FACTOR/AIM을 이용한 통합자동 생산시스템의 성능분석을 위한 비교연구*

황흥석**

A Comparative Study of FMS Performance Evaluation Modeling Using FACTOR/AIM

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〈Abstract〉

A variety of approaches on performance evaluation modeling have appeared in the technical literature for flexible manufacturing systems(FMS) which can be evaluated only through computer simulation. This study represents a comparative approach for FMS performance evaluation modeling based on reliability, availability and maintainability, and life cycle cost. The methodology proposed in this research includes the following three-step generative approaches. First, a static model to find the initial system configuration is considered under the assumption that the system availability is given as one (failure and maintenance are not considered), and in second step, a stochastic simulation is proposed to serve as a performance evaluation model for FMS with stochastic failure and repair time. In the last step, we developed a simulation modeling using a simulator, FACTOR/AIM to consider a variety of performance factors and dynamic behavior of FMS. Also the applicability and validity of the proposed approaches has been tested and compared through the results of a sample problem using computer programs and procedures developed in each step.

Key words : FMS, Integrated Manufacturing Systems, Simulation, RAM, LCC

1. INTRODUCTION

A performance evaluation model for a FMS or an integrated computer controlled system of machine tools and automated material handling devices was developed. This model uses a step-by-step comparative approach considering the system performance factors: such as reliability, availability and maintainability(RAM), life cycle cost(LCC), system configuration, machining time, WIP, etc. In this study, following three approaches of modeling according to its design/operational environment have been developed and demonstrated its applicability through a sample problem.

First, a static model extended from CAN-Q[1] is pro-

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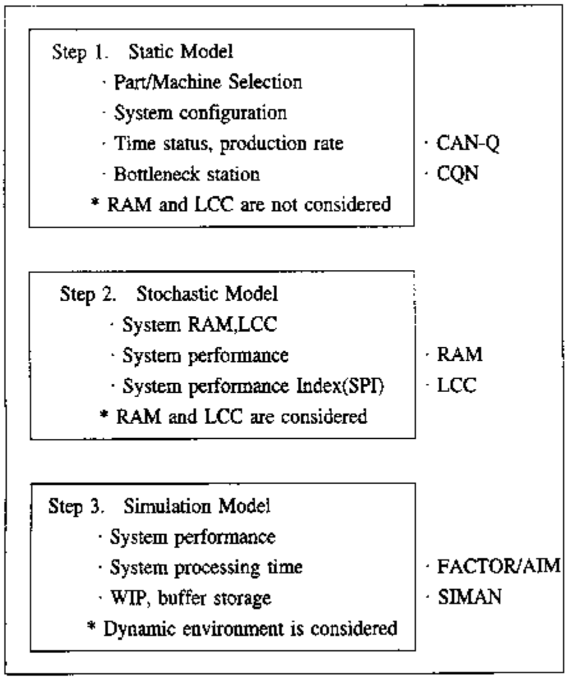
posed to find the initial system configuration to meet the required production rate. This approach provides a full range of methods for the part selection, machine selection, system configuration, and material handling system selection under the assumption that the value of system availability is one(system failures are not allowed). This model can be used to find the feasible system configuration to satisfy the required production demand, or to find the feasible production planning under the given system configuration.

Second, a stochastic model[2] is developed to optimize the system as regards RAM and LCC parameters. The main advantage in this type of approach is that it provides the system designers with a tool that allows them to examine various design alternatives for integrated manufacturing system. In this type of model, we can also examine various designs and operating policies(such as the system configuration, the use of standby back-up machines and preventive maintenance policies). In the third approach, we use FACTOR/AIM simulator[3], which is an integrated software system providing a full range of capacity management applications such as a detailed finite capacity scheduling, an accurate operations planning and loading, demand arrivals, WIP or buffer storage[4] and queueing policies. ⟨Figure 1⟩ outlines the design/analysis tools used in this study for resolving the problems encountered in designing and implementing a FMS. These tools encompass both analytical and simulated analyses.



Step 1. Static Model
- Part/Machine Selection
- System configuration
- Time status, production rate
- Bottleneck station

* RAM and LCC are not considered

- CAN-Q
- CQN

Step 2. Stochastic Model
- System RAM,LCC
- System performance
- System performance Index(SPI)

* RAM and LCC are considered

- RAM
- LCC

Step 3. Simulation Model
- System performance
- System processing time
- WIP, buffer storage

* Dynamic environment is considered

- FACTOR/AIM
- SIMAN

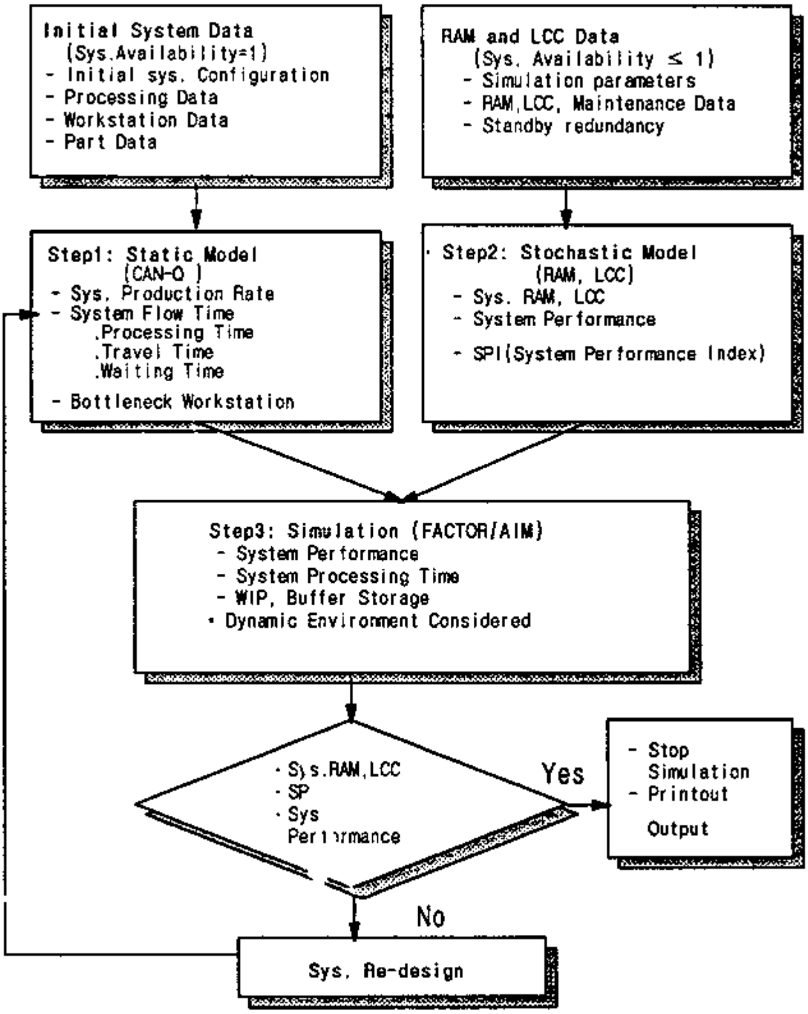
⟨Figure 1⟩ System Design/Analysis Tools

2. MODEL FRAMEWORK

A well known performance evaluation model of FMS is CAN-Q[5], and there have been many other simulation models developed[7][8][9]. In the early stage of the design, alternatives must be evaluated to get higher machine utilization, reduced work-in-process inventory(WIP), lower manufacturing lead time, more flexibility, precise control, and higher system performance with minimum cost[11]. Also Nagarur[10] emphasized the following eight performance measures for FMS in his research : 1) manufacturing lead time, 2) WIP or buffer storage, 3) machine utilization, 4) throughput, 5) system capacity, 6) flexibility, 7) performability and 8) good quality. In addition to Nagarur's, this study considers system availability and life cycle cost as the performance measures for evaluation as shown in ⟨Figure 2⟩.

In the Step 1, a static model is proposed to find the system configuration to meet the required production rate using an extended model from CAN-Q, and in second step, we developed a RAM and LCC model to find the system availability and life cycle cost. In the Step 3, we proposed a simulation modeling using FACTOR/AIM to consider a variety of performance factors in dynamic environment which are not provided in the former steps.

In this study, we have extended CAN-Q model to an interactive program and developed a computer program to calculate the system RAM and LCC [11]. To compute the system reliability[12] [13] and maintainability, we have



〈Figure 2〉 Framework of Proposed Model

derived equations for MTTF, MTBF, R(t), and MTTR and considered three types of maintenance policies[14]: preventive maintenance(PM), corrective maintenance(CM) and also a combined type of these two[2][15]. The equations used to computing the system reliability R(t) and maintainability M(t) up to time t are defined as in 〈Table 1〉 and the equations for availability are shown in 〈Table 2〉.

For describing the system availability, the followings need to be specified: 1) System failure process and reliability parameters, 2) Maintenance process and system maintenance parameters and 3) System configuration (which describes how the subsystems are functionally connected) and rules of operations. The system modeled in this research has the subsystems connected in series and one or more subsystems may have more than one machine connected in parallel as shown in 〈Figure 3〉.

The system reliability can be computed according to the rules of general system reliability theory[14]. The failure, repair and replacement times are generated from some known statistical distributions. The computer program which simulates the events(repair or failure) is developed.

We use the mean portion of time during which the system is in a functioning state as the system availability. 〈Table 3〉 summarizes the state descriptions for an example of two-machine subsystem.

〈Table 1〉 Equations for Reliability and Maintainability

R(t) = Pr[TTF • t]

$= 1 - F(t)$

MTTF = E[TTF]

$$= \int_0^\infty x\, f(x)\ dx'' ,$$

MTTF is applicable to non-repairable systems, and MTBF is used in the same sense of MTTF for repairable systems.

M(t) = Pr[TTR 〈 t]

$$= \int_0^t g(s)ds = G(t)$$

MTTR = E(TTR)

$$= \int_0^\infty y \cdot g(y)\, dy$$

where, MTTF : Mean Time to Failure
MTBF : Mean Time between Failure
MTTR : Mean Time to Repair
TTF : Time to Failur
TTR : Time to Repair
G( ) : Distribution function of TTR
F( ) : Distribution function of TTF

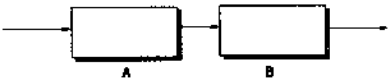
〈Table 2〉 Equations for Availability

$$A_t = \frac{Total\ Uptime}{Total\ Uptime + Total\ Downtime} \text{ during time interval } (0,t)$$

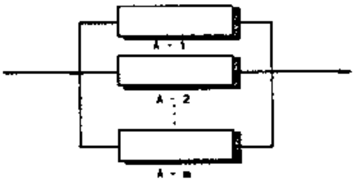
$$A_e = \lim_{t\to\infty} E[\frac{\sum_{i=1}^{U(t)} R_i}{\sum_{i=1}^{U(t)} R_i + \sum_{i=1}^{D(t)} D_i} = \frac{E[R]}{E[R]+E[D]}$$

where, D_i : ith down time interval
R_i : random interval between ith and i-1th down time
A_t : average availability during time interval(0,t)
A_e : steady state or equilibrium availability
U(t),D(t) : the number of up and down time during(0,t)

Here, we assume $\{R_i\}$ ($\{D_i\}$) is independent and identically distributed(i.i.d.) random variables and the distribution of $R_i(D_i)$ is the same as R(D).



a) System Structure



b) Subsystem Structure

〈Figure 3〉 System Block Diagram

〈Table 3〉 State Descriptions of a Two-machine Subsystem

Machine 1 State	Machine 2 State	Subsystem State
Up(working)	Up (working)	Available
Down(under repair or waiting repair, etc.)	Up (working)	Available
Up(working)	Down(under repair or waiting repair, etc.)	Available
Down(under or waiting repair)	Down(under repair or waiting repair, etc.)	Down(not available)

There are trade-off relationships between various availability factors(reliability and maintainability) and life cycle cost. In this research, the life cycle cost is defined as the sum of the acquisition costs, the discounted sum of maintenance costs, break-down repair costs, and logistics support costs during the period of intended use of the system. Mathematically, the total life cycle cost can be expressed as :

$$TCOST = \sum_{j=1}^{N} [\text{TCOST of Subsystem j incurred during intended time } (0,t)]$$

$$= \sum_{j=1}^{N} TCOST_j$$

where, N : the number of subsystems

$TCOST_j$ = (Acquisition Cost)
+ (Discounted Sum of Maintenance Cost)
+ (Discounted Sum of Breakdown Repair Cost)
+ (Discounted Sum of Logistics Support Cost of Subsystem j)

The maintenance cost consists of corrective and preventive maintenance cost, and logistic support cost is given by the percentage overhead costs attributed to maintenance actions.

The logistic support cost for subsystem j is given by:

$$\text{Logistic } Cost_j = \alpha_1 * CM_j + \alpha_2 * PM_j$$

where ; α_1 : percentage overhead costs for corrective maintenance,
α_2 : percentage overhead costs for preventive maintenance,
CM_j : corrective maintenance cost of subsystem j,
PM_j : preventive maintenance cost of subsystem j.

Thus, we can represent the total cost incurred during intended time interval (0,t) as :

$$\begin{aligned} TCOST_j &= AC_j + DSCM_j + DSPM_j + \alpha_1\ DSCM_j + \alpha_2\ DSPM_j + DSRC_j \\ &= AC_j + (1+\alpha_1)DSCM_j + (1+\alpha_2)DSPM_j + DSRC_j \end{aligned}$$

where ; AC_j : acquisition cost,
$DSCM_j$: discounted sum of CM_j,
$DSPM_j$: discounted sum of PM_j,
$DSRC_j$: discounted sum of break down repair cost.

To find the sum of $DSCM_j$ and $DSRC_j$ for subsystem j during intended time interval (0,t), we need the instants of breakdowns t's and the costs of specific breakdowns t's.

If we assume that MTBF are independent and identically distributed(i.i.d.) random variables, we can express the mean value of the sum of $DSCM_j$ and$DSRC_j$ as :

$$E[DSCM_j + DSRC_j] = E[USCM_j + USRC_j]\left[\frac{1-e^{-r \cdot n}}{e^{r}-1}\right]$$

where ; $DSCM_j$: corrective maintenance cost for breakdown od t
$DSRC_j$: repair cost for breakdown on timet
r : interest rate i*(E(R)+E(D))
n : greatest integer not greater than $\frac{t}{E(R)+E(D)}$

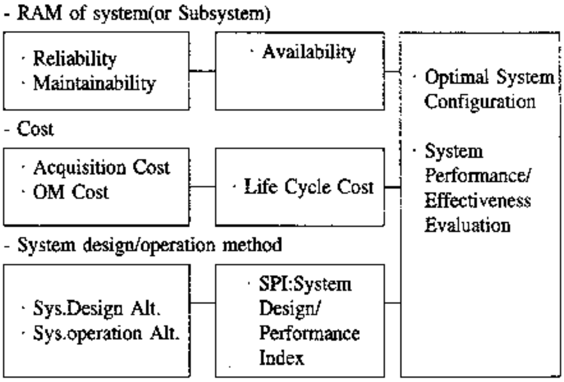
Similarly, the mean value of $DSPM_j$ for subsystem j is given by :

$$E(DSPM_j) = E(USPM_j) \cdot \left[\frac{1-e^{-g \cdot n}}{e^{g}-1}\right]$$

where, : q : interest rate i * PM interval
n : greatest integer not greater than $\frac{t}{PM\ interval}$

Therefore,

$$\begin{aligned} E(TCOST) &= \sum_{j=1}^{N} E(TCOST_j) \\ &= \sum_{j=1}^{N} \{AC_j + (1+\alpha_1)E(DSCM_j) + (1+\alpha_2) \\ &\quad E(DSPM_j) + E(DSRC_j)\} \end{aligned}$$



〈Figure 4〉 RAM and LCC Model

The decision making in FMS design is made generally on the basis of the required availability with minimum cost. Therefore, we used, in this research, a new tool for an cost-effective system design considering system life cycle cost and its availability together. Thus, we used a system performance index(SPI) such as present worth of LCC, system availability, COA(LCC per system availability), and COP(LCC per unit product) to make trade-off analysis between LCC and various availability or production rate. Such trade-off is useful for examining two or more competing alternatives.

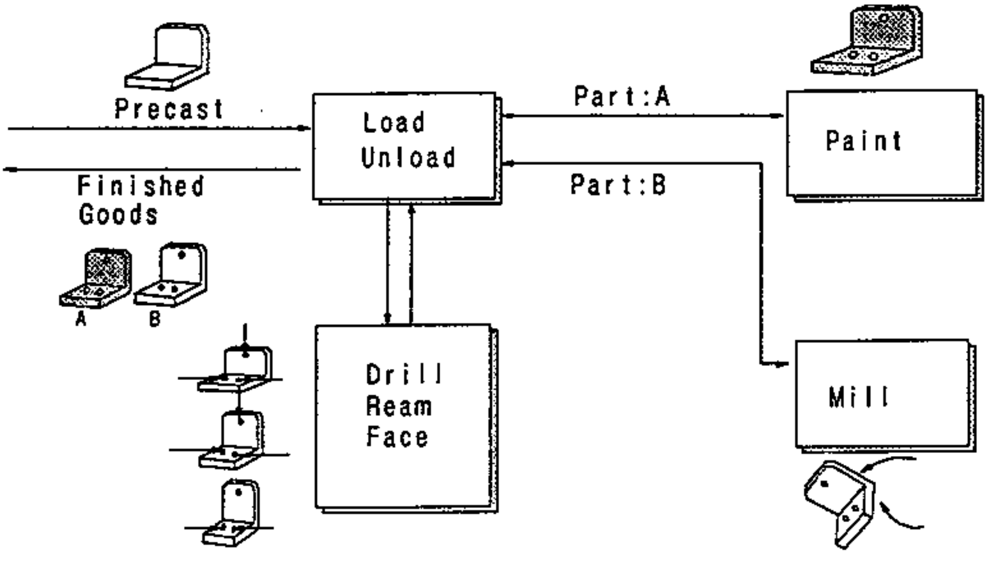
The number of production units and the costs generally depend on the system availability, thus SPI can be used as an optimality criterion for a system design and configuration alternatives on the basis of either cost or availability. 〈Figure 4〉 represents the relationships between RAM, LCC, and SPI.

3. APPLICATION TO L-TYPE BRACKET MANUFACTURING

For the illustration purpose, a L-type bracket manufacturing system is illustrated in the block diagram shown in 〈Figure 5〉. The example system is an integrated manufacturing system which produces two types of L-brackets. The part A is made from pre-cast parts through the 5 operations such as drilling, reaming, facing, milling, and painting. And the part B is made through the 4 operations without painting. The required production rate is 7 unit/hour at 100% system availability, and the production ratio for both part type A and B is 3:2. The input data for the initial configuration and for each part operations are summarized in 〈Figure 6〉.

Step 1: Static Model Using CAN-Q.

In this step, we have analyzed and improved the system configuration to find a set of conditions for better system performance using CAN-Q. We can find the production rate, average flow time, and the bottleneck workstation in each iteration in this model, and repeat redesigning the system by adding a machine to the bottleneck operation until the system production rate satisfies the required throughput. The output of the initial system is compared with that of five system alternatives. The results are summarized in 〈Figure 6〉 and 〈Figure 7〉 respectively.



〈Figure 5〉 L-Type Bracket Production Flow.

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SAMPLE PROBLEM FOR BRACKET(INITIAL CONFIGURATION) APRIL,1996.
--------------------------------------------------------------------------------------------
INPUT DATA SUMMARY:

                         NUMBER OF    VISIT     AVERAGE      RELATIVE      WORKLOAD
            STATION      SERVERS      FREQ.     PROC.TIME    WORKLOAD      PER SERVER

   1        L/UNL           1         .27778     5.00000     1.38889       1.38888
   2        D.R.F           1         .27778    20.00000     5.55556       5.55555
   3        MILL            1         .27778    18.00000     5.00000       5.00000
   4        PAINT           1         .16666    15.00000     2.50000       2.50000
--------------------------------------------------------------------------------------------
NUMBER OF ITEMS IN SYSTEM = 16
MEAN NUMBER OF OPERATIONS TO COMPLETE AN ITEM = 3.60000
--------------------------------------------------------------------------------------------
SYSTEM PERFORMANCE MEASURES:
PRODUCTION RATE = 2.8076 ITEMS PER HOUR
PRODUCTION RATES BY PRODUCT TYPE

                                   NUMBER       VALUE

      PRODA                        1.684        505.188
      PRODB                        1.123        224.524

      TOTAL VALUE = 729.715
--------------------------------------------------------------------------------------------
AVERAGE TIME IN SYSTEM = 213.78 MINUTES

            PROCESSING                                           52.00
            TRAVELING                                             3.60
            WAITING                                             158.18
--------------------------------------------------------------------------------------------
THE BOTTLENECK STATION IS 2
--------------------------------------------------------------------------------------------
STATION PERFORMANCE MEASURES:

      STATION            STATION      SERVER                    AVE. NO. OF
      NUMBER              NAME      UTILIZATION                BUSY SERVERS

         1                L/UNL        .234                        .234
         2                D.R.F        .936                        .936
         3                MILL         .842                        .842
         4                PAINT        .421                        .421
         6                AGV          .168                        .168
--------------------------------------------------------------------------------------------
```

〈Figure 6〉 CAN-Q Output of Initial System Configuration

In this step, we can make two kinds of trade-offs as follows:

1) To find the optimal system configuration to satisfy the required production rates,
2) To find the optimal production planning(product mix) with a given system configuration.

Classification	Initial Sys.Alt.	1st Sys.Alt.	2nd Sys.Alt.	3rd Sys.Alt.	4th Sys.Alt.	5th Sys.Alt.
System Configuration	L/UNL 1	1	1	1	1	1
	D.R.F 1	2	2	3	3	3
	Mill 1	1	2	2	2	3
	Paint 1	1	1	1	2	2
	AGV 1	1	1	1	1	1
Pro.Rate:Unit/hr	2.807	3.304	5.080	5.543	6.160	7.277
Sys. Flow Time	213.78	181.60	118.12	108.25	97.40	82.45
- Process	52.00	52.00	52.00	52.00	52.0	52.00
- Traveling	3.60	3.60	3.60	3.60	3.60	3.60
- Waiting	158.18	126.00	62.52	52.65	41.80	26.85
Bottleneck St.	W/S #2	W/S #3	W/S #2	W/S #4	W/S #3	W/S #2

〈Figure 7〉 Comparison of CAN-Q Outputs.

Step 2: A Stochastic Model with RAM and LCC

To make CAN-Q model more robust, we considered the system RAM and LCC in simulation (the input data omitted). The sample outputs of RAM and LCC for initial and final system configuration are shown in 〈Figure 8〉, and the outputs are summarized in 〈Table 4〉.

The impact of system RAM and LCC on the system performance is very serious. The production rate of the final system is 7.27 unit/hr, while it decreased to 6.25 unit/hr in Step 2 where a flexible availability is considered for the system performance factors.

The sample outputs of initial and final system shown in 〈Table 4〉 provide the following benefits:

1) Improvement of about 150% on efective time for production.

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RAM AND LCC ANALYSIS
(FINAL SYS. OF BRACKET)              May, 1996

  SYSTEM AVAILABILITY:             .8598281
  COST RATE:                       1.9205410 W PER HR
  LCC/UNIT:                        0.3073 W PER UNIT
  PW OF LCC:                     8258.3260 W

  SYSTEM COST:
    TOTAL CAPITAL COST.              1800.000 W
    OPERATING COST:
    TOTAL CM COST...                 4034.896 W
    TOTAL PM COST....                 146.627 W
    TOTAL MATERIAL COST...            476.803 W

  WORK STATION                     AVAILABILITY
  WORK ST.                         AVAILABILITY
    L/UL                                .991
    DRF                                 .977
    MILL                                .990
    PAINT                               .976
```

```
RAM AND LCC ANALYSIS
(INITIAL SYS. OF BRAKET)             May, 1996

  SYSTEM AVAILABILITY:             .5669794
  COST RATE:                       1.5976960 W PER HR
  LCC/UNIT:                        1.0042 W PER UNIT
  PW OF LCC:                     4537.4550 W

  SYSTEM COST:
    TOTAL CAPITAL COST..              750.000 W
    OPERATING COST:
    TOTAL CM COST...                 2689.617 W
    TOTAL PM COST....                  52.584 W
    TOTAL MATERIAL COST...            295.254 W

  WORK STATION                     AVAILABILITY
  WORK ST.                         AVAILABILITY
    L/UL                                .934
    DRF                                 .810
    MILL                                .684
    PAIN                                .889
```

〈Figure 8〉 Sample Output of RAM and LCC of Initial and Final Systems

〈Table 4〉 Output Comparison of Initial and Final Systems

Performance Factor	Initial Configuration	Final Configuration
- Sys. Availability	0.5669	0.8598
- LCC(unit 1,000 ₩)	4537.4550	8258.326
- Cost Rate(LCC per Operation Time, ₩/hr)	1.597	1.920
- LCC/unit product: (COP₩/hr)	1.004	0.307
- Production Rate(unit/hr)	1.591	6.250

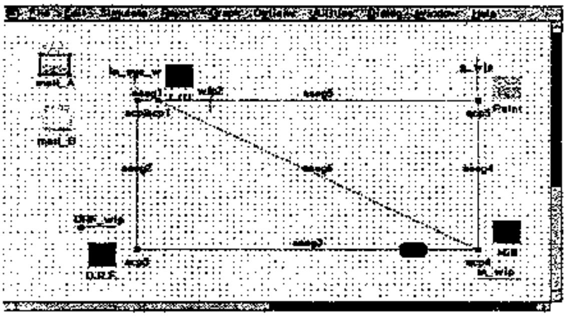
2) Decrease in life cycle cost per unit product from 1.004 per unit product to 0.307 per unit product. That is an improvement about 300% on market price competition level. It should be noted that there is a significant increase in present worth of life cycle cost during the simulation time for revised design.

Step 3: Simulation Using FACTOR/AIM

FACTOR/AIM is an integrated software system developed by Pritsker[3] and it provides a variety of modeling capabilities and output modules. It has graphic user interface tools for capacity engineering, schedule development and schedule management of automated manufacturing systems. Its major output modules are summary reports, performance reports, status reports and trace reports with graph module.

The same example problem with the former steps was run by FACTOR/AIM. 〈Figure 9〉 shows FACTOR/AIM model for L-bracket problem.

For the sample run of the bracket example, FACTOR/AIM input data are prepared as in 〈Table 5〉, and 〈Table 7〉. The several kinds of FACTOR/AIM outputs, such as the system layout, alternative, material, resource and pool summaries are available from this model. The outputs of initial and final system are given in 〈Table 8〉.



〈Figure 9〉 FACTOR/AIM Model of Example Problem

〈Table 5〉 FACTOR/AIM Input Data for Bracket Example

- Total Simulation Time : 5,000 hr
- Number of AGV and its Speed : 1 AGV , 50ft/Min
- Order Arrival Number of Parts Released
  Part A = 21 Unit / day
  Part B = 14 Unit / day
  Load Size = 1 Unit

〈Table 6〉 Setup Time and Processing Time(N(μ , σ))

St. No.	Part A	Part B
	Processing Time(hr/LD)	Processing Time(hr/LD)
1	N(0.088, 0.008)	N(0.088, 0.008)
2	0.333	0.333
3	0.300	0.300
4	0.250	-

N(μ ,σ) means normal distribution with mean μ and variance σ

〈Table 7〉 WIP and Maintenance Data

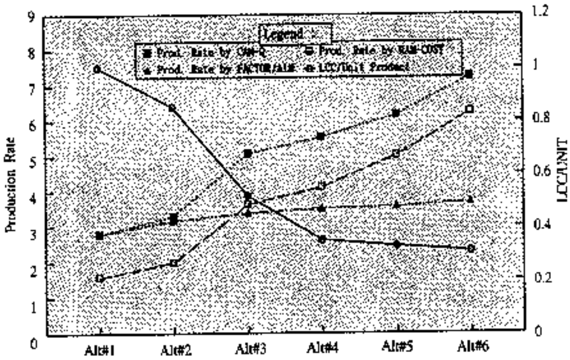
St. No.	WIP Size	PM		CM
		Interval (Day)	PM Time (hr)	CM Time(hr)
1	5	15	2	N(0.5 ,0.05)
2	5	15	2	N(0.5 ,0.05)
3	3	15	2	N(0.5 ,0.05)
4	3	15	2	N(0.5 ,0.05)

N(μ ,σ) means normal distribution with mean μ and variance σ

When we compare the results of the L-bracket example outputs, there are some defferences between the outputs of CAN-Q in Step 1, and that of FACTOR/AIM in Step 3. The CAN-Q model over-estimates the production rate

〈Table 8〉 FACTOR/AIM Output Summary

Output Factor	Initial System	Final System
System Configuration	L/UNL : 1 D.R.F : 1 Mill : 1 Paint : 1	L/UNL : 1 D.R.F : 3 Mill : 3 Paint : 2
Production Rate(Unit/hr)	2.799	3.686
Average Waiting Time(hr)	8.462	4.885
Processing Time (hr)	4.409	4.100
System Utilization Rate	L/UNL : 0.441 D.R.F.: 0.645 MILL : 0.617 PAINT : 0.413	L/UNL : 0.391 D.R.F.: 0.304 MILL : 0.415 PAINT : 0.286



〈Figure 10〉 Comparison of System Performances

〈Table 9〉 Comparison of Sample outputs of Six System Alternatives by CAN-Q and FACTOR/AIM ( ) : output of CAN-Q

Sys. Performance	Alt.1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
Prod. Rate (unit/hr)	2.799 (2.807)	3.179 (3.304)	3.397 (5.080)	3.499 (5.543)	3.577 (6.160)	3.686 (7.277)
Bottleneck W/S	W/S 2 DRF (W/S 2 DRF)	W/S 3 Drill (W/S 3 Mill)	W/S 4 Paint (W/S 2 DRF)	W/S 2 DRF (W/S 4.PAINT)	W/S 2 DRF (W/S 3 MILL)	W/S 1 L/U (W/S2 DRF)
Processing Time (hr/unit)	4.41 (0.866)	4.14 (0.866)	4.11 (0.866)	4.18 (0.866)	4.10 (0.866)	4.11 (.806)
Waiting Time	8.46 (2.636)	8.501 (2.100)	5.81 (1.042)	5.02 (0.977)	4.89 (0.696)	4.46 (0.477)
Required Production Rate	7.0 unit/hr (at 100% Availability)					

a little more than the model of FACTOR/AIM. For example, the production rate of alternative 6 obtained by CAN-Q is given by 7.277 unit/hr, but it decreases to 3.686 unit/hr in the case of FACTOR/AIM as shown in 〈Table 8〉. The results of sample output of FACTOR/AIM are shown in 〈Table 9〉 and they are superior to the other models. The reason is that it is capable of considering a variety of system design factors and operational conditions, such as load size, WIP, queueing policies, maintenance policies, and blocking. The result of comparison of sample output was shown in 〈Table 9〉.

A comparative study of FMS performance using CQN, RAM-LCC, and simulation models was done, The result of system predicted performances under the six alternative configurations shows the final alternative(6th alt.) to be useful for high production rate and low LCC/unit. These results are summarized on Figure 10.

4. CONCLUSIONS

This research proposed a three-step generative performance evaluation model for FMS using CAN-Q, RAM-LCC, and FACTOR/AIM. In Step 1, a static model is proposed to find a initial system configuration to meet the required production rate under the assumption of no failures and repairs. In the second Step, we developed a RAM-LCC model to consider the system availability and life cycle cost in system performance evaluation. For the systematic decision support for designers, we have developed a system performance index from the results of Step 2. We used this as optimality criteria for a system alternatives on the basis of either cost or availability. In third step, a simulation model was used to consider a variety of real world for the system performance evaluation.

A sample problem of L-type bracket manufacturing is run by the proposed three-step model. In the first step, the system availability is given as one(system failures are not considered). CAN-Q model is a little simple and easy to use but a little over-estimates the system performance than FACTOR/AIM. The results obtained by sample runs have shown a superior performance in case of models by FACTOR/AIM prevailing in a variety of output modules. The simulation method by FACTOR/AIM will provide a good tools to analyze the FMS performance. Furthermore, it can be extended easily for various problems solving with a variety form of outputs.

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