3-7) Change of expected total cost at 10% level.

7)Form fit list: Fit list includes the available list tasks which will fit into the current station such that

$$\sum_{i\in S_k} \mu_i \leq \rho C \tag{2.3-1}$$

8)Check if fit list is empty: If it is empty, the station is closed, return to step (4). If it is not empty, go to step (9).

9)Check if the tasks are highly skewed: The task time distribution is called highly skewed if the moment coefficient of skewness much deviates from zero, this means that the distribution is highly asymmetrical. A specific number is suggested, 75% or more one sided area of the total area of the task time distribution; it is the area left or right to the mode value. If the skewness is positive, the small values of task time observations are found with larger frequencies, therefore, such a task can be assigned to last part of the station at which the probability of incompletion is high. On the other hand, if the skewness is negative, the large values of task time observations are found with larger frequencies, therefore, such a task can be assigned to first part of the station at which the probability of incompletion is low. By the computer experimentation, it is found that the probability of station completion reaches its extreme improvement at about 75% to 80% utilization. Thus the cycle time, in sense, can be divided into two parts, about 75% first and 25% second and assigned by two different ways. If the group of tasks in the fit list is highly skewed, go to step (10); otherwise, go to (11).

10)Test the remain time: If it is greater than or equal to 0.25C, assign the fit list task of minimum skewed time distribution; otherwise, assign the fit list task of maximum skewed time distribution. Return to step (5).

11)Check if the tasks are highly kurtic: The task time distribution is called highly kurtic if the moment coefficient of kurtosis is very large, this means that the distribution is highly peaked (has at least one mode with very large frequency). A specific number is suggested, 30 (ten times normal distribution) or more. The mode value may be corresponding to an observation has a value more than mean time, this situation increases the chance of exceeding the allocated time at the high kurtosis. Therefore, such a task can be assigned to first part of the station at which the probability of incompletion is low. If the fit list tasks are highly kurtic, go to step (12); otherwise go to step (13).

12)Test the remain time: If it is greater than or equal to 0 25C, assign the fit list task of maximum kurtic time distribution; otherwise assign the fit list task of minimum kurtic time distribution . Return to step (5).

13)Check if the current station is empty: If the current station is just opened and no tasks were assigned, assign the fit list task of largest number of immediate followers to increase the size of available list; in turn this increases chance of better next assignment; return to step (5).Otherwise, if the station is not empty, go to step (14).

14)Compute task-station coefficient of variation: This parameter is computed for each task in the fit list each time the procedure reaches this step because it depends on the tasks assigned before in the current station k. For each candidate task j, it is a function of time means and variances of the set of tasks, S_k ,which assigned before in addition to such task. Nevertheless this parameter is a very simple statistic, it has an important indication to the load of variation assigned to the operator along his station span, specially when he finished a task and starts another one. It differentiates tasks for assignment; it is estimated as

$$Cov_{j\in E} = \sqrt{\sum_{i\in S_k} \sigma_i^2 + \sigma_j^2} \,/\, [\sum_{i\in S_k} \mu_i + \mu_j] \qquad (2.3\text{-}2)$$

This is used as a decision parameter to control and regulate the variability along the station. Also, minimizing this parameter may reduce the chance of incompletion for a group of tasks. At least, it helps in selecting a task from fit list, such that, it helps in smoothing the mean time assigned to the operator and alleviating the sudden launching effort. That can be achieved when the mean time is fairly large in relation to its standard deviation. Go to step (15).

15) Form preferable list: Preferable list includes the fit list tasks which have coefficients of variation less than or equal to their task-station coefficients of variation. Formally such that

$$\{Cov_i \setminus i \in E\} \le \{Cov_i \setminus i \in S_k\} \qquad (2.3\text{-}3)$$

Then, go to step (16).

16) Check if preferable list is empty: If it is empty, go to step (17); otherwise, assign the fit list task of largest incompletion cost in order to avoid being forced to assign it where there is a significant chance of work incompletion, and return to step (5).

17) Rank fit list tasks: The fit list tasks are ranked according to two parameters and the average rank is considered. First, rank according to incompletion cost; the smallest value is ranked "0" and the rank increased by one in the direction of increasing incompletion cost tasks. Second, in the same manner, rank according to coefficient of variation. Making the average rank helps in taking from the two advantages of low incompletion cost low coefficient of variation. Assign the fit list task of smallest average rank to improve the situation of having no preferable tasks and which may increase the chance of needing more time than allocated. Return to step (5).

18) Output current balance: This phase outputs a *layout* and its *deterministic parameters*. Go to the second phase.

A. Layout structure-which shows the tasks assigned to each station, the cumulative time means and variances at each point in each station.

B Deterministic parameters-These are balance delay *B.D.*, smoothness index *S.I.*, and line break *L.B.* (Soltan[37]). If M_k is the mean time assigned to station k, then

$$B.D. = (KC - \sum_{i=1}^{N} \mu_i) \,/\, KC \qquad (2.3\text{-}4)$$

$$S.I. = \sqrt{\sum_{k=1}^{K} (C - M_k)^2} \qquad (2.3\text{-}5)$$

$$L.B. = (C - \max. M_k) \,/\, (C - \min. M_k) \qquad (2.3\text{-}6)$$

where

$$M_k = \sum_{i\in S_k} \mu_i \qquad (2.3\text{-}7)$$

2.4 EVALUATION OF STOCHASTIC OPERATING COSTS

2.4.1 Evaluating Procedure

This procedure approximates the probability of incompletion of each station and the whole line, and the total operating cost It is mainly based on a proposed Monte-Carlo method for evaluating the probabilities and a proposed stochastic cost function for evaluating the total operating cost. It is very simple and saves time and effort consumed in complicated mathematical calculations. From the results of this phase, the planner can catch a complete judgment for the candidate layout The procedure will be stated and clearly explained in the next steps

1)Assign a random number for each task observation: For this purpose, a uniformly distributed random number generator is used. Forth and hence, the observation is identified by the random number allocated. Several studies have been made on using random number, Gottfried [11] and Kleijnen [22]. Hence, a modified generator is used. Go to step (2)

2)Begin with a new run: An initial simulation run is proposed to begin the process. After that the run length must be increased until the probability reaches the steady state. Go to step (3).

3)Begin with a new station: Experimentation begins with the first station and after that, it proceeds to following neighbor station until the line is finished. Go to step (4).

4)Begin with a new task: The performance of the first task in a station is considered for event occurrences and the experimentation proceeds to the next successors until the station is finished. Go to step (5).

5)Generate a random number: The control transfers to the random number generator each time a task is finished and another one is required. If the number generated is corresponding to an observation for the current task, this represents an occurrence of an event. If no matching found, another number must be generated. Go to step (6).

6)Accumulate time in the current station: Each time an observation for a task is allocated, its time is accumulated to the station time which begins zero. Go to step (7).

7)Test if the current station is closed: The station is closed when all assigned tasks have been processed If it is not closed, return to step (4); otherwise go to step (8).

8)Test if the station time exceeds the cycle time: Compare the accumulated time with the cycle time and register the exceeding (station down) if exists. Go to step (9).

9)Test if the station simulation is over: If the processing of the current station with the current run is finished, compute the incompletion probability of station. This probability is computed from the frequency distribution definition by dividing the number of exceeding by the run length; and then,
go to step(10). Otherwise, return to step (4).

10)Test if the line is closed: The line is closed if all stations have been processed with the current run. If this has not occurred, return to step (3). Otherwise compute the line incompletion probability P as

$$P = 1 - \prod_{k=1}^{K}(1 - P_k) \qquad (2\ 4\text{-}1)$$

where P_k is the probability of failure of station k, given that all station work independently. Go to step (11).

11)Output the evaluated probabilities: For the current run, output the probability of incompletion of each stations and for the whole line. Go to step (12).

12)Test if all runs are processed: If all of the runs have not been finished and it is required to process the line with other runs, return to step (2); otherwise go to step (13).

13)Compute non-integrated stochastic cost function: The total operating cost can be computed through a proposed three-component stochastic cost function when the automation is not integrated, i.e. with zero third component. The probability of incompletion is an important factor in the function This function will be introduced and explained in details in section (2 4 2) Go to step (14).

14)Output non-integrated stochastic cost function: This step outputs the labor cost, the expected incompletion cost, and the expected total operating cost for a production unit. Go to step (15).

15)Begin with a new automation level: The automation level is a proposed factor, and is defined as the maximum probability allowed for station incompletion, at which the human labor can not achieve significant improvement and it fails to complete the assigned work . It is proposed that when the probability of station incompletion is greater than or equal to the maximum probability allowed, such station may be catered with a machine. The experimentation has been made with three levels, 10%, 15%, and 20% Go to step (16)

16)Compute integrated stochastic cost function: The total operating cost is computed when an automation level is imposed; in such a case the third component may be greater than zero. Go to step (17).

17)Output integrated stochastic cost function: This step outputs the labor cost, the expected incompletion cost, the expected automation cost, and the expected total system cost for one production unit. Go to step (18).

18)Test if all levels are over: If all three levels are over, go to step (19); otherwise return to step (15).

19)Test if all cycle times are over: If all cycle times proposed by the manager are processed, stop. Otherwise return back to step (3) in balancing procedure.

2.4.2 Three-Component Stochastic Cost Function

Kottas and Lau [24] and Carter and Silverman [7], early have developed two stochastic cost functions considering off-line repair. Silverman and Carter [36] have developed a stochastic cost function considering stoppage repair. They have proposed that the total operating is the sum of two components, the normal operating cost and the cost of repairing the uncompleted units. This section presents a three-component stochastic cost function and a design for modular system on which the incompleted tasks are repaired at the end of line. It is a modification to what have been proposed by Soltan [37]. The modular system consists of one or more stations catered at the end of the assembly line. Its function is to complete (repair) the incompleted tasks, single or multiple manning can be two alternatives This helps in reducing the work-in-process, smoothing the product flow, and avoiding unpredictable conditions. In each cycle, the expected number of uncompleted units, K_p, can be estimated as

$$K_p = KP \tag{2 4-2}$$

where P is the probability of line failure and K is the number of line stations. The arrival distribution of the uncompleted units may be general; or critically, uniform K_p will be used to have information about the necessary labor required to repair uncompleted units in a particular cycle, and this labor must be enough to avoid congestion at the end of line. The minimum expected time required to repair a unit can be approximated by

$$C_e = (K - K_p + 1)C / K_p \tag{2 4-3}$$

Hence, expected labor size of the modular system, K_e, will be the ratio between cycle time, C, and C_e, formally

$$K_e = K_p / (K - K_p + 1) \tag{2 4-4}$$

Since the modular system carries out all incompleted tasks, no restriction imposed on its physical place. But all required facilities must be supplied and may be duplicated to speed the work. K_e is an initial estimator, practically, it can be adjusted to accommodate the incurred incompletion through sampling the line failures along a time span. After a working period, the size of the modular system can reach the steady state. However, the most important purpose of such modular system is to meet the market demand although it increases the total operating cost.

The stochastic cost function consists of per unit, normal labor cost, expected incompletion cost, and automation cost. Normal labor cost, $L.C.$, is the operating cost of the main line to assemble a unit. If L is the normal labor rate,

$$L.C. = LCK \tag{2 4-5}$$

Expected incompletion cost, $I.C.$, is the cost of operating the modular system to repair one unit. The cost per unit time, R_m, of operating the modular system with penalty, r, is

$$R_m = (rL)K_e \tag{2 4-6}$$

Hence,

$$I.C. = CR_m \tag{2.4-7}$$

Expected automation cost, $A.C.$, is the cost of automating the critical stations in a particular cycle to complete one unit. The critical station is the station which registers a probability of incompletion greater than or equal to a maximum level, allowed; beyond this level, the human labor is assumed obsolete. In such a case, a machine must replaces the human labor in such a station. A maximum is called, in this paper, the automation level. That component will be

$$A.C. = aCK_a \tag{2.4-8}$$

where a is the cost rate of operating the automated stations and K_a is the expected number of automated stations. Number of automated stations is evaluated, from phase two, by counting number of stations that have probability of failure (incompletion) more than or equal to the imposed level of automation. Station may be partially or completely automated; if it is not made completely, equation (2.4-8) needs to an additional term expressing the labor integrated along with the machine. Expected total operating cost per assembled unit will be

$$T.C. = LC(K - K_a) + (rL)CK_e + aCK_a$$

$$= C[L(K - K_a) + rLK_e + aK_a] \tag{2.4-9}$$

If a is expressed in a penalty figure from L, $\hat{r}\,L$, then

$$T.C. = CL[K + rK_e + K_a(\hat{r} - 1)] \tag{2.4-10}$$

If $r = \hat{r} = 1$, then $$T.C. = LC[K + K_e] \tag{2.4-11}$$

The latter form is attractive since it indicates that the problem of incompletion may be solved by extending the main line with K_e work stations; in consequence, the production rate will be less

Generally, the decisions concern such mix of automation and labor employed by an organization are embedded in the long-term strategic plan since the composition of productive capacity impact on an organization's ability to survive and compete. Given output goals and the availability and costs associated with obtaining and maintaining labor and automation, the optimal mix of these components of productive capacity can be obtained over time As a result, the organization's level of capacity, operating costs, flexibility, quality of the output, and price may be determined in the steady state of the system. In this concern, studies have been made such as Cooper and Schendel [8], Barr [3], Wheelwright [40], Gaimon [9], Miller [27], Groover [12], and Gaimon [10]. Kamali et al.[19] have examined the abilities and the dynamic limitations of combined utilization of humans, robots, automation, and conveyors in the assembly systems. The comparison was made on basis of a proposed approach to illustrate that the integration of such types can enhance the productivity of assembly systems.The proposed approach is not concerned with the elements of automatic systems, or the framework for the selection of the appropriate automation, but it advises when and where it may be used alongside the labor in the assembly system. The literature are surveyed to validate such integration and to collect the required information about the automation rate and costs.

3. Analytical Computer Application

A "FORTRAN 77" comprehensive computer program ,is prepared for the users. This program is constructed to be conversational in the response and alarms with error signals when data are incorrect or confusing during the conversational session made on to a specific assembly problem. For the purpose of application, a single model, "6-Cylinder V Type Engine" had been chosen from *'Nasr Cars Manufacturing Co.'*. The existing system consists of 17 series stations and 5 rear stations on subassembly. The main assembly work is carried out on a powered conveyor line which carries the product across the main stations in which the tasks are performed. The subassembly work is carried out on tables provided adjacent to the conveyor. The line was balanced by using a conventional method on a 20-minutes cycle time with single manning policy. Therefore, the work sampling had been carried out by breaking the original job into suitable number of tasks; each task was observed through 15 times The precedence diagram is shown in Fig. (3-1).

Fig. (3-2) depicts the relation between labor cost (per unit cost required to operate the line on normal situation) and cycle time which has better fashion, over the total range, than those in previous relations and such cost registers inverse proportionality to utilization. Thus making it possible to predict such cost which is considered the first important parameter. Fig. (3-3) depicts the most serious parameter, probability of line completion, versus cycle time at different utilization values. The probability of line completion is the probability that all line stations will complete their assigned tasks within the cycle time All of the coming parameters are dependent on such probability. At100% utilization, the probability indicates a very good constant function which nears zero and this represents hazardous situation. But, it is obvious that when utilization shifts below 100%,e.g. to 95%, the probability shifts than zero by about 10% at cycle time 15 min. and reaches about 81% at cycle time 33 min. in quick and predictable routine. At 90% and 85% utilization, line probability achieves more sharp improvement until reaches 100% and stables at about 55% of the cycle times. At 80% utilization, the probability stays near by 100% with a very good fit. It is evident that at all utilization values, the results are controllable and many different alternatives can be caught. Although 100% completion probability can be reach but that is restricted by the expected total cost of operating the line. However, improving the probability is compared with improving the expected incompletion cost and some bad effects on the deterministic parameters; that because increasing idle time is the main source of such improvement.

Fig. (3-4) depicts the first function, expected incompletion cost, of incompletion probability versus cycle time at different utilization values. Expected incompletion cost is the cost of operating the modular system to repair, off-line, an incompleted production unit. At 100% utilization, it represents a very good fit (trend) at the maximum value can be reach At utilization 95%, it is seen that the cost registers about 50% drop at cycle time 15 min., then registers a sharp drop at cycle time 17 min. and continues in drop fluctuating about near regular value until reaching cycle time 33 min. or more. At utilization 90% and 85%, the cost follows trends approaches negative straight lines. At utilization 80%, the trend can be approximated by a constant value and very close to zero. It is evident that at all utilization values, the cost of incompletion represents a controllable and predictable function of cycle time. Fig. (3-5) shows the relation between expected total cost and cycle time. Expected total cost is the cost incurred to produce a unit and it equals to the sum of labor and incompletion costs. In turn, it represents a function of line incompletion probability. The description is similar to that cited for expected incompletion cost except the shift incurred due to integrating the labor cost. From this quantity, one can cite the judgment about the critical line probability of completion and at what extent one can permit idle time.

Fig. (3-6) depicts another type of probable costs, expected automation cost at level 10% versus cycle time. Expected automation cost is the per unit cost required to merge a specific number of mechanized stations. It is similar to expected incompletion cost, cost, but it is a function of incompletion probability greater than or equal to the specified limit. It follows a bowl phenomenon and it has a middle cyclic part at utilization 100%. But, the function has a lower and a better trend fluctuating about negative straight line at utilization 95%. The trend goes lower at utilization 90% and approaches negative straight line with small variation at 85% At utilization 80% the cost stays constant at zero. Thus making it possible to predict such cost at all utilization values below 100%. The bowl phenomenon is attributed to the stations appeared exceed the limit disappeared again due to sudden change of probability

Fig. (3-7) shows expected total cost at automation level 10% versus cycle time at different utilization limits. That represents the sum of three components, labor cost, automation cost, and the remain incompletion cost. The behavior shifts little from Fig. (3-6) due to adding components, specially at 90%, 85%, and 80% utilization values. It appears, from the three-component stochastic cost function (described in section (2.4.2)), that expected automation cost and expected total cost when merging automation are functions of the number of stations automated at a specific level, therefore, these functions are near in behavior to the expected number of automated stations with some distortion

Fig. (3-8) depicts the effect of cycle time on the number of stations automated at level 10% At 100% utilization, it registers an inverse cyclic proportionality with bowl phenomenon little than what occurs in the costs. At 95% utilization, a more better trend appears fluctuating about negative straight line. At utilizations 90% and 85%,the trend becomes fitter with lower values and reaches zero early. At 80% utilization, it registers a constant fit close to zero. It is seen that, the probability of completion controls such behavior; thus making it predictable and controllable.

Fig (3-9) describes the effect of utilization change on the labor cost at different cycle times, 24, 25, and 27 min. to make some assurance about the behavior. It is intuitive to register the inverse proportionality, but the new is to have linear equations, which makes it very easy to predict the labor cost at in between utilizations for various cycle times with tighter control limits. Fig. (3-10) shows the frequency of stations automated at the different limits, 10%, 15%, and 20%. Their trends indicate similar damped frequencies, that because the small number occurs with high frequency and vise versa; in turn, the functions of such parameter tend to be minimized. Thus making it easy to interpret and predict what occurs during handling those dependent functions. Fig. (3-11) shows an agglomerated plot describes the effects of utilization and line completion probability on expected total operating cost. Such cost is decreased with increasing probability until the effect of labour cost appears, i.e. the cost improvement is not monotonous. As known before, the increase in probability of completion improves the expected incompletion cost until reaching the steady state at the first 100% probability. The expected total cost reaches its minimum value at a certain completion probability may be less than 100%, here about 94%, and begins to increase in a monotonous fashion beyond the minimum limit, in such a case, that probability improvement goes useless. Utilization is opposite, but it is a mirror to what occurs in the behavior of line completion probability and it depends on the cycle time as evident with three cycle times, 24, 25, and 27 min.. That total cost decreases in the same direction of decreasing utilization until reaches its minimum value and begins to increase again in a monotonous fashion because of the effect of increased labor cost It is evident that change in the probability and the utilization must be controlled by the compared effect on the expected total operating cost. However, the trend appears very good which making the prediction possible about such serious component.

Fig. (3-12) describes the effect of utilization on the line probability of completion at different cycle times. It is evident that both cycle time and utilization effect the probability Also, each cycle time has a different routine with a predictable fashion and all of them are distributed about the diagonal of the plot. It is seen that decreasing utilization is compared with increasing in completion probability which begins from zero at utilization 100% and reaches 100% with phase difference. In that concern cycle time 26 min. behaves in a more regular fashion. This plot assures that a shift down 100% utilization is necessary to avoid risky failures, in spite of the inverse effect caught from Fig. (3-13).

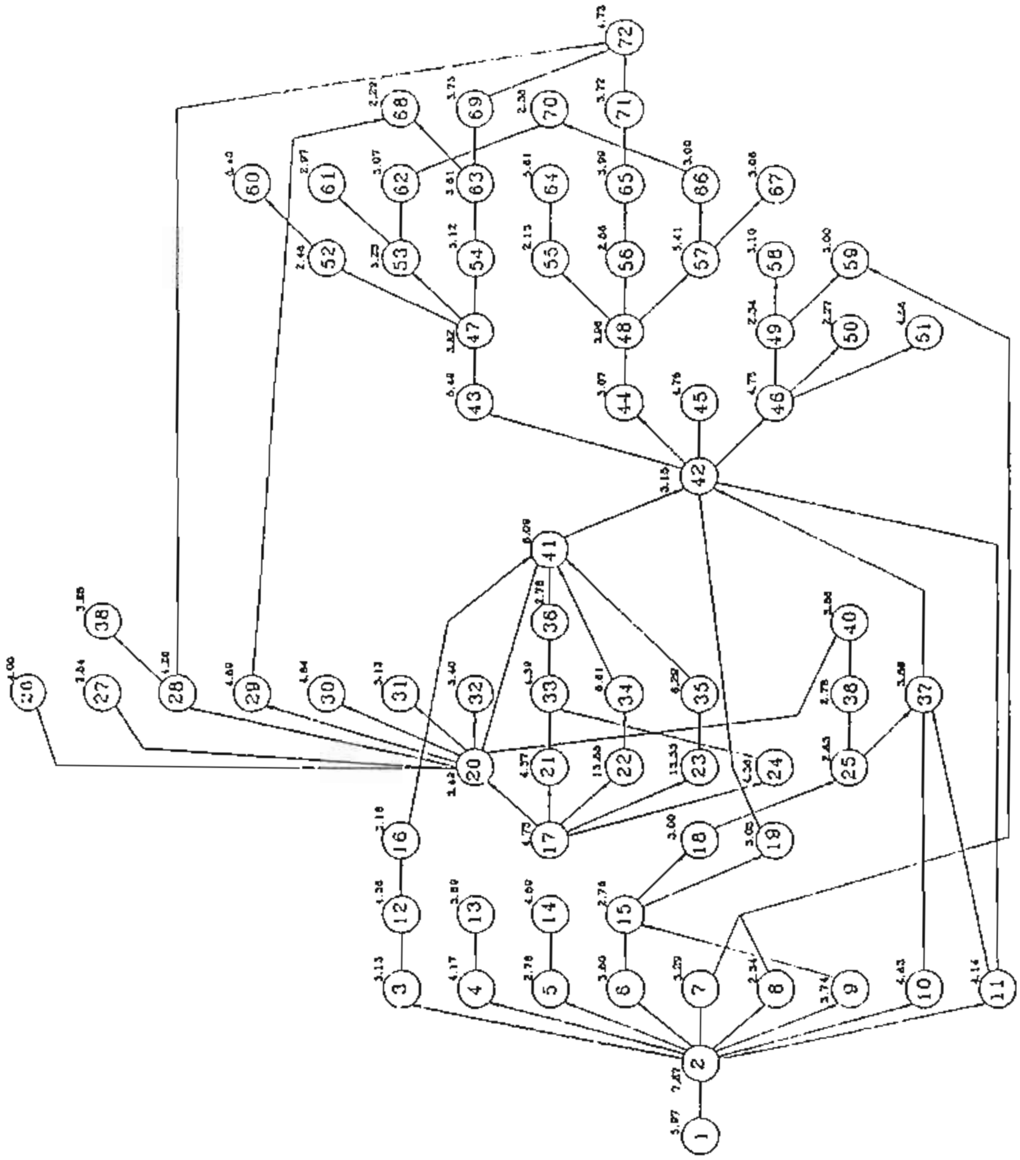

Fig. (3-1) Precedence diagram of the case engine.

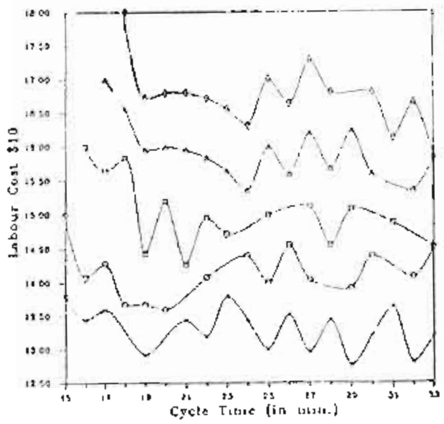

Fig. (3-2) Change of labor cost.

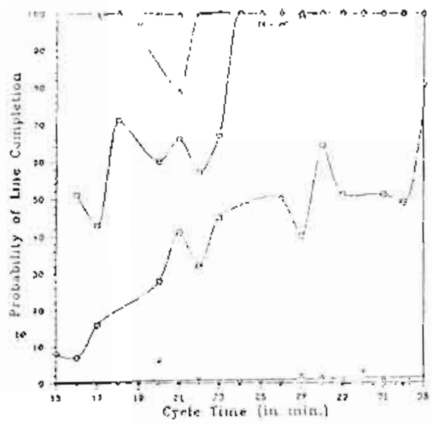

Fig. (3-3) Change of probability of line completion.

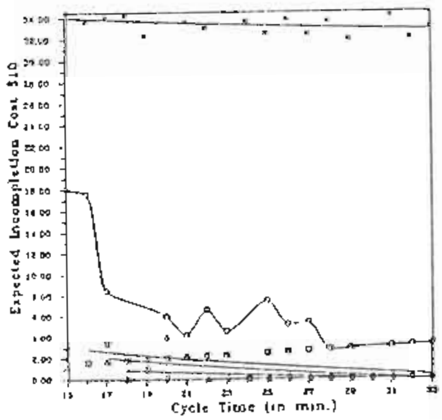

Fig. (3-4) Change of expected incompletion cost.

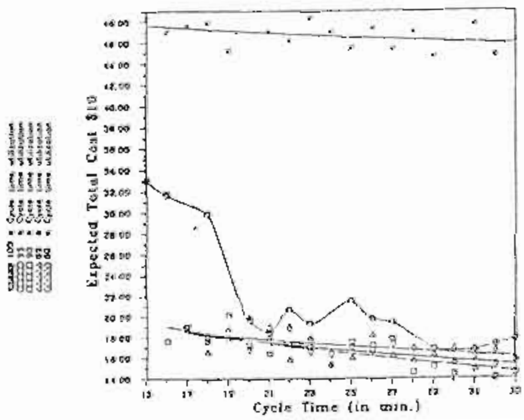

Fig. (3-5) Change of expected total cost.

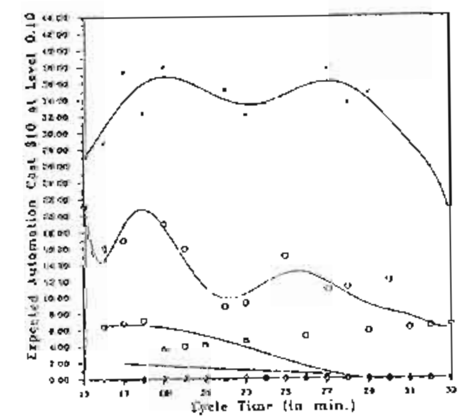

Fig. (3-6) Change of expected automation cost at 10% level.

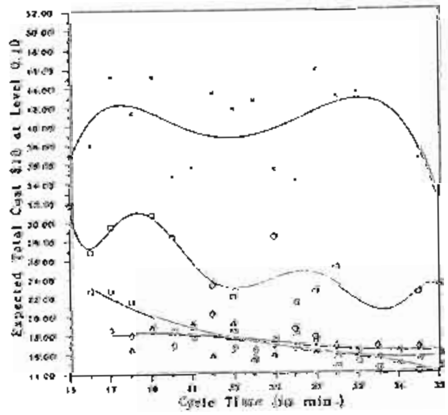

Fig. (3-7) Change of expected total cost at 10% level.

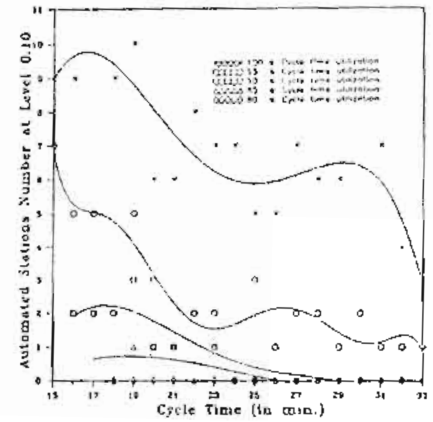

Fig. (3-8) Change of expected number of auto stations at 10% level.

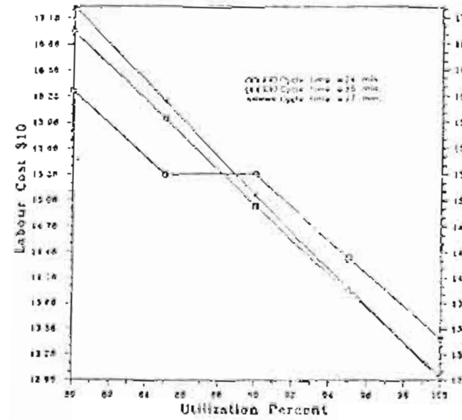

Fig. (3-9) Utilization effect on labor cost.

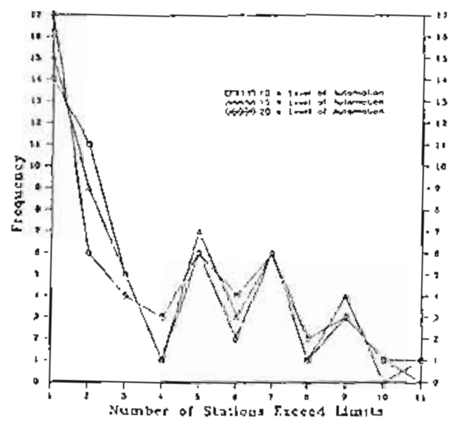

Fig. (3-10) Frequency of auto stations at three levels.

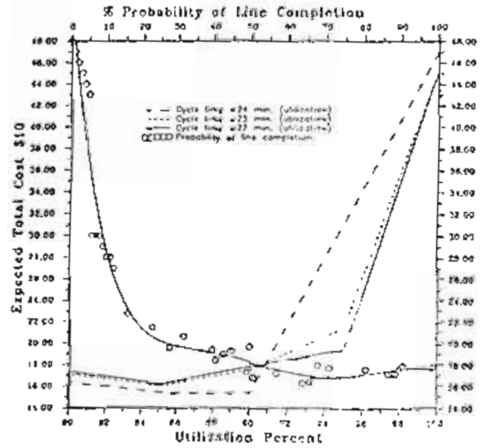

Fig. (3-11) Effect of utilization and line completion probability on expected total cost.

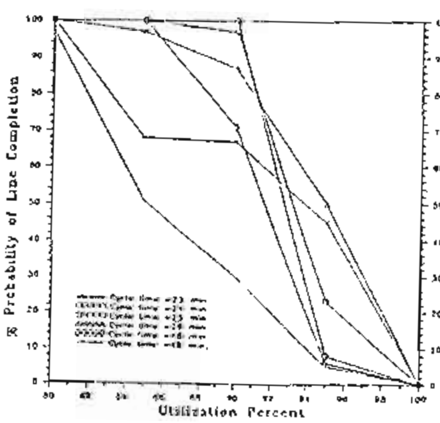

Fig. (3-12) Effect of utilization on line completion probability.

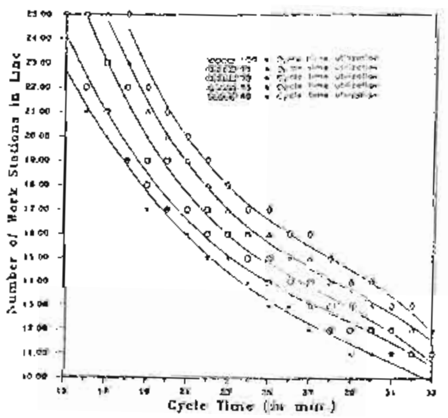

Fig. (3-13) Utilization and number of work stations.

4. Conclusions

This study confirms that, when the central objective is to improve the stochastic parameters, it may be compared with a little inverse shift in the deterministic parameters which may increase the labour cost but minimizes the expected total cost of operating the line. Also, it is seen that all of the deterministic parameters inversely proportion to utilization and the stochastic parameters do the opposite. The effect of utilization reaches the remain stochastic parameters through the probability of completion in the sense those are implicit functions of utilization. The approach recommends the automatic stations when there are significant probabilities of incompletion and facilitates this by trying to allocate the tasks which have larger variability to the same current station. The balancing procedure carries out the task assignments considering minimizing the three-component stochastic cost function proposed to evaluate the total operating cost also, reducing sudden actions can be encountered by the worker, that can be got through different decision points and rules.

The balancing procedure represents a significant departure from those in the literature because it is explicitly based on the cost and statistical considerations. The rank and average concept helps to get the merits of less variability and less incompletion cost. Also, it assigns the tasks to a current station considering the change incurred in the performance rate of the workers due to fatigue and monotonous work which lead to change in incompletion chance Therefore, each part of a station is assigned by means of a different rule considering the different distributions of task times which may be skewed or kurtic. Whatever the distribution of task times, the procedure is able to differentiate them. The three-component stochastic cost function depends upon a very simple probability mechanism dispenses with the complicated and tedious mathematical computations, it approximates the station probabilities from the classical and the frequency definitions. It facilitates the prediction of what total cost may be expected to operate the line at different conditions. Thus making it possible to evaluate any proposed rearrangements and differentiate various alternative layouts. Various alternative designs come from other balancing procedures can be compared on basis of expected total operating cost by integrating this function assuming the repair is made off-line.

Acknowledgement-The authors thank the referees and the journal editor due to their valuable remarks to reach the current form of the article.

References

1. Akagi, F.; Osaki, H.; Kikuchi, S.; and Fujii, T.; "An assembly line balancing method considering the performance rate of each work station," Bul. JSME, Vol. 29, No. 225, 1986, pp. 3224-3229.
2. Arcus, A.L., "COMSOAL-a computer method of sequencing operations for assembly lines," Int. J. Prod. Res., Vol. 4, No. 4, 1966, pp. 259-277.
3. Barr, D.F., "Decision making on the deployment of new technology-a practical approach," European J. Ops. Res , Vol. 11, 1982, pp. 380-389.
4. Braverman, J.D., "Fundamentals of business statistics," Academic Press, Inc., New York, USA, 1978.
5. Brennecke, D., "Two parameter assembly line balancing model, " M.P. Hottenstein (Ed.), in Models and Analysis for Production Management, Int. Textbook Co. Scranton, Pa., 1968.

6. Carraway, R.L., "A dynamic programming approach to stochastic assembly line balancing," Mgmt Sci., Vol. 35, No. 4, 1989, pp. 459-471.

7. Carter, J.C., and Silverman, F.N., "A cost-effective approach to stochastic line balancing with off-line repairs," J. Ops. Mgmt., Vol 4, No. 2, 1984, pp. 145-156.

8. Cooper, A., and Schendel, D., "Strategic responses to technological threats," Business Horizons, February, 1976, pp. 61-69

9. Gaimon, C., "Optimal times and levels of acquisition of automation," Ohio State University, Proceedings, TIME-ORSA Conference on Flexible Manufacturing Systems, August, 1984a.

10. Gaimon, C., "The optimal acquisition of automation to enhance the productivity of labour," Mgmt. Sci., Vol. 31, No. 9,1985, pp. 1175-1190.

11 Gottfried, B.S., "Elements of stochastic process simulation," Prentice Hall, Englewood Cliffs, New Jersey, USA, 1984.

12. Groover, M.P., "Automation, Production Systems, and Computer-Aided Manufacturing," Prentice-Hall, Englewood Cliffs, New Jersey, U.S.A., 1980

13. Gutjahr, A.L., and Nemhauser, G.L., "An algorithm for the line balancing problem," Mgmt. Sci, Vol. 11, No. 2, 1964, pp.308-315.

14. Held, M., Karp, R.M.; and Shareshian, R.; "Assembly line balancing-dynamic programming with precedence constraints," Ops. Res., vol. 11, No. 3, 1963, pp 442-459.

15. Helgeson, W.B., and Birnie, D.P., "Assembly line balancing using the ranked positional weight technique," J. Ind. Engng., Vol. XII, No. 6, 1961, pp. 394-398.

16. Henig, M.I., "Extensions of the dynamic programming method in the deterministic and stochastic assembly line balancing Problems," Comp. & Ops. Res., Vol. 13, No. 4, 1986, pp. 443-449.

17. Ignall, E.J., "A review of assembly line balancing," J. Ind. Engng., Vol. XVI, No. 4, 1965, pp. 244-254.

18 Johnson, R.V., "A branch and bound algorithm for assembly line balancing problems with formulation irregularities," Mgmt. Sci., Vol. 29, No. 11, 1983, pp. 1309-1324.

19. Kamali, J; Moodie, C.L.; and Salvendy, G.; "A framework for integrated assembly systems: humans, automation, and robots," Int J. Prod. Res., Vol. 20, No. 4, 1982, pp. 431-448.

20. Kao, E P C, "A preference order dynamic program for stochastic assembly line balancing," Mgmt. Sci., Vol. 22, No. 10, 1976, pp. 1097-1104.

21. Kao, E.P.C., "Computational experience with a stochastic assembly line balancing algorithm," Comp. & Ops. Res., Vol. 6, No. 2, 1979, pp. 79-86.

22 Kleijnen, J.P C, "Analyzing simulation experiments with common random numbers," Mgmt. Sci., Vol. 34, No. 1, 1988, pp 65-74.

23. Kottas, J.F., and Lau, H.S., "A cost-oriented approach to stochastic line balancing," AIIE Trans., Vol 5, No. 2, 1973, pp. 164-171.

24 Kottas, J.F., and Lau, H.S., "A total operating cost model paced lines with stochastic task times," AIIE Trans., Vol. 8, No. 2, 1976, pp. 234-240.

25. Maani, K., and Hogg, G.L., "A stochastic network simulation model for production line systems," Int. J. Prod Res., Vol. 18, No. 6, 1980, pp. 723-739.

26. Mansoor, E.M., and Ben-Tuvia, S, "Optimizing balanced assembly lines," J Ind. Engng., Vol. XVII, No. 3, 1966.

27 Miller, R.,"The bottom line: justifying a robot installation," Robotics World, April, 1983, pp. 32-35.

28. Mitten, L.G., "Preference order dynamic programming," Mgmt. Sci., Vol. 21 NO. 1, 1974, pp. 43-46.

29.Moodie, C.L., and Young, H.H., "A heuristic method of assembly line balancing for assumption of constant or variable work element times," J. Ind. Engng., Vol. XVI, No. 1, 1965, pp. 23-29
30.Nkasu, M.M., and Leung, K.H., "A stochastic approach to assembly line balancing" Int. J. Prod. Res., Vol 33, No. 4, 1995, pp 975-991.
31 Ramsing, K., and Downing, R., "Assembly line balancing with variable element times," Ind. Engng, January, 1970, pp. 41-43.
32.Rauf, A., and Tsui, C.L., "A new method for assembly line balancing having stochastic work elements." Comp. & Ind. Engng, Vol. 6, No. 2, 1982, pp. 131-148.
33 Reeve, N.R., and Thomas, W H., "Balancing stochastic assembly lines," AIIE Trans., Vol. 5, No. 3, 1973, pp 223-229.
34.Shin, D., "Efficient heuristic for solving stochastic assembly line balancing problems," Comp & Ind. Engng., Vol. 18, No. 3, 1990, pp 285-295.
35.Shtub, A., "The effect of incompletion cost on line balancing with multiple manning of work stations," Int J Prod. Res., Vol. 22, No. 2, 1984, pp. 235-245.
36.Silverman, F.N., and Carter, J C., "A cost-based methodology for stochastic line balancing with intermittent line stoppages," Mgmt. Sci., Vol. 32, No. 4, 1986, pp. 455-463.
37.Soltan, H.A.M., "Study of stochastic assembly line balancing techniques and its application on a local industry," M.Sc. Thesis, 1989, Mansoura Univ., Mansoura, Egypt.
38.Sphicas, G P., and Silverman, F.N., "Deterministic equivalents for stochastic assembly line balancing," AIIE Trans., Vol. 8, No. 2, 1976, pp. 280-282
39.Vrat, P., and Virani, A., "A cost model for optimal mix of balanced stochastic assembly line and the modular assembly system for a customer oriented production system," Int J. Prod. Res., Vol. 14, No. 4, 1976, pp. 445-463.
40 Wheelwright, S., "Reflecting corporate strategy in manufacturing decisions," Business Horizons, February, 1978, pp. 57-66.