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## Models for Economic Evaluation of Flexible Manufacturing Systems

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MODELS FOR ECONOMIC EVALUATION  
OF FLEXIBLE MANUFACTURING SYSTEMS

BY

DANIEL PABLO SALOMON  
B.I.E., Universidad Iberoamericana, 1981

RESEARCH REPORT

Submitted in partial fulfillment of the requirements  
for the degree of Master of Science  
in the Graduate Studies Program of the College of Engineering  
University of Central Florida  
Orlando, Florida

Fall Term  
1983



## ABSTRACT

The current methods of economic justification are not suitable for identifying the benefits of automated manufacturing systems. // This study is an introduction to Flexible Manufacturing Systems (FMS), its main features, and the economic benefits that can be expected. /

→ The models are designed to perform the following analyses:

1. Analysis of direct cost savings.
2. Analysis of the impact of incremental implementation on capital recovery costs.
3. Analysis of the cost effects of improving machine utilization and reducing manufacturing lead time.
4. Sensitivity analysis of the after-tax equivalent uniform annual cost of a FMS and a conventional system.

// → The models are built to (1) utilize readily available data or output data from simulation studies, (2) provide reliable results, and (3) simplify reality to a small package of information that facilitates effective decision making. // To explain the models and to analyze empirically the economic performance of an FMS, the models were fed with published, assumed, or generated data. // The output of each analysis is summarized in tables, depicted in graphs, and specific conclusions are synthesized at the end of each model presentation.



## ACKNOWLEDGMENT

I want to thank:

Dr. John Biegel who helped me to open my eyes to the exciting capabilities of FMS, directed my work and friendly supported me during graduate studies.

Dr. J. A. Sepulveda who guided my efforts when specific difficulties arose and gave me support since I first arrived to UCF.

Dr. Douglas McNeil who motivated my interest in Economic Analysis.

Brenda Komers whose editorial assistance proved invaluable.

Most of all, I want to thank my wife, Esther, who did not only helped me as a "very-smart typist" and performed some computations but also provided me with understanding and a unique source of motivation to complete this work.



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## SYMBOLS AND ABBREVIATIONS

A/F	Sinking fund factor
A/P	Capital recovery factor
ATEUAC	After-tax equivalent uniform annual cost
ATPC	After-tax present cost
CS	Conventional system (see note in page 17)
DC	Direct cost in a CS
DLC	Direct labor cost in a CS
DLCS	Direct labor cost savings
f%	Inflation
FMS	Flexible manufacturing system
F/A	Compound amount factor for an annuity
F/P	Compound amount factor
FSC	Floor space cost
i%	Cost of capital
ICC	Inventory carrying cost
ICI	Increased implementation costs due to incremental implementation
IDC	Average inventory direct cost
INV <sub>CS</sub>	Investment in a CS
INV <sub>FMS</sub>	Investment in a FMS
IR	Ratio of the investment in a FMS to the investment in a CS

L	Percentage of the total workpiece's cost contributed by direct labor in a CS
LC <sup>+</sup>	Percentage increase of unit labor cost due to a higher degree of specialization
L/M	Labor content/Material content ratio
LT <sup>-</sup>	Percentage decrease of labor content of the workpiece
M	Percentage of the total workpiece's cost contributed by material in a CS
MC	Material costs
MU	Machine utilization
N	Economic life of investment
NCF <sub>x</sub>	Net cash flow in year x
n <sub>m</sub>	Total number of machines through which the part must be routed
P	Investment
P/A	Present value factor for an annuity
P/F	Present value factor
Q	Batch size
S	Scrap
SV	Salvage value
TOC <sub>CS</sub>	Total operating cost of a CS
TOC <sub>FMS</sub>	Total operating cost of a FMS
TOCR	Ratio of the total operating cost of a FMS to the total operating cost of a CS
T <sub>m</sub>	Machining time
T <sub>mh</sub>	Percent of the machine time that there is a part on the machine



$T_{ml}$	Manufacturing lead time
$T_{mw}$	Percent of the machine time that the machine spends without parts
$T_{no}$	Non-operation time
$T_o$	Operation time
$T_{su}$	Machine setup time
$T_{th}$	Tool handling time
$T_w$	Workpart handling time



CHAPTER I  
INTRODUCTION

Evolutionary developments in manufacturing technology, as well as the rapid growth in the capabilities of digital computers, are making it technically feasible to successfully achieve the development and implementation of computer controlled automated production systems. There are social trends and economic incentives that are helping to encourage the utilization of these systems. However, diverse factors are obstructing a more widespread use of automated production systems. These social trends, economic incentives and obstructive factors will be analyzed.

Social Trends

Today, the major long-range social trend that affects the manufacturing field is the coming of the post-industrial society. Such a society is based on services. The importance of information and knowledge outweighs the importance of raw muscle power or energy.

The transition to a post-industrial society (a services society) from an industrial society (goods-producing society in which machinery predominates) has been taking place in the United States since the late 1960's.



In the 1965-81 period, manufacturing industries' share of total employment declined from 29.7% to 22.1% (7.6% loss based upon total employment but a 26% decrease in manufacturing employment based upon manufacturing employment in 1965); while the service producing sector increased its share from 63.9% to 72% (8.1% based upon total employment but a 13% increase based on services employment in 1965).

During this period, employment in service industries increased 69% (based upon number of employees) providing jobs for more than 27 million more workers. The non-agricultural goods producing sector of the economy increased employment only 17%, and provided fewer than 4 million new jobs in the 1965-81 period (see Table 1).

This transition is marked by several associated social trends that directly affect manufacturing:

1. Workers prefer to work in service industries rather than in manufacturing industries.

The percentage of the work force employed in manufacturing has been declining, from 30% of the work force in 1947 to 23% in 1979. Projections for the year 2000 vary from 2% to 10% (Groover 1980).

2. Employers have clearly recognized the worker's need for motivation.



TABLE 1

NUMBER AND PERCENT DISTRIBUTION OF PERSONS ON PAYROLLS OF NON-AGRICULTURAL  
ESTABLISHMENTS BY INDUSTRY DIVISION: ANNUAL AVERAGES 1965 AND 1981

Industry	Percent Distribution		Number in Thousands		Change Based on Number of Employees
	1965	1981	1965	1981	
Mining	1	1.2	632	1,104	+75%
Construction	5.3	4.7	3,232	4,307	+33%
Manufacturing	29.7	22.1	18,062	20,261	+12%
<u>Goods Producing Total</u>	36.1	28	21,926	25,672	+17%
Transportation and Public Utilities	6.6	5.6	4,036	5,151	+28%
Wholesale and Retail Trade	20.9	22.7	12,716	20,738	+63%
Finance, Insurance and Real Estate	4.9	5.8	2,977	5,531	+79%
Services	14.9	20.3	9,036	18,598	+106%
Government	16.6	17.5	10,074	16,054	+59%
<u>Service Producing Total</u>	63.9	72	38,839	65,872	+69%
<u>TOTAL NON-AGRICULTURAL</u>	100	100	60,765	91,544	+51%

SOURCE: U.S. Department of Labor (1982).



Achievement (the personal satisfaction obtained from the job) and the job content itself are two important motivational factors. These factors are difficult to achieve in repetitive and mechanized jobs.

3. Governments are taking active roles in requiring improved working conditions.

Dangerous, unhealthful, uncomfortable, and undesirable conditions are not uncommon in the manufacturing environment. This fact partly explains why workers prefer employment in the service industries. Employers have directed some attention to this situation. However, in most of the industrialized countries, government has taken a more active role by requiring the development of the technology necessary to achieve improved working conditions.

#### Economic Incentives

In terms of production volume, manufacturing plants can be classified into three categories:

1. Job shop production.
2. Batch production.
3. Mass production.

Mass production transfer lines are a good example of productivity because they are specifically designed to repetitively make one part in the most efficient manner. Mass production calls for a set of production machines



dedicated to the manufacture of a single part; so if the installation cost is to be recovered, the annual production of the part clearly must be large enough to keep the machines running almost continuously. The highly mechanized lines are inflexible and can not tolerate variations in part design. A changeover in part design requires the line to be shut down and retooled. If design changes are extensive, the line may be rendered obsolete.

For many manufactured items there simply is not sufficient confidence in a continuous high demand to warrant the installation of special machines. If this is the case then general purpose machines must be used because they are capable of making a wide variety of parts using suitable tooled and skilled workmen.

To machine a single unit with general purpose tools may cost one hundred times as much as to manufacture the same part by the most efficient mass production methods (see Fig. 1).

Between these extremes lie parts of many kinds that are batch produced; both the costs and the quantities are moderately high. It has been estimated that between 50% and 75% of the total national outlay for parts manufacturing is accounted for by batch production methods where the individual batch size is 50 units or fewer (Cook 1975). Metalworking manufacturing accounts for about 40% of the total manufacturing employment.



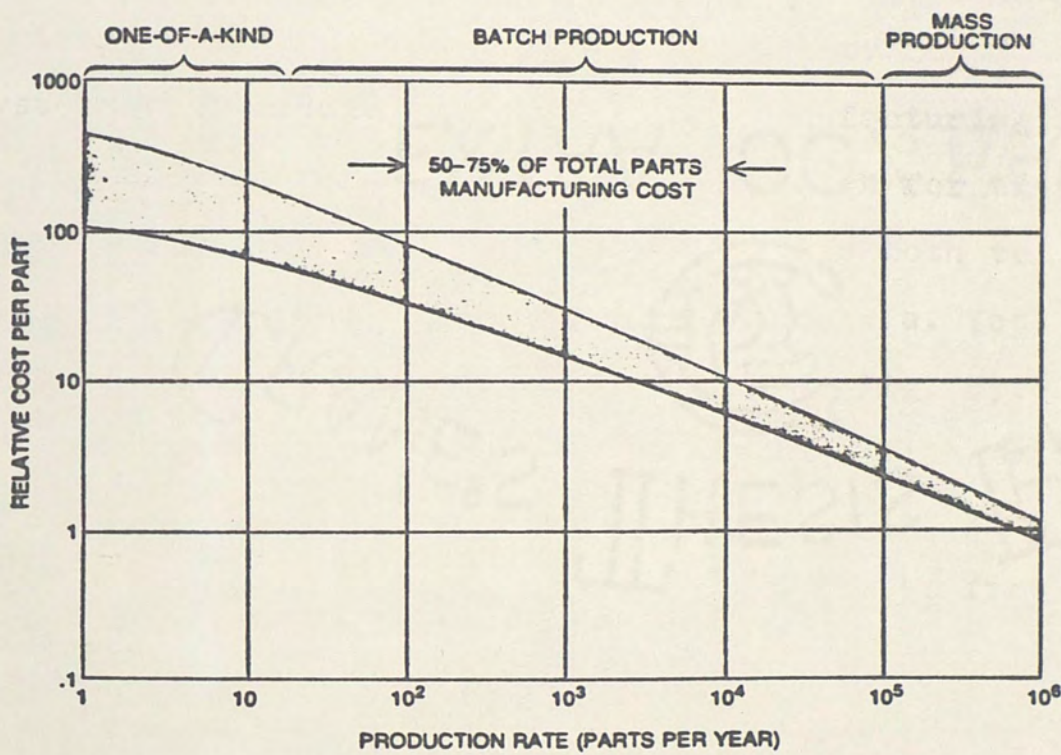


Fig. 1. Cost of machining a part for different volumes of production (taken from Cook 1975).



The average workpiece in batch-type metal cutting production shop spends only about 5% of its time on machine tools, and only about 30% of that 5% (or 1.5% of the overall time) is actually spent as productive time in removing metal. This situation (as illustrated in Fig. 2) is hardly economic or productive.

A Flexible Manufacturing System (FMS) is designed to solve the conflict between productivity and flexibility that exists in the mid-volume, mid-variety manufacturing systems (the middle ground of batch manufacturing). This is the area where part variety is too high for transfer lines and also where production volume is both too low for transfer lines and other dedicated processes. Yet, volume is too high for job shop production (see Fig. 3).

Another important economic consideration is that the cost of manufacturing labor is increasing faster than manufacturing productivity. In the United States from 1973 to 1981, the average manufacturing output per hour increased by 1.7% while the average compensation per hour increased 9.6% (see Table 2).

The only way to stop this process is by increasing manufacturing productivity, or decreasing the labor intensiveness of manufacturing, or both. Both tasks can be achieved with the development and implementation of highly productive, automated manufacturing systems. One example



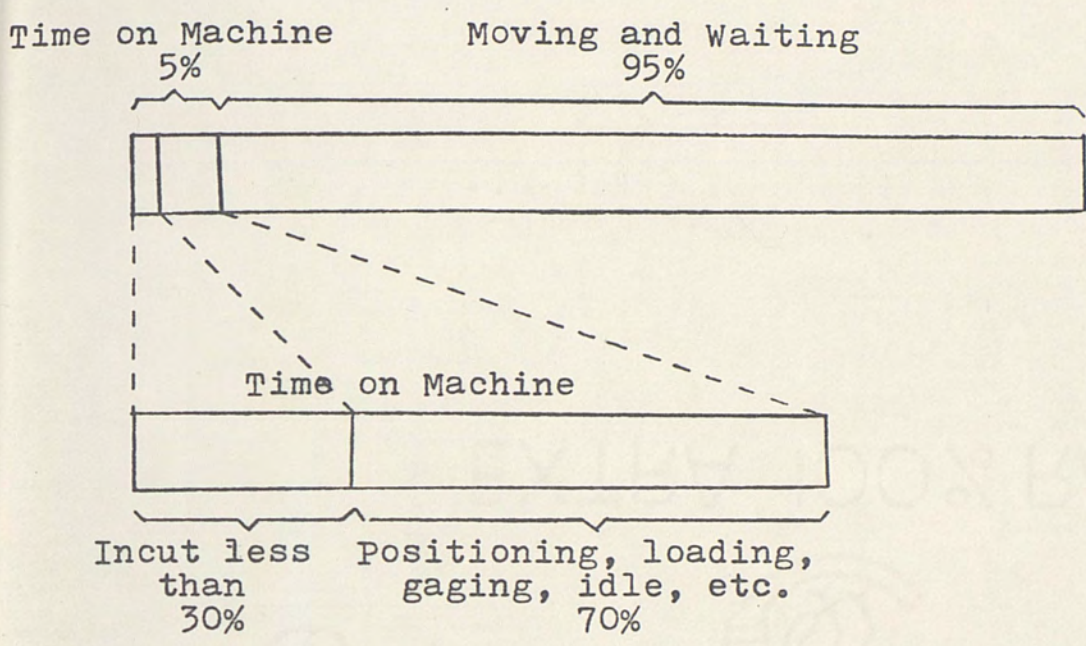


Fig. 2. Life of the average workpiece in the average batch-type production shop (redrawn from Merchant 1977).



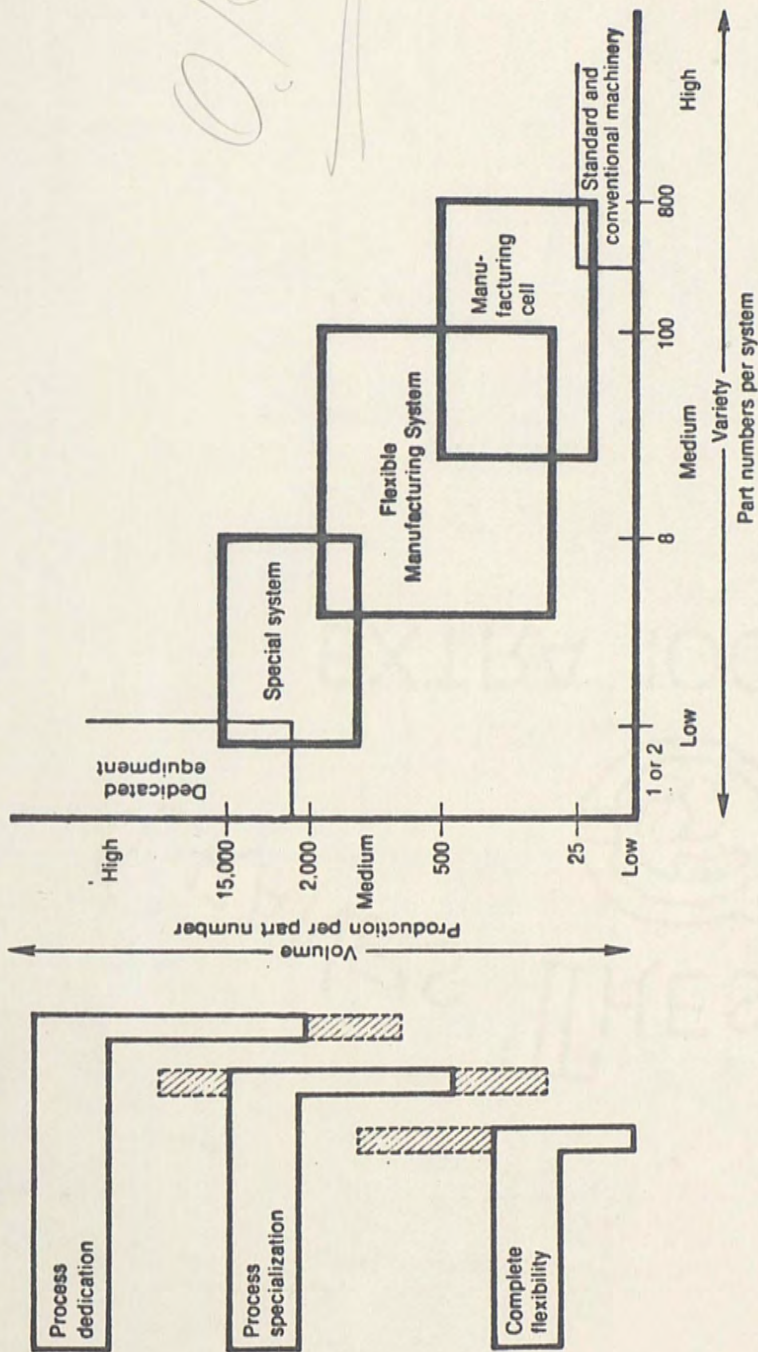


Fig. 3. The conflict between productivity and flexibility can be solved by the application of the Flexible Manufacturing System concept (taken from Hegland 1981).



TABLE 2

AVERAGE ANNUAL PERCENT CHANGE IN: OUTPUT PER EMPLOYEE  
 HOUR, COMPENSATION PER HOUR AND UNIT LABOR  
 COST IN MANUFACTURING, 1973-81

	Average annual percent change (1973-81)			
	Output per hour	Compensation per hour	Unit Labor Costs U.S. Dollars	National Currency
United States	1.7	9.6	7.7	7.7
Canada	1.4	11.1	6.5	9.6
France	4.5	15.1	9.4	10
Germany	4.6	9.4	9.2	4.7
Japan	6.8	9.7	7.2	2.7
United Kingdom	2.2	19.1	15	16.1

SOURCE: U.S. Department of Labor (1983).



of this type of system is the Flexible Manufacturing System (FMS), also known as Flexible Machining System or Variable Mission Manufacturing System (VMMS).

### Factors Against the Automation of the Manufacturing Operations

Despite the need to improve working conditions and productivity in manufacturing operations, many corporations have not implemented any significant changes in their methods of operation. There are a number of factors that help to explain why top management has tended to avoid the difficult decisions required to automate their manufacturing operations. The main factors are discussed in the following sections.

#### Non-economic Factors

1. Unfamiliarity with existing technology.

2. Resistance to change. This follows from factor 1.

Due to feelings of uncertainty, insecurity and of increased job complexity.

3. Absence of manufacturing strategy. Most companies do not have a clear plan for the development of their manufacturing capabilities and the integration of these with other business functions (product design, marketing, etc.) (Groover and Hughes 1981).



4. Pressure of labor unions. Automated manufacturing systems obviously reduce the labor intensiveness in manufacturing operations. Labor leaders, in general, are not willing to accept the displacement of their workers.

#### Economic Factors

1. Insufficient investment incentives. Government deregulation of banks and saving associations and the evolution of the economy and the tax laws have resulted in an economic climate such that many companies do not have the incentive to reinvest in their own manufacturing facilities.

Mutual funds, certificates of deposit, money market funds, U.S. Treasury bills and other financial assets are attracting many companies' investments away from their own line of business.

2. Economic decision-making for the short term. In order to obtain immediate returns and short-term advantages, many manufacturing executives prefer to maximize output from current facilities, instead of investing in innovative manufacturing technology that offers long-term payoffs.

#### Objective of Study

The current methods of economic justification today are not suitable for identifying the benefits of automated



manufacturing systems. Therefore, the objective of this study is to integrate the economic advantages of FMS into mathematical models, that will present a robust economic analysis of the cost and benefits of the development and implementation of FMS.



## CHAPTER II

### MODELS FOR ECONOMIC EVALUATION OF FMS

A Flexible Manufacturing System (FMS) consists of a group of processing stations (numerically controlled machine tools) connected together by an automated workpart handling system. This group of machines and related equipment are brought together to completely process a group or family of parts. It functions as an integrated system under computer control. The primary components of a FMS include:

1. Machine Tools.
2. Material Handling System (MHS).
3. Computer Control System.

#### General Characteristics of a FMS

Group Technology (GT) is a prerequisite for a FMS. GT is a manufacturing philosophy in which similar parts are identified and grouped together into part families to take advantages of their similarities. A part family is a collection of parts which are similar either because of geometric shape and size or because similar processing steps are required in their manufacture.



Any workpiece among the part families can be randomly introduced to the FMS. This is done by clamping it in place onto the fixture that is specifically designed to be able to hold different parts within a family. The fixture is then attached to a pallet and/or cart that serves to transport the part from station to station. This workpart setup is accomplished in the load/unload area and therefore is external to the FMS. The pallets and/or carts form part of the material handling system that is controlled by the computer system to achieve independent movement of the palletized workparts as well as temporary storage or banking of the parts. Other main functions of the computer control system are:

1. Storage and distribution of the numerical control (NC) part programs.

2. Monitoring and control of the tooling status and location.

3. Monitoring and reporting of system performance.

Human intervention is reduced to performing the following functions to support the operation of the FMS.

1. Load raw workparts onto the system.

2. Unload finished parts from the system.

3. Equipment maintenance and repair.

4. Tooling setup. Preset off-line, by loading the preset tools required for the job into the tool drum at that station.



### General Requirements of the Models

To design, develop, install and test a FMS requires a considerable investment; a commitment of the firm's capital to a long-term project. The initial cost outlay of a FMS is usually larger than that of a conventional system, but once in operation, substantial cost reductions are obtainable. Are these reductions large enough to offset a larger capital investment and to make a FMS economically attractive? There is no clear cut answer to the question.

In this chapter, several models for economic evaluation will be proposed. They are intended to provide the analyst with ample criteria applicable to different situations, therefore permitting one to assess the economic feasibility of a FMS for a specific manufacturing process. The emphasis of this chapter is on normative theory, establishing decision criteria that will help decision makers attain the goals of their firm, agency or organization.

The models must fulfill three major requirements.

1. Utilize input data that is readily available from the entity that usually deals with that type of information, i.e. product engineering, financial department, manufacturing engineering, sales department, vendors.



2. Provide reliable results with a reasonable degree of accuracy.

3. Simplify reality to a small package of information that facilitates effective decision making by top management.

Important Note. Throughout this paper the abbreviation CS will be continuously used; it stands for conventional system and does not denote any specific manufacturing system. Conventional System (CS) is considered any system against which the FMS is being compared for a certain application, unless otherwise noted.

#### Analysis of Direct Cost Savings

Several studies have been published about the direct cost reductions of a FMS.

In 1973, Hutchinson and Bayne simulated the operation of a FMS configuration that incorporated the features of a system that was already in commercial production. Advantageous sets of good operating decision rules were found. They also concluded:

Simulation studies indicate that parts made on a FMS as compared with stand alone NC or DNC production offer unit part cost reductions of 30 to 70 percent.

Cook used available data in 1975 to find out that a FMS compared with a standard job shop of similar capacity, needs only between 10 and 30 percent as much direct labor.



Klahorst reported in 1981 that through the use of FMS direct labor content in the workpiece is reduced to one fourth of the previous level.

Ottinger in 1982, did not estimate the direct cost savings specifically, but he did point out that if the system can work through lunch and break periods, productivity increases at least 12%.

The above cited studies do not explain what assumptions were made, or what type of product was being manufactured. The evaluation techniques proposed throughout this paper are broad enough to be effectively applied to different situations, by allowing the user to change variables or assumptions.

### Assumptions and Considerations

Direct costs are those costs that vary with volume of production and that can be conveniently and economically charged to products or jobs on which the costs are incurred. For the purpose of this analysis we will work under the following assumption: Only direct labor and direct material contribute to direct cost.

Some firms use the direct costing method as opposed to the full absorption costing method, and therefore separate factory overhead costs into fixed and variable factory overhead costs. For these cases, the assumption



disregards variable factory overhead costs, so the models presented in this section can not be applied directly and provisions should be taken. The reasons for which this assumption was made are explained below.

1. The same logic applies if any variable factory overhead cost should be included, but by using only two variables (direct labor and direct material), the methodology for the analysis is simple and more explicit.

2. The input data for the models is easier to obtain for any specific situation.

3. Many firms as well as many authors do not separate overhead costs into fixed and variable.

We hardly need to emphasize that FMS calls for considerably less direct labor than conventional manufacturing systems. However, direct labor cost does not decrease in the same proportion as direct labor content because the workers' degree of specialization increases, hence increasing their compensation. On the other hand, reduction of direct labor diminishes operators' errors. This in turn drastically reduces rework and virtually eliminates scrap. This implies that less raw material is used to produce the same amount of pieces, hence there is a potential for material cost reductions also.

To assess the potential savings for a specific FMS application we first need to know what proportion of the



direct cost is contributed by labor and by material in a CS.

$$DC = (L \times DLC) + (M \times MC) / 100$$

DC: Direct Cost in a CS.

DLC: Direct Labor Cost in a CS.

MC: Material Costs in a CS.

L: Percentage of the total workpiece's cost contributed by direct labor in a CS.

M: Percentage of the total workpiece's cost contributed by material in a CS.

$$L + M = 100\%$$

#### Variables To Be Tested

The effects on direct cost of the following variables will be tested:

1. L/M: Labor content/Material content ratio.
2. DLCS: Direct Labor Cost Savings.

Percentage of the direct labor cost of a conventional system that is saved through a FMS; where

$$DLCS = DLC \times LT^- \times LC^+$$

LT<sup>-</sup>: Percentage decrease of labor content of the workpiece.

LC<sup>+</sup>: Percentage increase of unit labor cost due to a higher degree of specialization.

3. S: Scrap.

Percentage of scrap in a conventional system that is eliminated through a FMS.

Table 3 shows the percent direct cost savings (DCS%) for reduction in scrap values of 0%, 5% and 10%. The following equation was used for the computations:

$$DCS\% = 100\% - L(100\% - DLCS) + M(100\% - S) / 100$$



TABLE 3

PERCENT DIRECT COST SAVINGS FOR DIFFERENT COMBINATIONS OF LABOR CONTENT/MATERIAL CONTENT (L/M) RATIOS AND DIRECT LABOR COST SAVINGS (DLCS) FOR SCRAP = 0%, 5% AND 10%

L/M	Direct Labor Cost Savings (DLCS)							Scrap
	10%	25%	33%	50%	67%	75%	90%	
70/30	7	17.5	23.3	35	46.7	52.5	63	0%
	8.5	19	24.8	36.5	48.2	54	64.5	5%
	10	20.5	26.3	38	49.7	55.5	66	10%
60/40	6	15	20	30	40	45	54	0%
	8	17	22	32	42	47	56	5%
	10	19	24	34	44	49	58	10%
50/50	5	12.5	16.7	25	33.3	32.5	45	0%
	7.5	15	19.2	27.5	35.8	40	47.5	5%
	10	17.5	21.7	30	38.3	42.5	50	10%
40/60	4	10	13.3	20	26.7	30	36	0%
	7	13	16.3	23	29.7	33	39	5%
	10	16	19.3	26	32.7	36	42	10%
30/70	3	7.5	10	15	20	22.5	27	0%
	6.5	11	13.5	18.5	23.5	26	30.5	5%
	10	14.5	17	22	27	29.5	34	10%



### Synthesis of the Direct Cost Savings Analysis

The systems that benefit more from FMS applications are those that work with high labor content/material content ratios (see Fig. 4) and those in which scrap levels are relatively high.

Direct cost savings have a lower limit of 3% (for  $L/M = 30/70$ ,  $DLCS = 10\%$  and  $S = 0\%$ ) and an upper limit of 66% (for  $L/M = 70/30$ ,  $DLCS = 90\%$  and  $S = 10\%$ ). These are the extreme theoretical cases, but in practice a conventional system lies more in the middle. Assuming that direct labor costs are reduced 67%, if a system is currently manufacturing items of which the direct cost is contributed in equal parts ( $L/M = 50/50$ ) by labor and material, and operating at scrap levels of 5%, then direct cost savings of approximately 35.8% could be obtained by switching to a FMS (see Table 3).

Moreover, as the  $L/M$ ,  $DLCS$  and  $S$  parameters are data that is usually available in any particular manufacturing operation, the proposed model is broad enough to be applied to different systems and evaluate potential direct cost savings concisely and reliably.



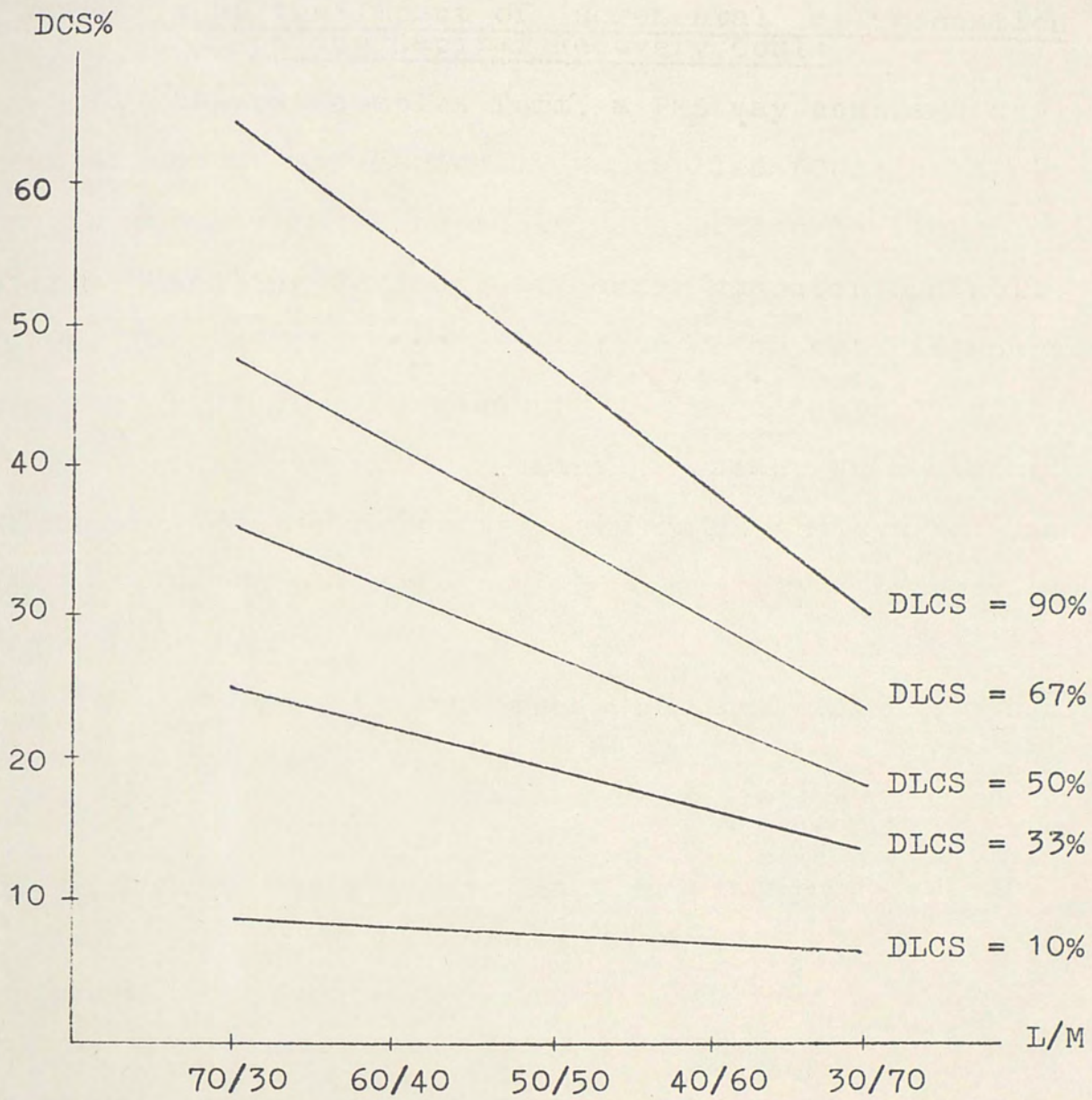


Fig. 4. Percent Direct Cost Savings (DCS%) as a function of L/M ratios for scrap = 5%.



Analysis of the Impact of Incremental Implementation  
on the Capital Recovery Costs

In its most complex form, a FMS may comprise a group of Computer Numerically Controlled (CNC) machining centers, special machine tools, inspection machines and material handling devices, all under computer control. However, one of the characteristics which sets it apart from other alternative concepts is the capability of incremental implementation. A firm can start with a single stand-alone machining center, and build the system around that machine through the addition of other elements in planned steps.

This section is concerned with analyzing how this incremental implementation affects the capital recovery costs of a FMS facility. Capital Recovery Cost (CR) for a project is the equivalent uniform annual cost of the capital invested. It is an annual amount which covers the following two items:

1. Depreciation (loss in value of the equipment).
2. Interest on invested capital.

Variables To Be Tested

The effect of the following variables will be analyzed independently.



1. Cost of Capital (i%). For the purpose of this study cost of capital, also called minimum attractive rate of return, is defined as the weighted average, or composite of the various costs of the funds that the firm uses to finance its capital expenditures. It includes cost of debt, preferred stock and common equity. It is a discount rate with the property that an investment with a rate of return exceeding this rate will increase the value of the firm and vice versa.

2. Inflation (f%). Average annual increase of the cost of the FMS elements as a percent per year.

3. Increased Implementation Costs due to Incremental Implementation (ICI%). This factor is a provision for those cases in which incremental implementation causes costs that otherwise would not exist, i.e., reprogramming, or shutting down the line for a few days.

4. Speed of Expandibility. How often can a FMS expand to match capacity requirements?

5. Increase Rate of Annual Capacity Requirements. Measure of how the annual capacity requirements increase every year.

#### Objective and Procedure

The analysis to be performed is aimed to estimate empirically the effects of the above variables on capital



recovery costs when capacity requirements are assumed to be increasing:

1. By a constant factor every year (schedule #1).
2. At a constant exponential rate every year (schedule #2).

Schedule #1 will be generated by arbitrarily assuming that capacity requirements start at 100 in year 1 and increase 10 units each year (see Table 4). Schedule #2 also assumes that capacity requirements start at 100 in year 1 and increase 10% every year (see Table 5).

The following investment plans will serve as a basis for the analysis.

Plan A1. Total implementation plan. Meet capacity requirements for schedule #1, committing to the project all the capital from the beginning of period 1.

Plan A2. Same as above but for schedule #2.

Plan B1. Incremental implementation plan. Invest at the beginning of periods 1 and 6, to meet capacity requirements for the next 5 years for schedule #1.

Plan B2. Same as above but for schedule #2.

Plan C1. Faster incremental implementation plan. Invest at the beginning of periods 1, 3, 5, 7 and 9, to meet capacity requirements for the next two years for schedule #1.



TABLE 4

## CAPACITY REQUIREMENTS SCHEDULE #1 AND INVESTMENT PROGRAMS FOR PLANS A1, B1 AND C1

Year	Capacity Requirement	Investments*		
		Plan A1	Plan B1	Plan C1
1	100	190	140	110
2	110			
3	120			20
4	130			
5	140			20
6	150		50	
7	160			20
8	170			
9	180			20
10	190			
TOTALS		190	190	190

\* Investments occur at the beginning of that period.



TABLE 5

CAPACITY REQUIREMENTS SCHEDULE #2  
AND INVESTMENT PROGRAMS  
FOR PLANS A2 AND B2

Year	Capacity Requirement	Investments*	
		Plan A2	Plan B2
1	100	235.79	146.41
2	110		
3	121		
4	133.1		
5	146.41		
6	161.05		89.38
7	177.16		
8	194.87		
9	214.36		
10	235.79		
TOTALS		235.79	235.79

\* Investments occur at the beginning of that period.



Plan B1 will be tested versus plan A1 to measure the effects of cost of capital, inflation and increased implementation costs. Plan C1 will be tested versus plan A1 to measure the effects of the speed of expandability. Plan B2 will be tested versus plan A2 to measure the effects of the rate of increase of annual capacity requirements.

### Assumptions

1. The investment/capacity ratio has a constant value of one.

This simplifying assumption is not realistic, but does not negatively affect the results because:

a) It has the same effect on plans A1, A2, B1, B2 and C1.

b) The savings in CR are measured on a relative basis.

2. All the investments are assumed to have an economic life of 10 years with a zero salvage value.

It has been estimated that 12 years is the average economic life of projects in industries within the fabricated metal products group (Park 1983). Under the Economic Recovery Tax Act of 1981 the allowed recovery period for machinery and equipment is 5 years. At this stage we are not considering depreciation for tax purposes, but only as the real loss in value of the asset. We deem it appropriate to use a 10 year economic life with no salvage value. A



depreciation method is not specified because no matter which method is used, the relative equivalent annual cost of the capital recovery is the same.

Table 4 shows schedule #1 as well as the investment programs for plans A1, B1 and C1. Note that an investment of 50 at the beginning of year 5 in plan B1 will be able to meet the capacity requirements for the next 5 years because the existing investment already meets the requirement of 140 and  $190 - 140 = 50$ . For plan C1 capacity requirements must be met for the two following years. Therefore, for example, the required investment at the beginning of year 3 is 20, because we have to meet the requirement of 130 but we already had 110. Table 5 shows schedule #2 and the investment programs for plans A2 and B2 when the same logic is applied.

### Analysis

The general formula to be used for the calculation of the capital recovery costs is:

$$CR = (P - SV) (A/P, i\%, N) + SV(i\%)$$

CR: Capital Recovery Costs.

P : Investment.

SV: Salvage Value.

i%: Cost of Capital.

N : Economic life of investment (years).

As salvage value was assumed to be zero, and the economic life 10 years; the above formula is simplified to:

$$CR = P (A/P, i\%, 10)$$



The following equations will be applied to compute the capital recovery costs of plans A1 and A2.

$$CR_{A1} = 190(A/P, i\%, 10)$$

$$CR_{A2} = 235.79(A/P, i\%, 10)$$

The following equations will be applied to estimate the capital recovery costs of plans B1 and B2.

$$CR_{B1} = 140(1 + ICI\%) (A/P, i\%, 10) + 50 (1 + ICI\%)$$

$$(F/P, f\%, 5) (A/P, i\%, 10) (F/A, i\%, 5) (A/F, i\%, 10)$$

$$CR_{B2} = 146.41(1 + ICI\%) (A/P, i\%, 10) + 89.38 (1 + ICI\%)$$

$$(F/P, f\%, 5) (A/P, i\%, 10) (F/A, i\%, 5) (A/F, i\%, 10)$$

The term  $(1 + ICI\%)$  inserts the effect of increased implementation costs. In the second term the factor  $(F/P, f\%, 5)$  inserts the effect of inflation. The factor  $(A/P, i\%, 10)$  spreads the investment made in year 5 in the next 10 years (from year 5 to year 15). Factor  $(F/A, i\%, 5)$  eliminates the 5 annual costs that occur after the end of the period of study, by situating the annual costs incurred from year 5 to 10 in a single future cost at the end of year 10. Finally, factor  $(A/F, i\%, 10)$  annualizes that future cost and spreads it back into the 10 years comprised within the study period (from beginning of year 1 to end of year 10). It might be argued that the model favors the incremental investment concept because the costs incurred in the last 5 years of the economic life



of that part of the investment made at year 5 are not included. This situation is compensated for by the fact that at the end of year 10 the asset still represents a value for the firm because, according to the 10 year economic life assumption, it can still produce economically and it has a positive salvage value.

With the same line of reasoning, the following equation estimates the capital recovery costs for plan C1.

$$\begin{aligned}
 CR_{C1} = & 110(A/P, i\%, 10) + \\
 & 20 (F/P, f\%, 2) (A/P, i\%, 10) (F/A, i\%, 8) (A/F, i\%, 10) + \\
 & 20 (F/P, f\%, 4) (A/P, i\%, 10) (F/A, i\%, 6) (A/F, i\%, 10) + \\
 & 20 (F/P, f\%, 6) (A/P, i\%, 10) (F/A, i\%, 4) (A/F, i\%, 10) + \\
 & 20 (F/P, f\%, 8) (A/P, i\%, 10) (F/A, i\%, 2) (A/F, i\%, 10)
 \end{aligned}$$

Finally to estimate the changes of CR obtainable from an incremental implementation plan on a relative basis; the differences between CR of total implementation plan A and CR of incremental implementation plan B or C are divided by CR of plan A. The results of this computations using different combinations of cost of capital, inflation and increased implementation costs values, are summarized in Table 6.

#### Synthesis of the Analysis of the Impact of Incremental Implementation on the Capital Recovery Costs

Higher cost of capital/inflation ratios produce an increase in the percentage of the savings in capital



TABLE 6

PERCENT CHANGE IN CAPITAL RECOVERY COSTS FROM TOTAL TO INCREMENTAL IMPLEMENTATION PLANS, FOR DIFFERENT VALUES OF COST OF CAPITAL, INFLATION AND INCREASED IMPLEMENTATION COSTS

Line No	Parameters			Incremental CR/Plan	VS	Total CR/Plan	Change in Capital Recovery Costs
	Cost of Capital i%	Inflation f%	Incremental Implementation Costs ICI%				
1	10	5	0	26.75/B1		30.92/A1	-13%
2	10	10	0	27.79/B1		30.92/A1	-10%
3	10	25	0	32.28/B1		30.92/A1	4%
4	10	5	5	28.09/B1		30.92/A1	- 9%
5	10	5	20	32.10/B1		30.92/A1	4%
6	10	20	10	33.57/B1		30.92/A1	9%
7	15	5	0	32.13/B1		37.86/A1	-15%
8	10	5	0	24.44/C1		30.92/A1	-21%
9	10	10	0	25.62/C1		30.92/A1	-17%
10	10	5	0	30.93/B2		38.36/A2	-20%
11	15	5	0	36.73/B2		46.98/A2	-21%
12	12	3	4	29.63/B1		33.63/A1	-12%



recovery costs (see Table 6; line 1 vs. 7). If inflation is equal to cost of capital (lines 2 and 9) there are savings to be realized. This is due to the deferment of costs incurred by the incremental investment program. High costs related to the incremental implementation plan considerably reduce the savings and may even offset them (lines 4 and 5), specially when inflation is higher than the cost of capital (line 6). If the FMS is able to expand faster, the possibility of shorter intervals between expansions make the incremental implementation plans more attractive (lines 1 vs. 8 and 2 vs. 9). A constant exponential rate of increase in annual capacity requirements makes the incremental implementation plan more attractive than a constant factor increase (lines 1 vs. 10 and 7 vs. 11).

In September 1983, the yield of 30 year Treasury Bonds and AA Corporate Bonds were in the neighborhood of 12%. The estimated inflation rate for the previous 12 months was 2.4%. It is not too optimistic to assess that implementation costs will rise 4% if the implementation is performed in two steps separated by 5 years instead of implementing the complete system at once. In line 12 of Table 6, we have estimated that in the current economic and financial conditions, a firm having a capacity requirements schedule similar to schedule #1 can save approximately 12% in capital recovery costs if a FMS is



implemented in an incremental basis as compared to total implementation.

Analysis of the Cost Effects of Improving  
Machine Utilization and Reducing  
Manufacturing Lead Time

The following analysis is intended to serve as a guide to analyze the cost effects of improving machine utilization and reducing manufacturing lead time. We first need to define the terms we will be using and determine how they will be affected by FMS applications.

Manufacturing Lead Time ( $T_{ml}$ ). Total time to process the part through the plant.

$$T_{ml} = n_m(T_{su} + QT_o + T_{no})$$

$n_m$ : Total number of machines through which the part must be routed.

$Q$ : Batch size.

Machine Setup Time ( $T_{su}$ ). Nearly all production machines must be set up to process a particular workpiece. Setup time is considered to be the period in which the machine is being prepared, parts are waiting and there is no part loaded onto the machine. In a FMS, workpart setup is external to the system and tooling is preset off-line, therefore there is less wasted machine time while preparing to process the next part.

Non-operation Time ( $T_{no}$ ). Non-operation time is the time that an individual part spends during transportation, delays and inspections. Having an automated material



handling system, controlled by the computer that contains the manufacturing data base, permits a FMS to move parts efficiently and reduce transportation times and delays.

Operation Time ( $T_o$ ). Operation time is the time that an individual part spends on a machine.

$$T_o = T_m + T_h + T_{th}$$

Machining Time ( $T_m$ ). Time in which the part is actually being worked on. In this analysis we will assume that  $T_m$  is the same for a FMS as for the conventional system. This implies that the advantages of combined and/or simultaneous operations are either not achieved with the FMS or was already achieved with the conventional system.

Workpart Handling Time ( $T_h$ ). Period of time when the workpart is handled on the machine. Since in a FMS the palletized parts are registered automatically at each workstation,  $T_h$  is considerably reduced.

Tool Handling Time ( $T_{th}$ ). Tool handling time per workpart is the average time taken to change and adjust the tooling, while the part is on the machine. In a FMS tools are pre-set off-line by loading them into the tool drum. Automatic tool changing devices provide the capability of storing, selecting and changing tools. These features permit substantial reductions of  $T_{th}$ .



Machine Utilization (MU). Percent of the time that the machine is actually working on a part.

### Simplifications and Methodology

To provide the criteria applicable to different situations through the usage of decision tree analysis we need to make the following simplifications.

1. Of the total time taken to process the average part through the system ( $T_{ml} = 100\%$ ) it is either a) being transported or waiting for any reason ( $(T_{su} \cup T_{no})\%$ ) or b) on the machine ( $T_o$ ).

$$T_{ml} = 100\% = T_o\% + (T_{su} \cup T_{no})\%$$

2. Of the total time that the average part is on the machine ( $T_o = 100\%$ ) it is either a) being worked on ( $T_m\%$ ) or b) not being worked on ( $(T_{th} \cup T_h)\%$ ).

$$T_o = 100\% = T_m\% + (T_{th} \cup T_h)\%$$

3. Any machine at a given point of time is either a) without a part on it ( $T_{mw}$ ) because a1) there are no parts ready and/or a2) it is being set up; b) with a part on it ( $T_{mh}$ ).

$$T_{mw} + T_{mh} = 100\%$$

All the non-productive times ( $T_{su}$ ,  $T_{no}$ ,  $T_{th}$ ,  $T_h$  and  $T_{mw}$ ) could potentially be reduced with a FMS. To estimate exactly how much requires a thorough analysis of the specific FMS operation. Simulation studies help to generate



data of the system performance, however conditions of uncertainty will still exist for some parameters.

To face this problem we will use the optimistic-pessimistic approach for the analysis. It is a simple method that involves changing the estimated parameters of one or more elements in a favorable outcome (optimistic) direction and in an unfavorable outcome (pessimistic) direction to determine the effect of these changes. For a particular FMS application an optimistic estimate will mean a value of the element which we would expect to be bettered or exceeded in outcome not more than 5% of the time, while a pessimistic estimate is a value of the element which we would expect to be more favorable than the final outcome no more than 5% of the time.

Table 7 summarizes information about the parameters in a conventional system (Merchant 1977) compared to those that could be expected from a FMS; following the optimistic-pessimistic format.

Using the information given in Table 7, we can now calculate how much time the machine is being productive. Figure 5 depicts how the machine is utilized in the most likely performance of a FMS.

Figure 6 shows how an average part spends its time while in the shop for the most likely performance of a FMS.



TABLE 7

HOW MACHINES AND WORKPARTS SPEND THEIR TIME IN THE SHOP OF A CONVENTIONAL SYSTEM COMPARED TO A FMS; USING THE OPTIMISTIC-PESSIMISTIC FORMAT

Line No	Parameter	Conventional* System Performance	FMS Performance**	
			Pessimistic	Most Likely Optimistic
1	Percent of the machine time that the machine spends without parts ( $T_{mw}$ )	50%	35%	20% 5%
2	Percent of the machine time that there is a part on the machine ( $T_{mn} = 100 - T_{mw}$ )	50%	65%	80% 95%
3	Percent of the time that the part is not being worked on while on the machine $\frac{(T_t \cup T_{th})}{T_o}$	70%	35%	21% 7%
4	Percent of the time that the part is being worked on while on the machine $\frac{(T_m)}{T_o} = 100 - \text{Line 3}$	30%	65%	79% 93%



5	Percent of the manufacturing lead time that the part spends either moving or waiting $\frac{(T_{no} U T_{su})}{T_{ml}}$	95%	92.5%	90%	85%
6	Percent of the manufacturing lead time that the part spends on a machine $(T_o) = 100 - \frac{T_{ml}}{\text{Line 5}}$	5%	7.5%	10%	15%

\* Source: Merchant 1977.

\*\* Exact values depend on the specific FMS.



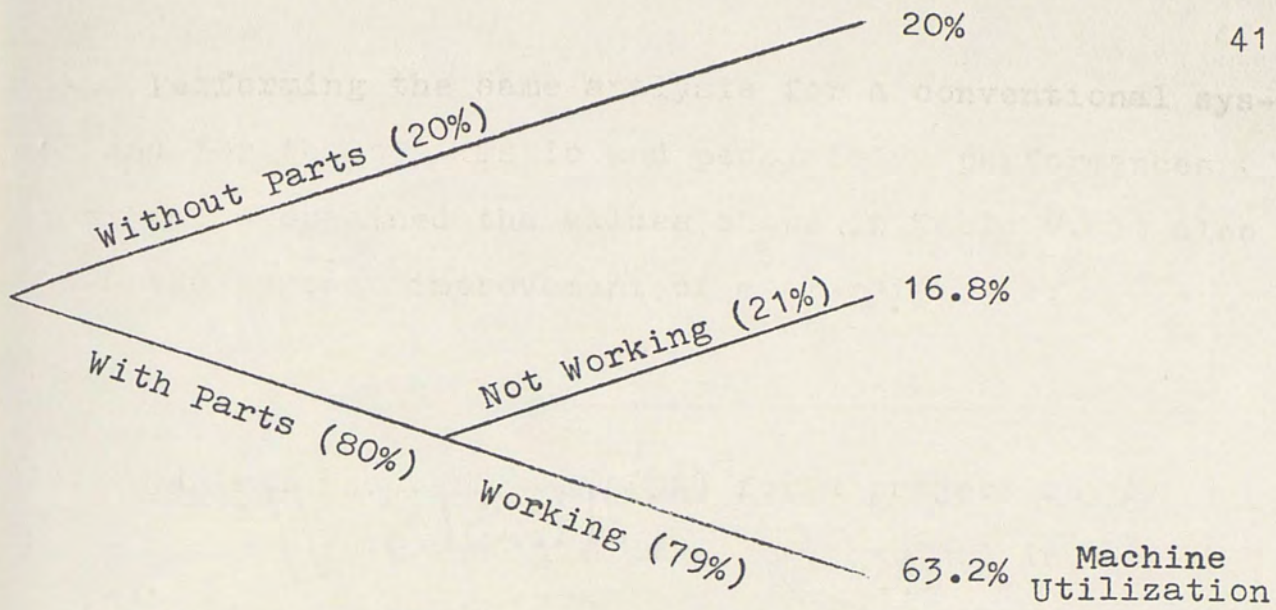


Fig. 5. Distribution of machine time for the most likely performance of a FMS.

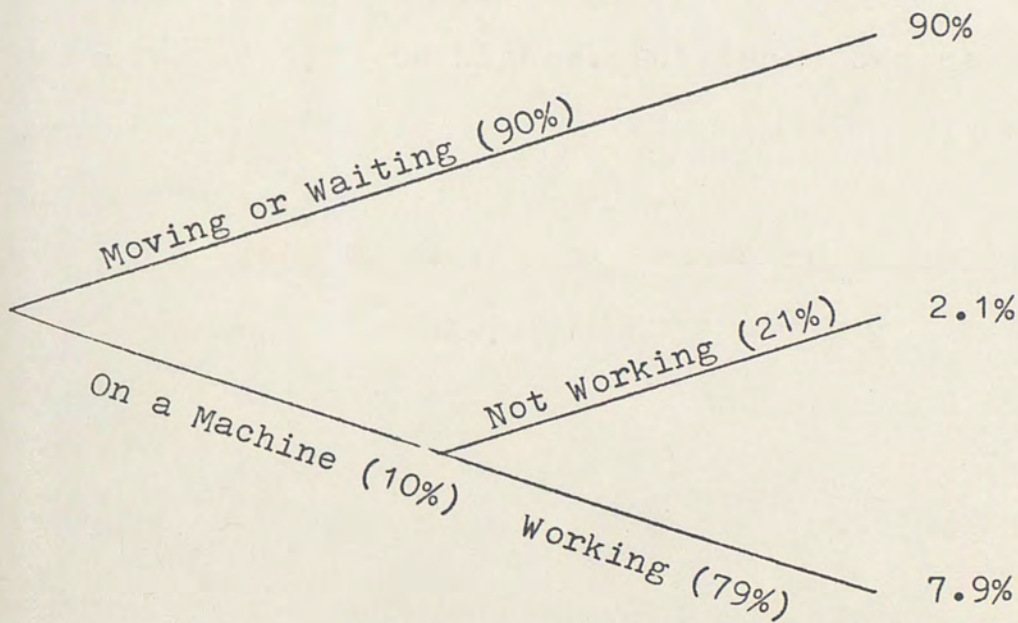


Fig. 6. Distribution of the manufacturing lead time for an average part for the most likely performance of a FMS.



Performing the same analysis for a conventional system and for the optimistic and pessimistic performances of a FMS we obtained the values shown in Table 8. It also shows the percent improvement of each parameter.

### Effects of Increased Machine Utilization on Capital Recovery Costs

Capital recovery cost (CR) for a project is the equivalent uniform annual cost of the capital invested. It is an annual amount which includes the following two items: Depreciation and interest cost on invested capital.

The initial investment outlay of a FMS is usually larger than for a conventional system. For the same cost of capital ( $i\%$ ), at first glance it may seem that CR for a FMS would also be higher. But increased machine utilization may offset the outcome. To explain this situation we need to know the four broad steps of costs analysis.

1. Breaking down total costs by functional location.
2. Classifying cost elements according to their causes, fixed and variable costs.
3. Determining cost responsibilities by defining exactly what resources are employed in manufacturing a certain part and identifying the specific costs associated with each of these resources.
4. Allocating costs according to responsibilities.



MACHINE UTILIZATION AND PERCENT TIME THAT THE AVERAGE PART IS  
BEING WORKED ON FOR A CONVENTIONAL SYSTEM AND A FMS;  
USING THE OPTIMISTIC-PESSIMISTIC FORMAT

Parameter	Conventional System Performance		FMS Performance	
	Pessimistic	Most Likely	Optimistic	Optimistic
Machine Utilization	42.2%	63.2%	88.3%	
Percent Improvement	181.0%	321.0%	489.0%	
Percent of the total time that the part spends in the shop in which it is being worked on.	15%	1.5%	7.9%	13.9%
Percent Improvement	227.0%	427.0%	827.0%	



In the third and fourth steps, either directly or indirectly, the firm allocates the CR of the machines to the cost of the parts regardless whether the machine was productive or not at a given point of time. Increased machine utilization would mean:

1. For every \$100.00 of CR, the FMS returns \$63.20 through machine utilization against only \$15.00 for a conventional system (see line 1 of Table 8).

2. A larger number of parts produced per unit of time for the same CR.

Same CR/More parts = Less CR per part

To expand the above statements, we will now quantify the effects of increased machine utilization on the CR allocated to the product for a conventional system and for the most likely performance of the FMS. The following assumptions will be made.

1. The percent improvement of machine utilization is equal to the increase of output.

2. The same cost of capital is used to evaluate both alternatives.

3. Both systems have a salvage value of zero. This permits us to base our analysis on the following equation:

$$\text{CR per part} = P (A/P, i\%, N) / \text{output per year}$$

P: Investment.

A/P: Capital Recovery Factor.

i%: Cost of capital.

N: Economic life of the investment.



To establish a point of reference, we now set the following values for the conventional system:

$$P = 100$$

$$\text{Output} = 100$$

$$N = 10 \text{ years}$$

$$i = 10\%$$

Therefore, the CR at the CS against which the FMS will be compared is:

$$\text{CR per part} = \frac{100(A/P, 10\%, 10)}{100} = \frac{100(.1627)}{100} = \$.1627/\text{per part}$$

Table 9 shows the percent change of CR due to increased machine utilization for the most likely performance of a FMS compared to the CR of the conventional system (CR = \$.1627 per part). The output per year for the FMS is considered to be 321 (see line 2 of Table 8).

#### Effects of Reduced Manufacturing Lead Time on Inventory Carrying Costs

In a conventional system, only 1.5% of the total time that the part spends in the shop is it actually being worked on (line 3 of Table 8), compared to 7.9% in the most likely performance of a FMS. This means that for a conventional system:

$$\frac{T_m}{T_{ml}} = .015, \text{ or } T_m = .015 T_{ml}, \text{ or } T_{ml} = 66.67 T_m$$



TABLE 9

PERCENT CHANGES OF CAPITAL RECOVERY COSTS PER PART  
DUE TO INCREASED MACHINE UTILIZATION FOR THE  
MOST LIKELY PERFORMANCE OF THE FMS COM-  
PARED TO THE CONVENTIONAL SYSTEM

Investment (\$)	Economic Life (years)				
	6	8	10	12	14
100	-61%	-64%	-69%	-72%	-74%
150	-41%	-46%	-53%	-58%	-61%
200	-21%	-28%	-38%	-44%	-48%
300	18%	8%	- 7%	-16%	-22%



and for a FMS:

$$\frac{T_m}{T_{m1}} = .079 , \quad T_m = .079 T_{m1} , \text{ or } T_{m1} = 12.65 T_m$$

$$\Delta \% = \frac{66.67 - 12.85}{66.67} \times 100 = 81\%$$

Therefore, according to the assumption we made previously that  $T_m$  is the same for a FMS and for the conventional system, we estimate that  $T_{m1}$  can be reduced 81% from the original  $66.67 T_m$ . As every part passes through the system much faster, at any given point in time fewer parts remain unfinished, waiting for a machine to work on them or waiting for other parts to be assembled. Hence there is a considerable reduction in in-process inventory.

In-process inventory carrying cost is the cost of floor space added to the cost of capital. In-process inventory is considered working capital and is not depreciable. Annual cost of floor space for in-process inventory is directly proportional to the average size of the workpart, the cost of floor space per unit of time and the average part throughput time. Annual cost of capital for in-process inventory is directly proportional to the firm's cost of capital, the average in-process inventory, its direct cost and to the time it spends idle. In 1982, Ottinger estimated that annual inventory carrying cost was between 16% and 30% of its direct cost.



The following simplified equation will be used to estimate the effect on in-process inventory carrying cost of reduced manufacturing lead time.

$$\begin{aligned} \text{ICC} &= (\text{FSC per unit of time} \times T_{m1}) + (\text{IDC} \times i \times T_{m1}) \\ &= T_{m1}(\text{FSC per unit of time} + \text{IDC} \times i) \end{aligned}$$

ICC: Inventory carrying cost.

FSC: Floor space cost.

IDC: Average in-process inventory direct cost.

i%: Cost of capital per unit of time.

If we assume that FSC per unit of time, IDC and the cost of capital remain constant regardless of which type of manufacturing system is in operation, we can see that  $T_{m1}$  is multiplied by a constant, therefore we can expect that inventory carrying costs will decrease in approximately the same proportion as  $T_{m1}$ .

#### Synthesis of the Analysis of the Cost Effects of Improving Machine Utilization and Reducing Manufacturing Lead Time

Probably the slots in columns 2 and 3 of Table 9 are the ones that would more faithfully represent real world situations. For the case in which economic life is 20% shorter and initial investment is doubled, CR would decrease 28%. If economic life remains equal and the investment is only 50% larger, then CR would decrease 53%. Observing the southwest and northeast of Table 9, it can be seen that CR would increase 18% if the FMS requires three times the initial investment of the conventional



system and has a 40% shorter economic life. In the other hand if FMS requires the same investment and has a 40% larger economic life, CR are reduced 74%.

The inventory carrying cost reductions that can be expected are approximately equal to the percentage reduction of manufacturing lead time. Reductions in the neighborhood of 81% can be obtained from the most likely performance of a FMS.

Sensitivity Analysis of the After-Tax  
Equivalent Uniform Annual Cost of a  
FMS and a Conventional System

Typically, comparison of a FMS and a conventional system (CS) is between a high investment, low operating cost project and a low investment, high operating cost alternative. In our previous analysis the operating cost reductions that have been estimated are the direct cost and the in-process inventory cost, other factors that significantly affect operating costs and have not been estimated in this study are: maintenance, energy and indirect labor costs. The following paragraphs provide important information to be considered when estimating these costs.

Maintenance Costs. As a result of complexity and increased machine utilization, preventive maintenance costs can be expected to be higher for a FMS than for a CS. On the other hand, the FMS is continuously monitoring itself



and a machine breakdown causes the the parts to be routed through other machines. If this happens the FMS would not operate at the same level of efficiency, but nevertheless would continue to operate. As a result of this process, corrective maintenance costs are contributed mainly by parts and labor with a low contribution of costs due to production time loss. These characteristics are not usually found in a CS, so corrective maintenance costs associated with machine breakdown can be expected to be lower for a FMS than for a CS.

Energy Costs. With the application of adaptive control technology, the machine tools and the MHS of a FMS make efficient use of energy. However, energy costs would more likely be higher for a FMS than for a CS because of the energy consumed by the automated MHS and the central computer.

Indirect Labor Costs. Full integration of computer aided design and manufacturing (CAD/CAM) is a major prerequisite of an effective FMS. Such integration offers the following advantages:

1. Data is originated in machine language as a by-product of the design phase.
2. Once in machine language, data is never re-entered, but it may be added to, deleted from, or modified.
3. A single database is used throughout the entire planning and control process.



As a result of the above advantages, fewer personnel are required to handle and communicate the information. Indirect Labor Costs would more likely be lower in a FMS than in a CS.

Estimates of the above discussed parameters as well as estimates of the parameters we have already analyzed (direct cost and in-process inventory cost) should be used to compute the total operating cost (TOC). However the estimates are obtained, conditions of uncertainty exist for the TOC parameter.

Another parameter for which uncertainty exists is the economic life of the FMS. Increased machine utilization can result in faster deterioration and a shorter economic life than expected. There is uncertainty associated with high technology obsolescence that could result in a shorter economic life than expected.

#### Methodology and Assumptions

The after-tax equivalent uniform annual cost (ATEUAC) for a CS and a FMS will be compared for different scenarios. The analysis will be performed to comply with the "accelerated cost recovery system" (ACRS). ACRS allows a 5 year "recovery period" for machinery and equipment with the following applicable percentages for computing annual depreciation from year 1 to 5: 15%, 22%, 21%, 21% and 21%. There is no provision for including a salvage value in



the calculations. A tentative 10% investment credit against income taxes is made available for depreciable property. We will assume a 10% investment credit at year 0 in which the investment was made.

To generate values of TOC that permit comparison between FMS and CS the following assumptions and line of reasoning will be used.

For a CS:

$$.85 \text{ Total Assets} = \text{Annual Sales} \quad (\text{Park 1973})$$

Assuming that the same relation holds true for any particular investment in a CS:

$$.85 \text{ INV}_{\text{CS}} = \text{Annual Sales}$$

$\text{INV}_{\text{CS}}$ : Investment in a CS.

Assuming that:  $\text{Annual Sales} = \text{TOC}_{\text{CS}} \times \text{Constant Margin}$

and  $\text{Constant Margin} = 15\% \text{ of } \text{TOC}_{\text{CS}}$

then:  $\text{Annual Sales} = \text{TOC}_{\text{CS}} \times 1.15$

Therefore for a CS:

$$.85 \text{ INV}_{\text{CS}} = \text{TOC}_{\text{CS}} \times 1.15$$

Finally  $\text{INV}_{\text{CS}} = 1.35 \text{ TOC}_{\text{CS}}$

The above relation will not hold for a FMS because the following ratios are not expected to be equal to 1.

$$\text{INV}_{\text{FMS}} / \text{INV}_{\text{CS}} = \text{IR}$$

$$\text{TOC}_{\text{FMS}} / \text{TOC}_{\text{CS}} = \text{TOCR}$$



If we know the values of those ratios and set a constant value for  $INV_{FMS}$ ; we can proceed to calculate  $TOC_{FMS}$  as a function of these parameters using the following equation.

$$TOC_{FMS} = INV_{FMS} / (1.35 \text{ IR} / TOCR)$$

The derivation of above equation is:

$$INV_{FMS} = IR \times INV_{CS}$$

$$TOC_{FMS} = TOCR \times TOC_{CS}$$

$$\frac{INV_{FMS}}{TOC_{FMS}} = \frac{IR \times INV_{CS}}{TOCR \times TOC_{CS}}$$

As  $\frac{INV_{CS}}{TOC_{CS}} = 1.35$

Then  $\frac{INV_{FMS}}{TOC_{FMS}} = (IR \times 1.35) / TOCR$

And  $TOC_{FMS} = INV_{FMS} / (1.35 \text{ IR} / TOCR)$

We also assume that the FMS has no salvage value regardless of its economic life.

The values used as the basis of the analysis were the following:

$$TOCR = 1/3 \quad IR = 2 \quad N = 10 \quad i = 10\% \quad INV_{FMS} = 12$$

To compute  $TOC_{FMS}$  for these values

$$TOC_{FMS} = 12 / (1.35 \times 2 / 1/3) = 1.48$$

The worksheet used to compute the after-tax net cash flows for  $TOC_{FMS} = 1.48$ ,  $INV_{FMS} = 12$  and  $N = 10$  with a 50%



income tax rate is shown in Table 10.

Note that the before-tax total annual costs entered from years 1 to 10 are the TOC values assuming they remain constant throughout the economic life period. Actual TOC values could increase every year due to inflation, increased maintenance and other factors. To address this issue a gradient factor can be included in the TOC calculations. The models presented in this section are flexible enough to be able to adapt to this type of change, but to keep the analysis simple we assume a constant TOC.

The after-tax present cost (ATPC) for these net cash flows is computed as follows.

$$\begin{aligned} \text{ATPC} &= 10.8 - 0.16(\text{P/F}, 10\%, 1) - 0.58(\text{P/F}, 10\%, 2) \\ &\quad - 0.52(\text{F/A}, 10\%, 3)(\text{P/F}, 10\%, 5) \\ &\quad + 0.74(\text{P/A}, 10\%, 5)(\text{P/F}, 10\%, 5) \\ &= 10.84 \end{aligned}$$

This present cost was then annualized to facilitate comparison of alternatives. The after-tax equivalent uniform annual cost (ATEUAC) was calculated as follows.

$$\text{ATEUAC} = 10.84(\text{A/P}, 10\%, 10) = 1.77$$

The general form of the above equations can be stated as follows.

$$\begin{aligned} \text{ATPC} &= \text{INV} \times .9 + \text{NCF}_1(\text{P/F}, i\%, 1) + \text{NCF}_2(\text{P/F}, i\%, 2) \\ &\quad + \text{NCF}_{3,4,5}(\text{F/A}, i\%, 3)(\text{P/F}, i\%, 5) \\ &\quad + \text{NFC}_{5 \text{ to } N}(\text{P/A}, i\%, N - 5)(\text{P/F}, i\%, 5) \end{aligned}$$



TABLE 10

WORKSHEET FOR AFTER-TAX NET CASH FLOW COMPUTATIONS  
 WITH INV<sub>FMS</sub> = 12 AND TOC<sub>FMS</sub> = 1.48

Year	Before-Tax Total Annual Cost	Recovery Rate	Depreciation for tax purposes	Taxable Income	Tax (50%)	After-Tax Total Annual Cost	After-Tax Net Cash Flow
0	-12						-10.8
1	+ 1.2						
1	- 1.48	.15	-1.8	-3.28	+1.64	-1.64	0.16
2	- 1.48	.22	-2.64	-4.12	+2.06	-2.06	0.58
3	- 1.48	.21	-2.52	-4	+2	-2	0.52
4	- 1.48	.21	-2.52	-4	+2	-2	0.52
5	- 1.48	.21	-2.52	-4	+2	-2	0.52
6	- 1.48	0	0	-1.48	+0.74	-0.74	-0.74
7	- 1.48	0	0	-1.48	+0.74	-0.74	-0.74
8	- 1.48	0	0	-1.48	+0.74	-0.74	-0.74
9	- 1.48	0	0	-1.48	+0.74	-0.74	-0.74
10	- 1.48	0	0	-1.48	+0.74	-0.74	-0.74



$$\text{ATEUAC} = \text{ATPC}(A/P, i\%, N)$$

$\text{NCF}_x$ : Net cash flow in year x.

N: Economic life.

$i\%$ : Cost of capital.

The ATEUAC equation may be modified to include the capital recovery changes due to increased machine utilization and/or an incremental implementation plan that we previously analyzed, by multiplying the right hand side by one plus the capital recovery change:

$$\text{ATEUAC} = \text{ATPC}(A/P, i\%, N)(1 + \text{change in CR})$$

This was not done in this analysis to keep it reasonably simple.

The ATEUAC value for a specific FMS can now be compared with the ATEUAC of a CS that is currently in operation, to decide whether it is economically convenient to make the replacement and when.

Our analysis is now extended to facilitate comparative studies assuming that the decision is either to install a FMS or a CS. The required information is: IR and TOCR,  $\text{INV}_{\text{FMS}}$  and the  $\text{INV}_{\text{CS}}/\text{TOC}_{\text{CS}}$  ratio.

$$\text{Assuming that: } \text{INV}_{\text{CS}} = \text{TOC}_{\text{CS}} \times 1.35$$

$$\text{and } \text{INV}_{\text{FMS}} = 12$$

$$\text{then } \text{INV}_{\text{CS}} = 12/\text{IR}$$

$$\text{and } \text{TOC}_{\text{CS}} = (12/\text{IR})/1.35$$



Therefore:

$$IR = 1.5 \quad \text{implies} \quad INV_{CS} = 8 \quad \text{and} \quad TOC_{CS} = 5.93$$

$$IR = 2 \quad \text{implies} \quad INV_{CS} = 6 \quad \text{and} \quad TOC_{CS} = 4.44$$

$$IR = 3 \quad \text{implies} \quad INV_{CS} = 4 \quad \text{and} \quad TOC_{CS} = 2.96$$

The worksheet used to compute the after-tax net cash flows for  $TOC_{CS} = 4.44$  and  $INV_{CS} = 6$  with a 50% income tax rate is shown in Table 11. Note that 50% differs from the current 46% income tax rate. The difference does not affect significantly the results, but it simplifies considerably the computations.

The ATEUAC for the CS for different  $TOC_{CS}$  values was computed using the same general equation as was used for the FMS but entering the appropriate net cash flows.

In Tables 12 and 13 the ATEUAC for CS and FMS for different economic lives (N), and costs of capital (i%) are shown respectively. The tables allow one to compare the CS and the FMS and also to analyze the sensitivity of the ATEUAC to changes in parameters.

Different  $TOC_{FMS}$  were generated using different combinations of IR and TOCR. These  $TOC_{FMS}$  were then used to obtain ATEUAC as a function of the IR and TOC parameters. The inputs and results of these computations are summarized in Table 14.



TABLE 11

WORKSHEET FOR AFTER-TAX NET CASH FLOW COMPUTATIONS  
 WITH INV<sub>CS</sub> = 6 AND TOC<sub>CS</sub> = 4.44

Year	Before-Tax Total Annual Cost	Recovery Rate	Depreciation for Tax Purposes	Taxable Income	Tax (50%)	After-Tax Total Annual Cost	After-Tax Net Cash Flow
0	-6						-5.4
	+0.6						
1	-4.44	.18	-0.9	-5.34	+2.67	-2.67	-1.77
2	-4.44	.22	-1.32	-5.76	+2.88	-2.88	-1.56
3	-4.44	.21	-1.26	-5.7	+2.85	-2.85	-1.59
4	-4.44	.21	-1.26	-5.7	+2.85	-2.85	-1.59
5	-4.44	.21	-1.26	-5.7	+2.85	-2.85	-1.59
6	-4.44	0	0	-4.44	+2.22	-2.22	-2.22
7	-4.44	0	0	-4.44	+2.22	-2.22	-2.22
8	-4.44	0	0	-4.44	+2.22	-2.22	-2.22
9	-4.44	0	0	-4.44	+2.22	-2.22	-2.22
10	-4.44	0	0	-4.44	+2.22	-2.22	-2.22



TABLE 12

AFTER-TAX EQUIVALENT UNIFORM ANNUAL  
 COSTS (ATEUAC) OF FMS AND CS FOR  
 DIFFERENT ECONOMIC LIVES WITH  
 IR = 2, TOCR = 1/3 AND  $i = 10\%$

Economic Life (N)	ATEUAC CS	ATEUAC FMS	Percent change
3	3.82	3.93	2.9
4	3.34	2.97	-11.1
5	3.05	2.40	-21.3
6	2.94	2.19	-32.2
8	2.81	1.92	-31.7
10	2.73	1.77	-35.2
12	2.68	1.66	-38.1
14	2.65	1.59	-40.0
15	2.63	1.57	-40.3



TABLE 13

AFTER-TAX EQUIVALENT UNIFORM ANNUAL COSTS (ATEUAC) OF FMS AND CS FOR DIFFERENT COSTS OF CAPITAL WITH  $IR = 2$ ,  $TOCR = 1/3$  AND  $N = 10$

Cost of Capital (i)	ATEUAC CS	ATEUAC FMS	Percent change
5%	2.58	1.47	-43
8%	2.67	1.64	-39
10%	2.73	1.77	-35
12%	2.80	1.90	-32
15%	2.90	2.10	-28
20%	3.09	2.48	-20
25%	3.29	2.89	-12
40%	3.97	4.24	7



AFTER-TAX EQUIVALENT UNIFORM ANNUAL COST (ATEUAC) OF FMS AND CS FOR DIFFERENT  
IR AND TOCR AND THEIR CORRESPONDING TOC WITH  $i = 10\%$  AND  $N = 10$

INV <sub>FMS</sub> /INV <sub>CS</sub> IR	INV <sub>FMS</sub>	INV <sub>CS</sub>	TOC <sub>FMS</sub> /TOC <sub>CS</sub> TOCR	TOC <sub>CS</sub>	TOC <sub>FMS</sub>	ATEUAC		Percent Change
						CS	FMS	
1.5	12	8	1/4	5.93	1.48	3.65	1.77	-51
1.5	12	8	1/3	5.93	1.98	3.65	2.01	-44
1.5	12	8	1/2	5.93	2.96	3.65	2.50	-31
1.5	12	8	2/3	5.93	3.96	3.65	3.01	-17
1.5	12	8	3/4	5.93	4.44	3.65	3.25	-11
2	12	6	1/4	4.44	1.11	2.73	1.58	-42
2	12	6	1/3	4.44	1.48	2.73	1.77	-35
2	12	6	1/2	4.44	2.22	2.73	2.13	-22
2	12	6	2/3	4.44	2.96	2.73	2.50	-8
2	12	6	3/4	4.44	3.33	2.73	2.69	-1
3	12	4	1/4	2.96	0.74	1.82	1.40	-23
3	12	4	1/3	2.96	0.99	1.82	1.52	-16
3	12	4	1/2	2.96	1.48	1.82	1.77	-2
3	12	4	2/3	2.96	1.98	1.82	2.01	10
3	12	4	3/4	2.96	2.22	1.82	2.13	17



Synthesis of the Sensitivity Analysis of the After-Tax Equivalent Uniform Annual Cost of a FMS and a CS

The FMS alternative gets more attractive than the CS as the economic life of the system gets longer (see Fig. 7). For economic lives of 3 years or less, the savings in operating costs do not occur during a sufficient period of time to offset the capital recovery costs of the higher FMS investment. For economic lives longer than 14 years, the ATEUAC of FMS and CS are not sensitive to this parameter, and the difference between ATEUAC of FMS and ATEUAC of CS does not increase significantly (see Table 12).

The ATEUAC of a CS is less sensitive to changes in cost of capital than the ATEUAC of a FMS (see Fig. 8). The FMS alternative gets more attractive than the CS as the cost of capital decreases. However, for very high costs of capital such as 40% (see Table 13), ATEUAC of FMS is higher than ATEUAC of CS because the present cost of the future operating cost of the CS is offset by the larger investment in the FMS made in year zero due to the very high discount rate.

For the total operating costs of FMS/total operating cost of CS ratios (TOCR) of  $1/4$ ,  $1/3$  and  $1/2$ , ATEUAC of FMS are lower than ATEUAC of CS regardless of the investment in FMS/investment in CS ratio (IR). However, when  $TOCR = 3/4$ , the breakeven point between ATEUAC of FMS and



ATEUAC of CS occurs approximately at  $IR = 2.1$  and when  $TOCR = 2/3$  the breakeven point occurs approximately at  $IR = 2.5$  (see Fig. 9), for higher values of  $IR$ , ATEUAC of CS is lower than ATEUAC of FMS.

Probably the values that would more faithfully represent real world situations are the ones used as the basis of the analysis:  $TOCR = 1/3$ ,  $IR = 2$ ,  $i = 10\%$  and  $N = 10$ . For these values, we have estimated that the ATEUAC of FMS is approximately 35% lower than the ATEUAC of CS, under our assumptions.



ATEUAC

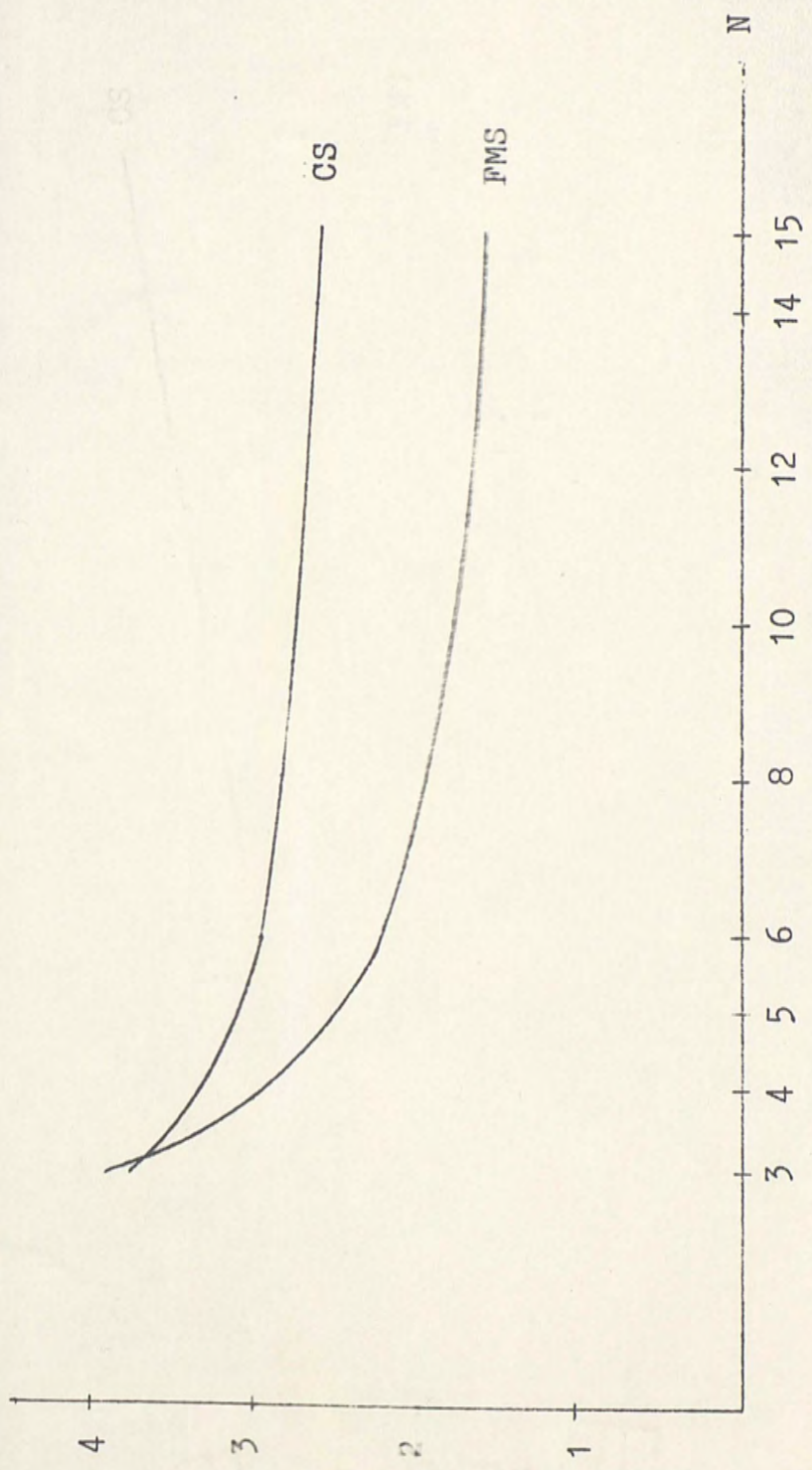


Fig. 7. After-Tax Equivalent Uniform Annual Cost (ATEUAC) of FMS and CS as a function of the economic life of the system with  $IR = 2$ ,  $TOCR = 1/3$  and  $i = 10\%$ .



ATEUAC

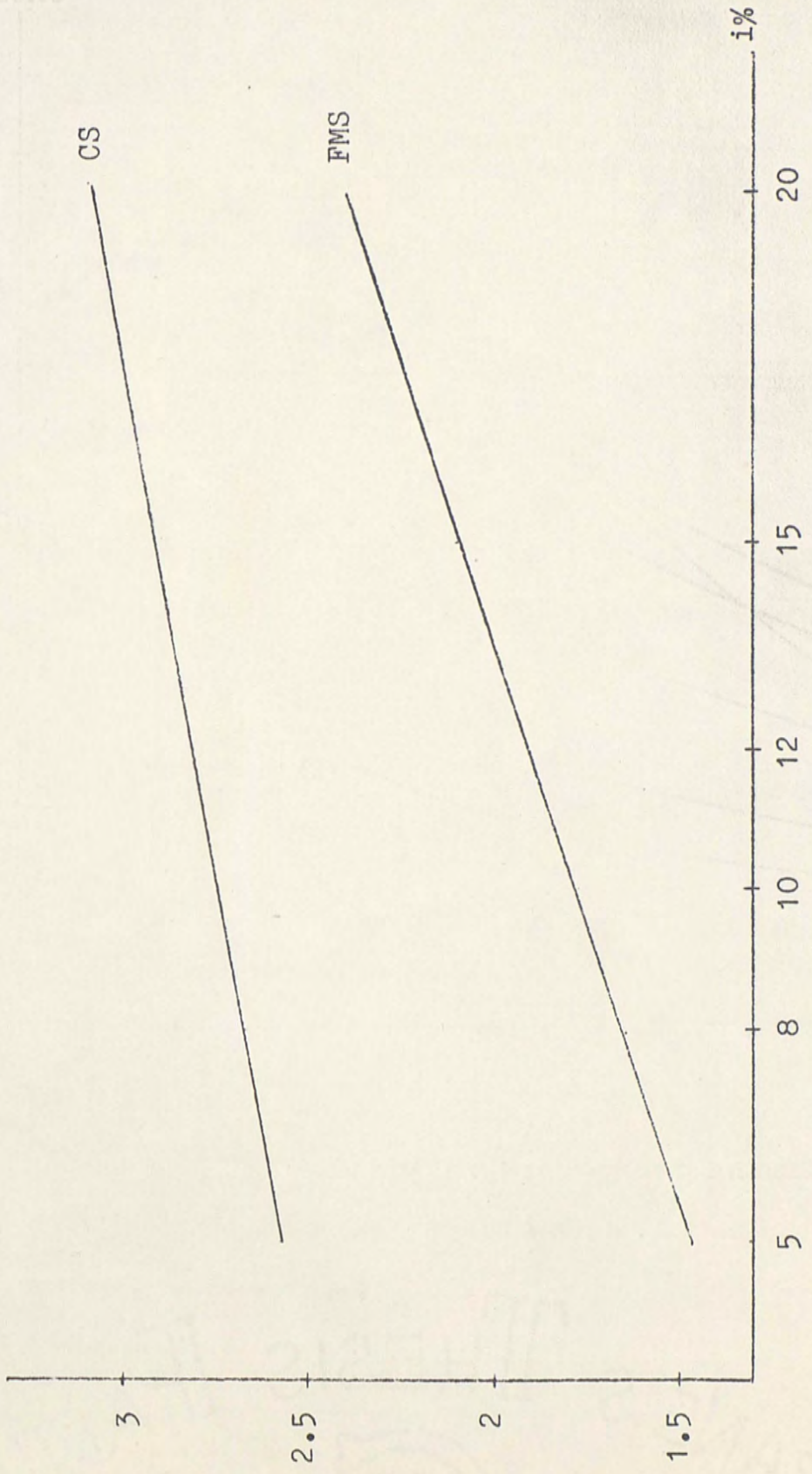


Fig. 8. After-Tax Equivalent Uniform Annual Cost (ATEUAC) of FMS and CS as a function of the cost of capital with  $IR = 2$ ,  $TOCR = 1/3$  and  $N = 10$ .



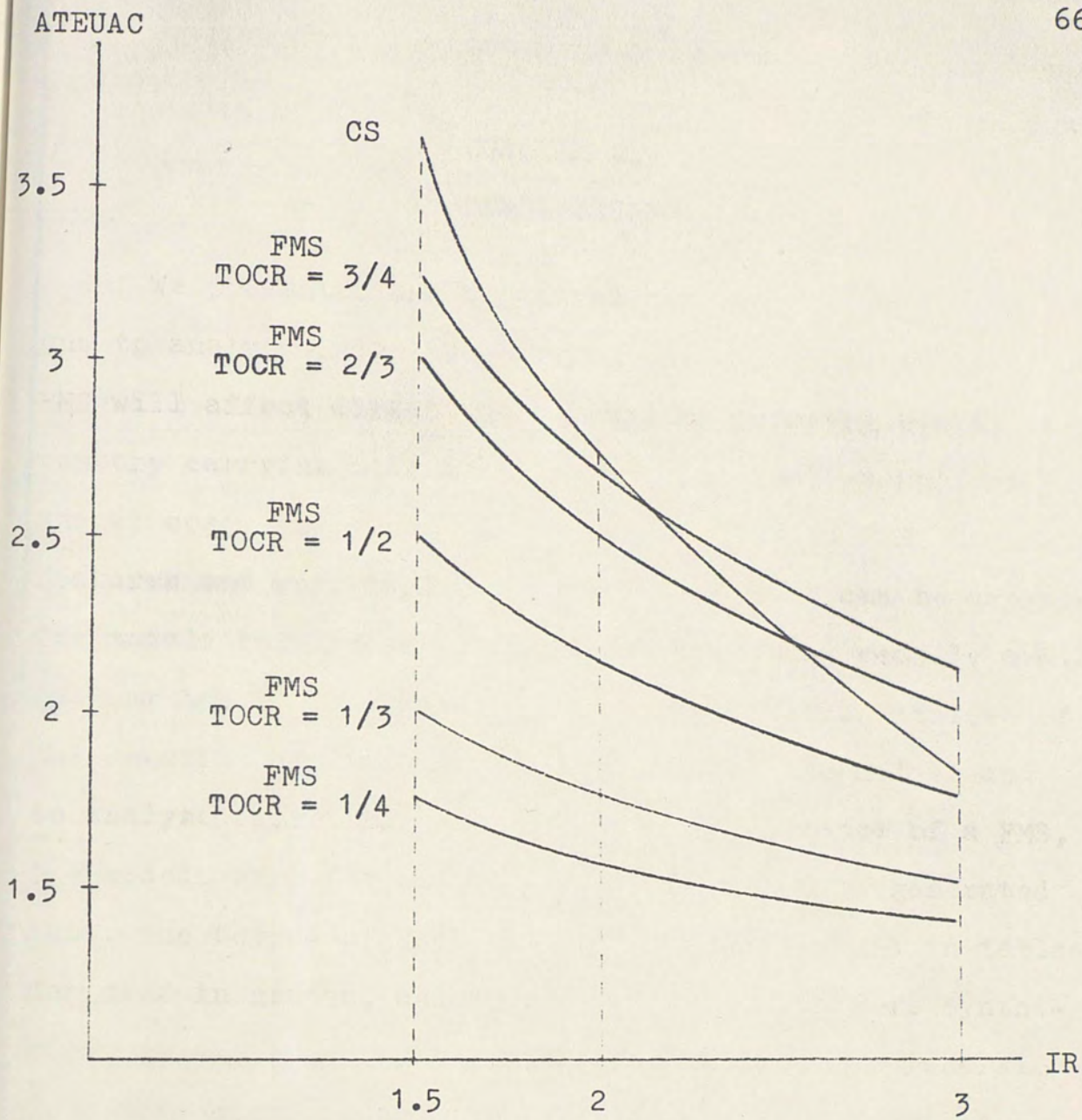


Fig. 9. After-Tax Equivalent Annual Cost (ATEUAC) of FMS and CS as a function of IR and TOCR with  $i = 10\%$  and  $N = 10$ .



### CHAPTER III

### CONCLUSIONS

We presented and explained several models that allow one to analyze independently how the characteristics of a FMS will affect direct costs, capital recovery costs, inventory carrying cost and after-tax equivalent uniform annual cost. The study is an introduction to FMS, its main features and what type of economic benefits can be expected. The models require input data that is either readily available or has to be generated through simulation studies of the specific FMS in question. To explain the models and to analyze empirically the economic performance of a FMS, the models were fed with published, assumed or generated data. The output of each analysis was summarized in tables, depicted in graphs, and specific conclusions were synthesized at the end of each model presentation. In general, from our empirical analysis we observed that there is a large cost reduction potential associated with the FMS alternative.

In 1981, Klahorst reported that in the FMS that had already been implemented, 55% of the benefits were related to cost reduction programs, 30% of the benefits to market response improvement and 15% to an increase of flexibility



in product design and production volume. The cost effects of improved market response and increased production flexibility were not analyzed in this study. However, with the information that has been published, we can expect that these two factors help to make the FMS alternative more attractive if the objective is to maximize shareholder wealth. But it can be argued that a business firm should not operate strictly in stockholder's best interests, because the firm is also partly responsible for the welfare of society. Since a good part of the economic attractiveness of a FMS is due to the fact that computer controlled machine tools replace human labor, serious doubts have arisen about the positive contribution to society's welfare of a FMS or any type of automated production system. Our personal point of view about this issue is expressed in the following paragraphs.

If the outlook for the future can be based on the experience of the past 200 years we can observe that technological innovations have brought growth of employment and real wages. Over the past two centuries technological innovation has caused an exponential growth of total output in the industrial economies accompanied by rising per capita consumption. At the same time, until after World War II, the easing of man's labor resulted in the progressive reduction of the average workweek (Leontief 1982). Increased



leisure has contributed greatly to the well-being of blue collar workers and salaried employees. Without the increase in leisure time the popularization of education and cultural advantages that have characterized industrial societies in the first 80 years of this century would not have been possible.

Labor in manufacturing usually takes place in conditions which are physically and mentally hostile to human effort. We believe that this kind of job should be the first to be automated, to provide workers with safer and more challenging jobs. The manufacturing automation industry will itself provide employment opportunities as has occurred with the computer industry, and the orientation of education and training must keep pace with the technological innovations. Workers can be retrained to repair and maintain the new machine tools, to undertake new activities within the firm such as planning and supervision or even programming and operating the computers.

Wage increases without an associated increase in productivity will result in inflation while improved productivity obtained through automation applications can result in better products and lower prices. According to the attribute analysis of consumer behavior introduced by Lancaster in 1966, consumer demand for a product is a derived demand for the services or attributes that the



product offers. The increased flexibility in production associated with a FMS facilitates the supply of products with a wide variety of attributes aimed to satisfy the particular needs of consumers. Better and more customized products at lower prices obtainable through automation applications will certainly improve our standard of living.

We believe that manufacturing automation will have a positive net contribution to the welfare of society. This fact, together with the economic incentives we have analyzed, provide us with the challenging task of developing the manufacturing automation strategies of tomorrow. Let's face this challenge.



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