A Model for Computer-Aided Process Planning System in Flexible Manufacturing Systems [+]

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Abstract

Most of computer-aided process planning(CAPP) systems have been developed to automate the process planning function.

In this paper, we describe an analytical model for a CAPP system in order to improve the performance of production system in flexible manufacturing systems (FMSs) for computer intergrated manufacturing(CIM) architecture.

This paper proposes an optimal process planning that minimizes the load time by minimizing the cycle time and the number of workstations using Kang and Hahm's heuristic approach so as to improve the performance of production system under the batch production of discrete products. We also perform simulation using SIMAN language to campare the line utilization of each for various product types.

The proposed algorithm can be implemented in existing FMSs for on-line control of product quantity using programmable logic controllers(PLC) and communication devices.

1. Introduction

Many computer-aided design (CAD), computer-aided process planning (CAPP), computer-aided manufacturing (CAM), computer-aided engineering (CAE) manufacturing resource planning(MRP II), and management information system (MIS) have been adopted by industries as independent contributions to enhance

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their productivity (Lim 1992). Especially, a CAPP has a key role in CIM as an interface between design and manufacturing (Lin et al. 1988). Therefore effective intergration of all manufacturing function is one of the best ways to achieve higher productivity, reduce the design, planning, manufacturing and delivery time; and to improve the overall performance of a factory (Lim 1992).

In among a process planning technique for CAPP, the line balancing technique to improve the line efficiency has contributed to the productivity and profit of enterprises. Also a line of facilites has developed mono-model production system into a type of multi-model production system in order to cope with a market structure and various products demand (Kang and Hahm 1992).

The trend of line balancing techniques has maximized the efficiency to minmize a total of idle time in assembly line using conveyor belt on the flow of complex products. (Kang and Hahm 1992).

According to the existing studies on the line balancing, Salverson (1955) read the first formal paper on the line balancing technique in the assembly line. Jackson (1956) has developed the enumeration which chooses the least required workstation to be a optimum value with all possible precedences. Helgeson and Birnie (1963) attempted to achieve the optimal line balancing by the ranked positional weight method. Hoffman (1963) has minimized a idle time by the enumerating the possible combination of work elements. Moodie and Young (1965) treated work time as random variables with a distribution, and then modeled a line balancing technique. Thomopoulos (1970) assumed that work time is a constant, and introduced line balancing technique on the multi-model production system. Tonge (1970) developed a line balancing technique that some work elements were collected by means of precedence relations, the group was formed, by which the work amount is controlled. Kottas and Lau (1973) were aimed at minimizing the cost required the treatment of incompleted products produced by worker's wages and assemble of products. Vrat and Birani (1976) introduced a line balancing technique using Kottas and Lau's (1973) method after simplifing multi-products into mono-products. Talbot, Patterson, and Gehrein (1984) compared some line balancing techniques on heuristic approaches with others and evaluated those. Talbot, patterson, and Gehrein (1986) computerized the integer programming method of the assembly-line network. Richard (1988) has developed a model which simultaneously considers the minimization of cycle time and the number of workstations in an assembly line balancing problem through the line balancing technique that is developed from such known zero-one integer programming as the Patterson and Albract (1975) and the Thangabelue and shetty models (1971). Ishfad Ahmad and Arif Ghafoor (1991) have proposed a new load balancing approach for large scale multi-computer systems, and then presented the concepts of a semi-distributed control through an extensive simulation study using Hadamard matrix (1986). Kang and Hahm (1990, 1991, 1992) have computerized a model that minimize a load time from the minimization of cycle time and number of workstations by heuristic approach so as to improve a performance of production system in an multi-products production line.

According to the existing studies on the a CAPP system, Lin, et al. (1988) have shown promising perspectives of GT application in CAPP using 14-digit chain-structure GT code. Charles et al. (1989) have decribed an extensive CAPP systems that made of FORTRAN code with computer managed process planning(CMPP). Heemskerk et al. (1990) have focussed on cycle time and plan robustness in order to achieve the optimization for CAPP of flexible assembly. Wu and Liu (1990) can do flexibly the process plans and have varied with the capabilities of available manufacturing facilities and desired production criteria from a method for automatically generating process plans and NC paths for finish maching in milling operation. Hou and Wang (1991) have shown a study of the impact of alternate routing and/or alternate machine on the performance of the FMS so as to determine an "optimal" process plan.

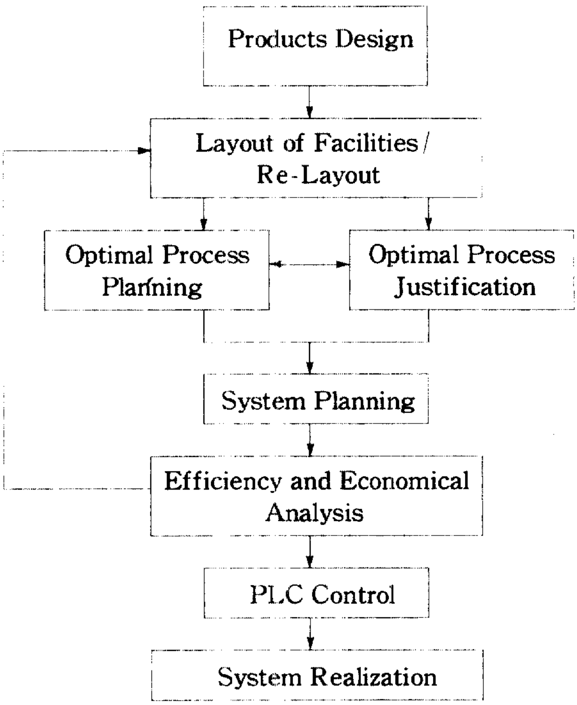
The purpose of this study therefore is to construct a CAPP model and to justify a CAPP system for CIM architecture in the future through an optimal process planning to minimize the load time and on-line control by the real time.

This paper is organized as follows. Section 1 has presented previous study on the process planning and CAPP. Section 2 describes the application of four procedure to CAPP system. Section 3 describes the development of three reusable software to CAPP control system. Section4 describes analysis results using these sostware through a case study. Finally, section 5 discusses conclusions drawn from this work.

2. System for the optimization of CAPP

An FMS is a CIM that incorporates automated handling systems, robots, numerical control machine tools, inspection, and group technonogy into a single production network of computers (Sharit and Salversondy 1986). In a short word, the definition of FMS can be refer to "the group of numerical control (NC) to use a computer which introduce group technology (GT) concepts to robot production line (Kang and Hahm 1991, 1992, Arbel 1984, Roch 1986)." This FMS can apply to all the fields regardless of multikind and small-quantity production, mass production, medium production, because it can cope with an external change in environment (Kang and Hahm 1991, 1992)

Some of the advantages of an FMS include shortened lead times and just-in-time manufacturing, reduced labour costs and work-in-process inventory, improved higher products quality and equipment utilization (Talavage and Shodhan 1992), but an FMS providing flexibility, reliability, and productivity follow the great capital of facilities. In a case where FMS facilities follow a great capital, therefore, CAPP can be regarded as the main problem in order to improve productivity, so that following procedures can be required:



: Consider GT application and products production method fitting FMS.

: Determine a type of layout by a P−Q chart and flow diagram.

: Use a operation chart and flow process chart for line balancing technique fitting multi-model production system, and then evaluate the line utilization of workstations through simulation.

: Develope software and hardware which consider flexibility, reliability, and productivity

: Analyze econonmic justification with output results

: Control real-time and product quantity by PLC for point of production (POP) system control.

: Construct a CAPP system fitting FMS.

Figure 1. A prodecure for a CAPP system

In the first step, as the price of products is determined essentially, the engineer takes part in this step, and then identify a shape of products, the number of tools used.

The benifit of utlizing GT in the entire manufacturing process has been reported to have 10% to 80% savings in parts design and drawing, production and quality control costs setup and throughput time, raw material, work-in-process and finished goods inventory (Lin et al. 1988).

In the second step, the level scope of GT is considered through a real approach in the field and facilites are rearranged by P−Q chart and flow digram. Especially, the layout of FMS should consider closely values for various resources parameters associated with these, such as buffer sizes, number of material handling equipment, default locations for robots, etc.

In the third, the optimal process planning is used to directly apply Kang and Hahm's (1991, 1992) technology to the field under batch production.

The batch level planning concentrates on decisions efficiently for a whole batch. Especially, the strategic nature of these decisions makes that batch level planning is closely related to the system layout design (Heemskerk 1990). Futhermore, The line utilization is calculated by the SIMAN simulation language for a efficient application to buffer sizes of line, and then it is identified the efficiency of buffer sizes.

In the fourth, hardware should be considered a manufacturing capacity of numerical control(NC) machines, material handlings in free conveyor, and information required to the operation of systems. In software field, database system have to construct software which controls and manages useful information systematically relating to apparatus, materials, tools and etc. (Kang and Hahm 1992). And then, it should control in charge of a supplementary role because the CAPP system constructs it through system phased extension from the precedence condition of dababase system.

In the fifth, a CIM by the FMS systems has drawn much attention in recent years as a strategy to cope with increasing pressure from intense global competition in markets damanding low-cost high-quality products (Kim et al 1992). There has been a considerable an amount of investment for automating manufacturing processes and development of information systems to maintain these as well as a factor of competiveness that can meet with the world market. Namely, the investment of FMS has been one of the major research areas in recent years because factory automation(FA) or robots for labour substitution is brisk practically investment on accont of high cost.

In the sixth, this section realizes the real time control system through on-line control by PLC with the real-time and products quantity, respectively. A real-time program must generate the right output at the right time. In other words, the program is incorrect if the output is generated too late or too early. Therefore, we should capture the behavior of real-time programs in a quantitative way rather than in a qualitative way(Liu & Shyamasundar). This control data contributes to the synchronization of point of sales(POS).

Finally, the optimum policy of CAPP architecture has realized through the results analysis.

3. Model description

3.1 Model Development for CAPP

3.1.1 Definitions and assumptions

Above all, the following definitions are applicable for this algothrim.

LE_j : In challenge method, the line efficiency for products j is the ratio of total processing times to the cycle time (C_j) multiplied by the number of workstations (N_j).

It is expressed as

$$LE_j = \frac{\sum_{i=1}^{k} P_{jk}}{N_j \cdot C_j} \times 100\% \qquad (1)$$

where P_{jk} = allocated work times at workstation k of products j, $j=1, 2, \cdots, M$
$k=1, 2, \cdots, K$

N_j = total number of workstations of products j, $j=1, 2, \cdots, M$

C_j = cycle time of products j,

LE_j = the line efficiency for products j, $j=1, 2, \cdots, M$

LE_c : The line efficiency of all products is calculated as $j=1, 2, \cdots, M$

$$LE_c = \frac{\sum_{j=1}^{M} G_j \cdot LE_j}{\sum_{j=1}^{M} G_j} \times 100\% \qquad j=1, 2, \cdots\cdots, M \qquad (2)$$

G_j = quantity of products j a day, $j=1, 2, \cdots, M$

LE_c : The line efficiency of all products

D : The total idle time is the sum of difference between the cycle time (C) and the workstation time.

WE : The work element is a part of the total work content in an assembly line process.

WS : The workstation is a location on the assembly line where work elements or elements are performed on the product.

PW : The positional weight(PW) determines for each work element(a positional weight of an operation corresponds to the time of the longest path from the beginning of the of the operation through the remainder of the network).

C : The cycle time is the time between the completion of two successive assemblies, assumed constant for all assemblies for a given conveyor speed. The minimum value of the cycle time should be greater than or or equal to the longest workstations time.

PD : The precedence diagram describes the ordering in which work elements must be performed. Some jobs cannot be performed unless its precedessors are completed. In fact, the layout of processes along the assembly line depends on the precedence diagram.

CM : As the above mentioned, the challenge method is a proposed method by the batch production for mult-model production line in FMS.

GM : The general method is usually the technology to use in an assembly line The line efficiency(LE_g) of general method is presented as

$$LE_g \text{ of general method for products } j = \frac{\sum_{i=1}^{N} ST}{n \cdot C} \times 100\% \quad j=1, 2, \cdots, M \quad (3)$$

where ST = station time of station i

n = total number of workstations

C = cycle time.

LE_g : In general method, the line efficiency for products j. $j=1, 2, \cdots, M$

LE_G : In general method, the line efficiency of all products.

Therefore, a notation to be use in order to accomplish a line balancing among process planning technologies is summarized as follows:

i = number of work elements

N, K= number of workstations

J = number of products

T = work time a day(generally 8 hours)

C_j = cycle time of products j, $j=1, 2, \cdots, M$

T_L = lower limit of total work load

T_U = upper limit of total work load

G_j = quantity of products j a day, $j=1, 2, \cdots, M$

t_{ji} = work element time of work element i for products j, $i=1, 2, \cdots, N$; $j=1, 2, \cdots, M$

T_i = work times of work elements i for all products j, $i=1, 2, \cdots, N$; $j=1, 2, \cdots, M$

T_k = work load at workstations k, $k=1, 2, \cdots, K$

P_{jk} = allocated work times at workstation k of products j, $j=1, 2, \cdots, M$; $k=1, 2, \cdots, K$

ⓗ$_{jk}$ = total work times of products j at workstations k, $j=1, 2, \cdots, M$; $k=1, 2, \cdots, K$

ⓗ$_j$ = expected work times of products j about workstation, $j=1, 2, \cdots, M$

ⓗ = total work times a day of about workstations

W_{ji} = ranked positional weight values of allocated work elements times i at products j, $j=1, 2, \cdots, M$; $i=1, 2, \cdots, N$

$$T_i = \sum_{j=1}^{M} G_j \cdot t_{ji}, \qquad j=1, 2, \cdots\cdots, M \qquad i=1, 2, \cdots\cdots, N$$

$$T_k = \sum_{j=1}^{M} G_j \cdot P_{jk}, \qquad j=1, 2, \cdots\cdots, M \qquad k=1, 2, \cdots\cdots, K$$

$$ⓗ_{jk} = G_j \cdot P_{jk}, \qquad j=1, 2, \cdots\cdots, M \qquad k=1, 2, \cdots\cdots, K$$

$$ⓗ_j = (G_j \cdot \sum_{i=1}^{N} t_{ji})/K \qquad j=1, 2, \cdots\cdots, M \qquad i=1, 2, \cdots\cdots, N$$

$$ⓗ = \sum_{k=1}^{K} T_k = \sum_{i=1}^{N} T_i \qquad k=1, 2, \cdots\cdots, K \qquad i=1, 2, \cdots\cdots, N$$

Some basic assumptions that are required to formulate an algorithm are listed below (Kang and Hahm 1991, 1992).

(1) Each worker carries out the work without a change of working place and work elements.
(2) Precedence relations are defined in assembly line.
(3) A learning of workers and effect of fatigue can be disregard by automated work.
(4) Products has a constant demand.
(5) Inputed assembly components are transfered automatically.
(6) All work elements times of work elements i are statistically indendent and follow normal distribution.
(7) A work time is regarded as constant.
(8) Some workers can be assigned to a workstation.
(9) Tool change overtime is disregarded.

3.1.2 Model Development for process planning

The subject of investigation is a free conveyor line which is transfered input to the final workstation regardless of a condition of workstations by the use of batch production method under the condition of multi-model production system of mono model production system in FMS. The purpose of this section is to construct CIM, to provide higher productivity through an optimal process planning.

This algorithm can be minimized a total of idle time by a combination of the number of workstations (N), cycle time (C), workstation time (T_k) unless all of them are fixed (Kang and Hahm 1991, 1992).

The procedure for a model is stated as follows (Kang and Hahm 1992):

First, a work element time be made of work time combined uniformly in order to minimize an idle time to the utmost by the operation chart and flow process chart with products sheet and standard time, and then a precedence relations and work elements times are presented.

Second the program for an algorithm is carried out by work elements times and positional weight value to show on precedence relations diagram. Therefore, a line efficiency (LE_j) is calculated by the combination of the number of workstations (N), cycle times (C), repeated heuristic approach repeatedly within cycle times (C) in order to acquire an optimal solution. Also, the proposed algorithm has developed into C-language.

Third, the operation rate of workstations is calculated through the simulation with SIMON language.

Fourth, a total productivity is acquired by Sumanth's theory (1984) with the data of total input and output to expect to the results of line efficiency (LE_j).

Finally, the total analysis is estimated.

The proposed algorithm is listed as follows (Kang and Hahm 1991, 1992):

(1) Simplify some work elements in a group.
(2) Allocate only a station that work elements are repeated.
(3) Re-distribute work elements efficiently.
(4) Group each station by a ranked positional weight values.
(5) Consider next work in the case where the precedent constraint is not feaible or a certain work element time has more than the allowance time remains at the present workstation.
(6) Start with next workstations if there are considerations no longer.

The mathematical statement can be stated as follows:

Step 1.

$$\text{Min. } D = [\text{Min. } N] \cdot [\text{Min}(\text{Max } T_k)] - \sum_{k=1}^{k} T_k \qquad (4)$$

Minimize total idle time by the combination of N, C, and T_k from equation (4)

Step 2.

$$\sum_{k=1}^{k} (T - T_k) = K \cdot T - \textcircled{h}, \text{ (where, } T \geq T_k,\ k = 1, 2, \cdots\cdots, K) \qquad (5)$$

Find alternatives of allocated work elements to minimize equation (5) within the range of precedence relations.

Step 3

$$T_l \leq T \leq T_u \qquad (6)$$

Determine lower limit and upper limit of total work load from equation (6).

Step 4.

$$\text{Min} \sum_{k=1}^{k} \sum_{j=1}^{M} | \textcircled{h}_j - \textcircled{h}_{jk} | \qquad (7)$$

Find a heuristic approach that achieve the optimal line balancing item by item to minimize a interval time of workstations among workstations from equation (7).

Step 5.

$$\text{Max}\ t_{ji} \le C \le \sum_{i=1}^{N} t_{ji} \tag{8}$$

Find the optimal cycle time of products j from equation (8).

Step 6.

$$\text{LE}_j = \frac{\sum_{i=1}^{K} P_{jk}}{N_j \cdot C_j} \times 100\% \tag{9}$$

Calculate LE_j or products j from equation (9).

Step 7.

$$\text{LE}_t = \frac{\sum_{j=1}^{M} G_j \cdot \text{LE}_j}{\sum_{j=1}^{M} G_j} \times 100\% \tag{10}$$

Calculate the total line efficiency (LE_t) of all products from equation (10).

Therefore, inputed data for an optimal process plan is rquired as follows:

(1) Each element time (t_{ij}).

(2) Each precedent relations.

(3) Each optimal cycle time (C_j).

(4) Each positional weight value (W_{ji}).

(5) Work load ($T_L \le T \le T_U$).

3.1.3 A program development for the line utilization

The inputed data in figure 2 is the workstation time, the number of workstations, a probability distribution, the number of trial. This program is aimed to justify a algorithm of challenge method between a general and challenge method in comparison with thw line utilization through simulation using SIMAN language.

Also, transient period is 1500 hours.

The following assumptions are made to calculate the line utilization.

(1) The first input follows statistically normal distribution.

(2) The time intervals in workstations are identically independent and follow exponential distribution.

The line utilization of workstations between a general and challenge method is depicted as shown in figure 2.

```
BEGIN;
PROJECT,        Multi-model Production System;
--------------------------------------------------------------------
ATTRIBUTES : OpTime ;
                ArrTime :
STATIONS :      1, PRESS ;
                2, OXY1 :
                3, DRY1 :
                4, OXY2 :
                5, DRY2 :
                6, ASSEM :
                7, ExitSystem ;
QUEUES :        6 ;
RESOURCES :     Machine(6) ;
--------------------------------------------------------------------
SEQUENCES :     1, 1, NORM(52, 6) & 2, NORM(37, 5) & 3, NORM(40, 5) &
                4, NORM(57, 6) & 5, NORM(40, 5) & 6, NORM(27, 4) & ExitSystem ;
COUNTERS :      JobsDone ;
TALLIES :       FlowTime ;
DSTATS :        NQ(1), PRESS Queue :
                NQ(2), OXY1 Queue :
                NQ(3), DRY1 Queue :
                NQ(4), OXY2 Queue :
                NQ(5), DRY2 Queue :
                NQ(6), ASSEM Queue :
                NR(1) * 100, PRESS OPER. RATE :
                NR(2) * 100, OXY1 OPER. RATE :
                NR(3) * 100, DRY1 OPER. RATE :
                NR(4) * 100, OXY2 OPER. RATE :
                NR(5) * 100, DRY2 OPER. RATE :
                NR(6) * 100, ASSEM OPER. RATE :
                (NR(1)+NR(2)+NR(3)+NR(4)+NR(5)+NR(6))*100/6, AVERAGE RATE;
--------------------------------------------------------------------
REPLICATE, 1, 1500, 100000 ;
END ,
```

Figure 2. A program for the line utilization

3.1.4 On-line control by PLC

This chapter shows how CAPP system can be implemented using one of the most ingenious devices to advance the field of manufacturing automation. The device, of course, is the PLC. The sequence of steps in the PLC is executed so quickly that it is typically appropriate to consider them as simultaneous. Thus, a

PLC continuously and virtually analyzes process input conditions, makes logic decisions, and dispatches output back to the process (Asfahl 1992). In this chapter, a real-time is defined as a processing time in each work element. In this chapter, PLC for on-line control is applied to the behavior of real-time programs in a quantitative way. Finally, a system for CAPP can be realized through the evaluation and analysis from the above mentioned.

4. Computational results and discussion of applications

This paper is addressed with the real manufacturing data in FMS field. A case study has been carried out to validate the challenge method. The lot sizes are between 20 and 39 parts. The manufacturing power of facilities is 30 products but the real size is 3 products. The work load includes two different jobs/part types. The facilities of the case study include 8 different work centeres which are formed based on the common manufacturing process that the 12 different machines perform. The machines run for two shifts and six days a week. Also the workers are 17 persons. Short interval schedules are produced for a period of one month. In order to apply a challenge method to this case study, data from the three products types were extracted from the real manufacturing processes and the production department. This paper deals with three products in real FMS. The inputed data of each sub-system and selection of distributions were listed as previously stated. Above all, computational results have shown between Table 1. The optimal process planning should perform within the range of precedence relations between Figure 3 and 4. The differences of line efficiency(LE_g, LE_c) by the general and challenge method have shown as shown from Table 1. The results of the operating rate of each products with the above outputed times of workstations by the general and challenge method are given from Table 1.

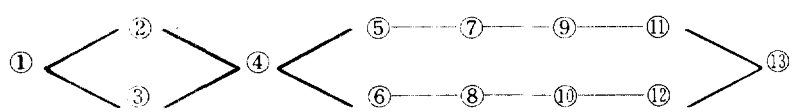


Figure 3. Precedence diagram for general method from three products

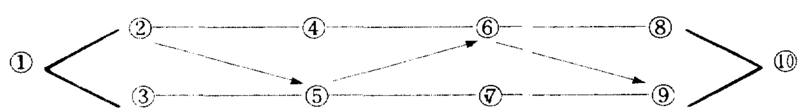


Figure 4. Precedence diagram for challenge method from three products

〈 Table 1 〉 Comparison of the challenge method with general method that is based on the computational results

Class	General method	Challenge method
Layout	Functional layout	U-type layout
Work method	Automation method by conveyor	Automation method by F/C
Cycle time(min) of products A	C = 60	C = 55
Cycle time(min) of products B	C = 60	C = 53
Cycle time(min) of products C	C = 40	C = 34
Efficiency (LE) of products A	70.28%	92.00%
Efficiency (LE) of products B	79.67%	90.19%
Efficiency (LE) of products C	77.5%	91.18%
Efficiency (LE) of all products	75.77%	91.11%
Operating rate of all products	77.63%	85.45%
Control method	Manual work	On-line control by PLC
Worker engaged in products A, B	17 persons	14 persons
Worker engaged in products C	14 persons	12 persons
Number of manufactures	30	30-35
Number of preoucts A	514250 (a monthly)	557075 (a monthly)
Number of preoucts B	514250 (a monthly)	574250 (a monthly)
Number of preoucts A	476175 (a monthly)	547600 (a monthly)
Total productivity		11.67% increase

Finally, a comparison was made between the general and challenge method as a whole Table 1. A summary of the comparisons between results are acquired as follows. Above all, as we have changed current layout in our case problem to U-type of *GT* layout from Table 1, the activity of space can be broaden (Kang and Hahm 1992).

A cycle time of products A, B, and C have decreased 8.33%, 11.67% and 15%, respectively, as shown from Table 1. A decrease of this cycle time can be efficiently improved a productivity in manufacturing process, because it is increaseed the productivity as much. Therefore, efficiency (LE) and the operating rate of all products for challenge method have increased 16.84% and 9.15%, respectively, as shown in Table 1. These results can be validated the optimal process planning.

Especially, on-line control for CAPP system from the challenge method can be maintained lower inventory level and applied to a field system easily. A total productivity measures its productivity improvement by measurement upon Suman's theory. From analysis of results, a total productivity for CAPP system by challene method has increased 11.67% as shown in Table 1.

5. Conclusion

An ideal one to perform a most CAPP system efficiently in FMS system depends on how it can do well a load allocation in planning of process and combine well each sub-system systematically. From the computational evidence to data and system analysis, the following conclusions can be drawn the practicality of the proposed model and its varients.

(1) An increase of total productivity of CAPP system can be brought the competition of enterprises (Kang and Hahm 1990, 1991, 1992).

(2) The efficient re-layout by the U-type of existing facilities and an optimal process planning can smmothe material flows, reduce standard time, and bring about delivery issuse (Kang and Hahm 1992).

(3) A model for CAPP system can be coped with a dynamic environment and CIM systems very efficiently because it has been considered the flexibility, reliability, and productivity.

(4) This paper has proposed an analytical model which optimizes the productivity by minimization of load time in problem of process planning (Kang and Hahm 1991 1992).

(5) An on-line control by PLC has contributed to the synchronization for POS.

(6) The systematic combination between the automation department and the others by the computerization of sub-system can be efficiently maintained the management system.

Consequently, the approach method described in this paper shows new possibilities for a model of CAPP system. Also the proposed CAPP model can be usufully applied to the practical solution of multi-model production system.

If the efficiency(LE) decreases in setting for automation systems, the recovery of fixed cost of FMS following a great investment is difficult and cannot combinate organically in construction of CIM systems (Kang and Hahm 1990, 1991, 1992, Puent and Macconail 1988, Rathmill and Macconail 1987, Hur 1989).

In this study, we can be considered future issues as a model for total productive maintenance (TPM), a detailed failure analysis of automated facilities, a construction of database systems practically in FMS systems, an economic analysis containing intelligent sides, and especially the architecture of CIM.

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