BALANCING AND SIMULATION ALGORITHM FOR MANUAL ASSEMBLY LINE OPERATIONS

نموذج حسابي للاتزان وتمثيل العمليات في خطوط التجميع اليدوية

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يشتمل هذا البحث على نموذج حسابي مبرمج يتكون من روتين لاتزان خطوط التجميع وروتين آخر لعمل تمثيل للعمليات في خطوط التجميع . ولقد تم استحداث هذا النموذج لتقدير عدد الوحدات - تحت التشغيل - التي يجب تخزينها بين المحطات في خط التجميع لاستخدامها وقت الحاجة . وحيث ان الوقت (وايضا تباين هذا الوقت) اللازم للعمليات الانتاجية في خطوط التجميع اليدوية ليس وقتا ثابتا ولكنه يخضع للتغير من وقت لآخر ومن منتج لآخر فقد تم تصميم هذا النموذج ليكون قادرا على تناول حالات مختلفة من الخطوط وذلك من جهة الوقت اللازم لعمليات التجميع وتباينه . ويمكن لهذا النموذج ان يعالج حالتين مختلفتين من مشاكل خطوط التجميع وهما :

اولا : خط تجميع غير متزن ويحتاج لعمل اتزان وايضا يحتاج لعمل تمثيل لعمليات التجميع وذلك لتقدير كميات الوحدات - وتحت التشغيل - المطلوب توافرها بين المحطات على امتداد الخط.

ثانيا : خط تجميع متزن ويحتاج فقط لتقدير كميات الوحدات - تحت التشغيل- والمطلوب توافرها بين المحطات على خط التجميع .

ولقد تم تطبيق النموذج على حالة دراسية وذلك لاختبار مقدرة النموذج على عمل الاتزان وكذلك تمثيل العمليات وايضا لدراسة العلاقة بين تباين وقت عمليات التجميع وكمية الوحدات - تحت التشغيل - التي يجب توافرها بين المحطات وبين مستوى الثقة .

ABSTRACT

This work consists of a model which is based on a computerized algorithm and eonsists of two main parts namely balancing and simulation routines. This model was used to determine the buffer in-process units required between work stations along manual assembly lines. Since the task durations and deviations vary from assembly of one product to another and from one task to another for the same product; this model was developed to handle different cases of wide and narrow work variability according to the type of assembly work.

The model is capable of handling two different assembly line problem cases. Firstly in case of an assembly line production without balancing, the balancing routine is invited first to produce a balancing solution for the problem and then the simulation routine is invited to determine the number of in-process units needed for each individual work station. Secondly in case of balanced assembly line production, the simulation routine is invited to simulate the work performance in each work station along the line and to determine the number of buffer in-process units needed for each individual work station.

An assembly line problem consisting of fourteen tasks was used to test the balancing and simulation capability of the model. The problem was prepared to produce a perfect balancing solution of three work stations. The resultant balanced problem data was then used to investigate the relationship between task variance, buffer in-process units between work stations and confidence level.

INTRODUCTION

In a manual assembly line production, the work passes or stays in eaeh work station along the line for some definite period of time thus yielding the production rate or the cycle time. Two cases existed for cycle time applications in manual assembly operations. In the first case the line paee is rigid and the work unit is available to the operator for certain duration of cycle time. In soch a situation if the operator at any work station has not completed the assigned tasks, an incomplete in-process unit will proceed from that work station to the next one. An incomplete in-process unit will leave any work station along the line is undesirable since the succeeding work station would be unable to carry out the assigned tasks. This would create a work stoppage at the succeeding work stations. The succeeding work stations would therefore starve for work while the share of work of these stations would not added up because of the fact that work at the previous work statinn was not completed.

In the second case the line pace may be flexible or manually operated and controlled by the operators. As soon as the operator at any work station has finished his assigned work, the work unit is delivered to the next work station making sure that a certain production rate or cycle time is satisfied as far as possible. In this case if an operator at any work station has not completed the assigned tasks in the given time (cycle time), more time will be consumed to complete the assigned tasks where as the succeeding work station will be starving for work. Any undesirable delay beyond the allowed cycle time at any work station along the line will create idle time for the succeeding work stations and ultimately will delay the line production.

Deterministic task duration consideration during assembly line balancing stage is the main reason behind the existance of the two problems as diseussed above. Moodie and Young (9) dispensed with the assumption of deterministic task durations and developed a balancing procedure consisting of two phases. The first phase dealt with assembly line balancing as a deterministic task balancing problem, the second phase of the procedure recognized the task duration variability, rearranged task assignments between work stations, so as to allow for variable performanee durations.

Mansoor and Ben-tuvia (8) Freeman and Jucker (4), and Mansoor (7) have extended the research work by Moodie and Young (9) and treated the task duration as a variable or stochastic duration rather than deterministic duration. Kala and Hitchings (6) have investigated the effects of station time variance on the operating characteristics of manual assembly lines. This sought to determine whether extreme variance could have significant effects on the line output. Raouf and Tsui (10) have introduced a new method for assembly line balancing and recognized the stochastic nature of task duration in manual assembly operations. Silverman and Carter (11) in a cost model for assembly line balancing examined the effects of stochastic task durations on the total cost of continuously paeed assembly line under the assumption that the line would stop whenever at last one work station required more than alloted time. Conrad (2) proposed a buffer storage or queue at each manned proeessing work station, and reported that, "Work feeds into a standing queue and the operator draws work along from his queue. The operator mean rate of working would then be the correet rate at which to feed the store and would be also be the output rate of the system". Davis (3) in a study of the pacing on manned assembly lines reported that "A number of studies were earried out which show that an assembly line can not perform the maximum efficiency (in terms of operator idle time and units completed) unless queues are provided before each work station. "A model proposed by Abdel-Shafi (1) determines the buffer in-process units between work stations on balanced assembly lines.

It can be seen from the above literature that stochastic task duration is an important piece of information which should be considered at an early stage during the balancing of the assembly line production by tackling the task durations as stoehastic rather than deterministic. Another approach would be to consider the task duration variablity later at the running and operating stage of assembly line production by introducing buffer in-process units between work stations. It is expected that the existanee of buffer units between work stations along the line will minimize the operating defectives such as production delays, incomplete products and idle time for work stations.

A large number of buffer in-process units between work stations may not only be impractical, it could tie up eapital (opportunity cost) and may result in occupancy of vital factory space. On the other hand too low a buffer in-process units between work stations would not solve the production problems completely.

Because of the random nature of work station-excess durations during the assembly work performance and the complex configuration of assembly work, it is generally difficult to develop analytical models which could be used to evaluate a correct buffer in-process units level requirement between work stations along assembly lines. However computer simulation programes eould be used to obtain a meaningful solution for some of real life assembly line problems.

MODEL DESCRIPTION

The eomputer algorithm developed in this study consists of two main routines. First is the line balancing routine where assembly line data is tackled to produce a deterministic balancing solution for the line, using the R. P. W. technique (5). The balanced line information are then fed into the seeond simulation rountine where the buffer in-process units level between work stations can be determined. In case the assembly line which is already balanced for a well established product and there is no need to use the balancing routine, the model switches automatically to the simulation routine (Figure 1).

Task Stochastic Duration:

The work performance in manual assembly lines is performed by human beings therefore, it is subjected to the following two criteria:

a- The working pace of each individual operator varies throughout the working period, and
b- No two operators work at the same pace through the working period.

Task durations are actually random variables can be approximated by normal distribution. Having known task deterministic durations and task variances, the task stochastic durations can be generated for any specified confidence level (Simulation procedure).

To determine the number of buffer in-process units between work stations along the assembly line, the following two phases algorithm is implemented on computer:

Phase I: It is a preperation phase where the model has been designed to handle any of the following two cases:

Case A concerns with the assembly line data which is unbalanced yet. Here the balance routine is invited to produce a balancing solution (Task-Station Assignments) for the line. The balance routine adopts the R.P.W. technique (5) with a modification to produce deterministic or stochastic balance solutinn as required. The results from the balancing routine are then fed to the simulation routine.
In case B the assembly line data is already balanced i.e. task-station assigmments are ready. In this case there is no need to invite the balancing routine and the data is fed directly into the second phase which is the simulation routine.

Phase II: It is a simulation phase where the assemhly work performance is simulated through the line work stations and the buffer in-process units required to be allocated between work stations are counted by the following procedure:

1. The simulation routine starts reading the input data which consists of the solution confidence level required to be covered, task deterministic durations and variations, task-station assignments and number of simulation runs (simulation length). It should be mentioned that number of simulation runs can be given in the data or can be calculated by the simulation routine as the number of cycles in the simulated period.

2. Based on the consideration that each task duration distribution is a normal distribution, the number of standard deviations corresponding to the given confidence level is calculated and new simulation run is started.

3. For each simulation run, the following steps are implemented:

a- For each task i, the task stochastic duration (SD_i) is generated:

$$UD_i = DD_i + [Z_{CF} * (V_i)^{1/2}]$$

$$LD_i = DD_i - [Z_{CF} * (V_i)^{1/2}]$$

$$SD_i = LD_i + R\,(UD_i - LD_i)$$

b- Assembly work performance for each work station along the line is simulated using the generated stochastic task durations.

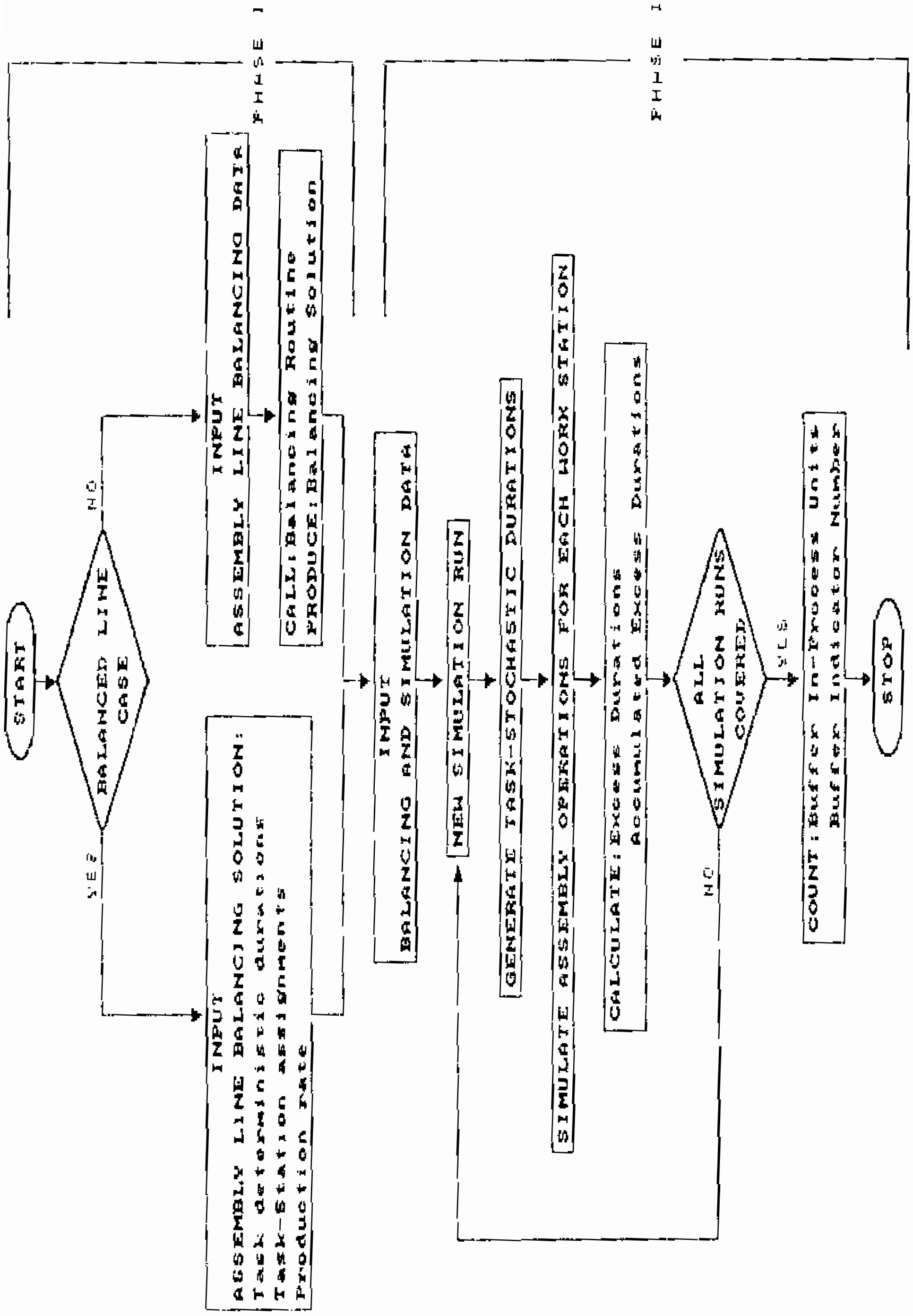

Fig.(1) Line Balancing and Simulation Routines c- The work station excess duration (SE_{jk}), if any, for each individual work station along the line is eounted fur the current simulation run (work station excess duration is the duration time needed by the work station, to complete its assigned work, more than the allowable cycle time):

$$SE_{jk} = [(\sum_{i=1}^{Nj} SD_{i,jk}) - C]$$

$$SE_{jk} = 0 \text{ if } [(\sum_{i=1}^{Nj} SD_{ijk}) - C] \leq 0$$

d- The accumulated work station excess duration (ASE_{jk}), if any, for each individual work station is counted up to the current simulation run:

$$ASE_{jk} = \sum_{k=1}^{K} SE_{jk}$$

$$= \sum_{k=1}^{K} [(\sum_{i=1}^{Nj} SD_{ijk}) - C]$$

4. The procedure switches to step 5 if all simulatiun runs are covered. If all simulation runs have not been covered yet, the procedure switches back to step 3.

5. The buffer in-process units level (BF_j) and the buffer indicator number (BFI_j) for work station j are calculated for all work stations along the line as follows:

$$BF_j = ASE_{(j-1),k} / C$$

BF_j raised to next integer if it is not integer

$$BFI_j = BF_j / K$$

Where:

ASE_{jk} = Accumulated excess duration for work station j up to the eurrent simulation run number k.

BF_j = Number of buffer in-process units needed for work station j for the specified simulated period.

BFI_j = Buffer indicator number for work station j is a general number which when multiplied by the number of cycles in the produetion period will result in the number of buffer in-process units needed for work station j for the specified production period.

C = Cycle time or the production rate.

DD_i = Deterministic duration of task i.

k = Simulation run number k or current simulation run k.

K = Simulation length or the total number of simulation runs.

LD_i = Lower duration limit for task i at the given confidence level.

Nj = Number of assembly tasks in the station j.

R = Random number between 0.0 and 1.0.

SD_i = Stochastic duration of task i .

SD_{ijk} = Stochastic duration of task i when involved in work station j and at simulation run number k

SE_{jk} = Excess duration of work station j during simulation run number k.

UD_i = Upper duration limit of task i at the given confidence level.

V_i = Duration variance of task i .

Z_{cf} = Number of standard deviations corresponding to confidence level CF.

The algorithm has been developed as a computer program which was written in FORTRAN language and implemented on VAX main frame computer. The general inputs and outputs of the computer program are outlined below:
Inputs for Balancing Routine:

a- Task deterministic durations.
b- Cycle time or production rate.
c- Task precedence and technological relationships
d- Task variances.

Output from Balancing Routine:

a- Task deterministic durations.
b- Cycle time or production rate.
c- Task variances.
d- Task-station assignments.

Input for Simulation Routine:

a- Task deterministic durations.
b- Cycle time or production rate.
c- Task variances.
d- Task-station assignments.
e- Simulation length or number of simulation runs.
f- Confidence level to be covered.

Output from Simulation Rountine:

a- Buffer in-process units required for each individual work station along the line.
b- Buffer indicator number for each individual work station along the line.

A CASE STUDY

The model was used to investigated an assembly line problem which consists of fourteen tasks and was prepared tu give a perfect balancing solution of three work stations for a cycle time of sixty time units. The balancing routine was used to produce the balancing solution, the results were as follows:

Work Station 1:-

Task Number	1	2	3	4	7
Deterministic Duration (Time units)	12	9	10	13	16
Succeeding Tasks	1,2,3	5,6	7	10	9,10

Work Station 2:-

Task Number	6	9	10	11
Deterministic Duration (Time units)	11	18	11	20
Succeeding Tasks	8	11	12	13

Work Station 3:-

Task Number	5	8	12	13	14
Deterministic Duration (Time units)	12	13	15	10	10
Succeeding Tasks	8	14	13	14	-

The balanced assembly line data obtained from the balancing routine is then fe to the simulation routine and used to investigate the relationship between buffer indicato number and confidence level for different cases of task variances (Figure 2). Task varianc has been taken as a fixed percentage of the task duration for all tasks involved in the asseml work. Different percentages are considered for the investigation purpose. The compute algorithm has the capability to tackle real life assembly line cases where task variance are different. In Figure 2, buffer indicator number has been taken as the average for a work stations along the line. The algorithm produces the buffer indicator number for eac individual work station as well as the average for the line and the number of in-proces units for each individual work station. From the figure it can be concluded that:

For a certain amount of task variances of manual assembly operations, as the confidenc level increases (i.e. it is needed to be more certain that there is no production delay c incomplete work) the buffer in-process units required between work stations are increase Also the buffer in-process units required between work stations are increased as task variance for assembly work increased.

Figure 3 shows the relationship between buffer indicator number and task varianc for different confidence levels. The buffer in-process units between work stations are neede to be increased for assembly work having large task variances. This number may also b increased when there is a need for more confidence regarding the assembly line performanc without production delay or incomplete work at the end of the line.

CONCLUSION

Past experience has shown that most of the assembly line production problem can not be solved analytically. A strong need is felt for computerized algorithms such a the model suggested in this work. Task duration variability in manual real life assembl operations resulted in production delay or incomplete work at the end. Therefor, it wa worth searching for a solution that could be applied to minimize these production defectives In this work it was suggested to introduce buffer in-process units between work station to offset task duration variability effects. A model has been proposed which has the capabilit to handle two different assembly line cases. First is the balanced work assembly line cas where there is a need to have a decision about buffer level between work stations. Th second case is the unbalanced work assembly line where there is a need to balance th line and then to determine the buffer level between work stations. Decision about buffe level is a vital one since a large number of units will tie up capital and consumes factor space, while a small number will not solve the production problems completely.

The suggested algorithm can be used to get a solution for the problem which i the determination of the number of buffer in-process units between work stations (buffe level). The resultant solution is not a unique but is affected by the selected confidenc level. Selecting a high confidence level will produce a solution with a high buffer leve and vice versa. Selecting the confidence level is a management decision and it depend

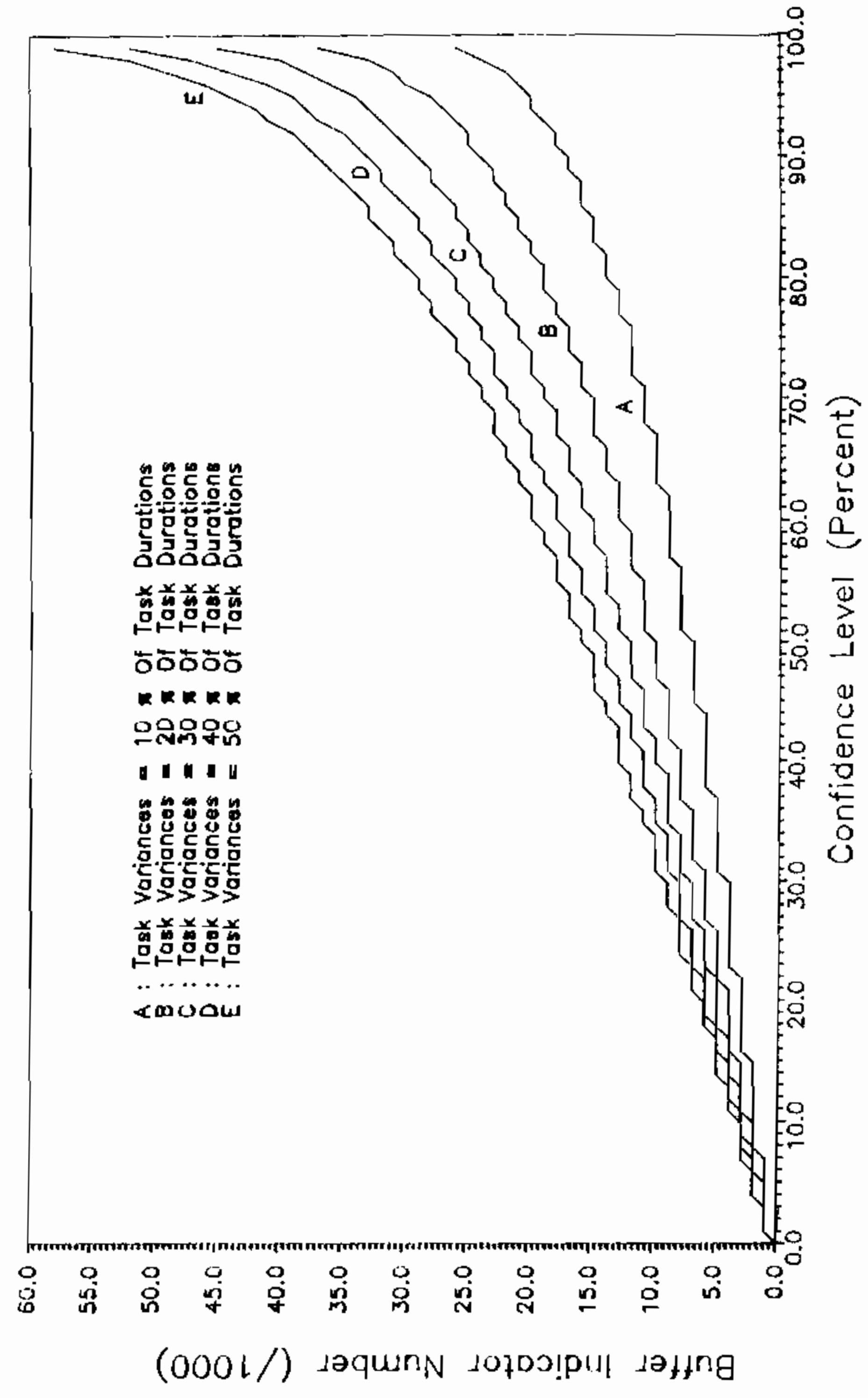

Fig.(2) Buffer Indicator Number For Different Confidence Levels

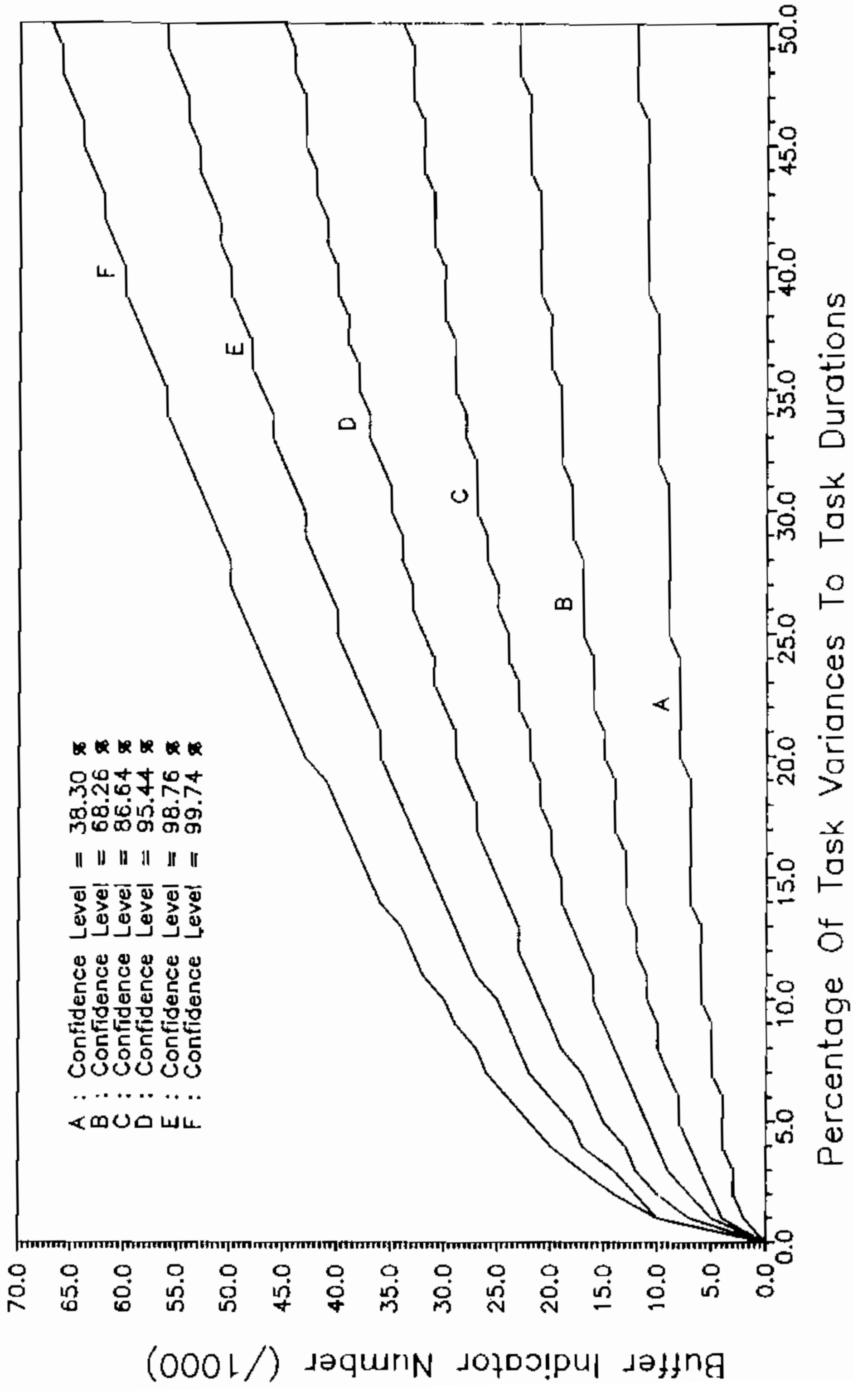

Fig.(3) Buffer Indicator Number For Different Task Variances on the extent of surety the management wants to achieve regarding the performance of assembly operation without production defectives. This flexibility has been incorporated in the model which allows for different solutions giving management and the engineers freedom to adopt the one most suitable to their conditions.

The algorithm has been used to investigate a theoretical case of assembly line operations and to establish the relationships between different parameters involved in buffer in-process level determination. It is worth mentioning that the proposed model is capable of handling real life assembly line operation in industry and can serve the management and engineers, as a very powerful tool for analysing the production defectives.

REFERENCES

1. Abdel-Shafi, A. A. A. "Buffer Stock Requirements Between Work Stations on Assembly Lines "Modeling and Simulation, Proceedings of the Ninteenth Annual Pittsburgh Conference, Vol. 19, Pittsburgh, Pennsylvania, May 1988.

2. Conrad, R. "The Rate of Paced Man-Machine System" Journal of Institution of Production Engineers, 1954.

3. Davis, L. E. "Passing Effects on Manual Assembly Lines" The International Journal of Production Research, Vol. 4, No. 3, 1966.

4. Freeman, D. R. and Jueker, J. V. "The Line Balancing Problem" Journal of Industrial Engineering, Vol. XVIII, No. 6, 1967.

5. Heigeson, W. P. and Birne, D. P. "Assembly Line Balancing Using The Ranked Positional Weight Teehnique" Journal of Industrial Engineering, Vol. XII, No. 6, 1961.

6. Kala, R. and Hitchings, J. J. "The effect of Performance Time Variance on a Balanced Four-Station Manual Assembly Line" International Journal of Production Research, Vol. II, No. 4, 1973.

7. Mansoor, E. M. "Assembly Line Balancing - A Heuristie Algorithm for Variable Operator Performance Levels" Journal of Industrial Engineering, Vol. XIX, No. 12, 1968.

8. Mansoor, E. M. and Ben-tuvia, S. "Optimizing Balanced Assembly Lines" Journal of Industrial Engineering, Vol. XVII, No. 3, 1966.

9. Moodie, C. L. and Young, H. H. "A Heuristic Method of Assembly Line Balancing For Assumption of Constant or Variable Work Element Times" Journal of Industrial Engineering, Vol. XVI, No. 1, 1965.

10. Raouf, A. and Tsui, C. L. "A New Method For Assembly Line Balancing Having Stochastic Work Elements" Comput. & Indust. Eng., Vol. 6, No. 2, pp. 131-148, 1982.

11. Silverman, F. N. and Carter, J.C. "A Cost-Based Methodology For Stochastic Line Balancing with Intermittent Line Stoppages" Management Science, Vol. 32, No. 4, 1986.